A decision support system for wildfire management and impact assessment in affected zones

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Keywords: Wildfire detection and monitoring, Airborne infrared imaging platform, GPS/INS, GIS, Change Vector Analysis

ABSTRACT: An integrated decision support system for wildfire management has been developed and operated by the Institute for Space Applications and Remote Sensing of the National Observatory of Athens (ISARS/NOA). It integrates EO, airborne imaging and satellite navigation technologies in order to meet fire modelling, fire detection and fire mapping requirements during and after the occurrence of the fire event. The system supports real-time monitoring of wildfires, dynamic detection and mapping of hot spots and fire fronts, real-time transmission of relevant information to the fire managers, accurate mapping of burnt areas as well as assessment of the fires' consequences at the end of the fire season. To fulfil the need for real-time monitoring the system operates an airborne remote sensing infrared platform lying on state-of-the-art technologies such as: (a) thermal infrared image processing and thresholding for real-time assessment of the recorded temperatures (b) satellite kinematic positioning in conjunction with inertial navigation systems for real time geo-referencing of the thermal infrared acquisitions and (c) dynamic integration and representation of the collected images in the GIS system operated by the wildfire managers. Moreover to meet the requirement for post-fire management, the system integrates and process EO data together with the airborne collected thermal data to derive accurate detection and delineation of burnt areas as well as maps and statistics indicating the land cover classes and areas affected by fire. Innovative image processing methods are implemented to precisely map the land cover changes at post-fire stage. To this end a specific change detection algorithm has been developed, tested and modified accordingly to meet the standardisation requirements of operational projects. The technique behind this algorithm is based on the principles of the so-called change vector analysis (CVA) method, using a 3n+2 dimensional feature space, with n denoting the number of spectral bands of the input satellite scenes. The paper presents the two basic components of the system comprising of the airborne part or subsystem and the "ground" (post-fire) subsystem. The characteristics, the performance and the functional elements of the two components are described in detail. The results of the airborne subsystem deployment over the Sithonia Peninsula in Chalkidiki are also presented. The airborne infrared subsystem was assessed for its temperature sensitivity (~6ºC /0-500ºC) and detection capability (fires of few square meters on the ground are easily detected). In addition the functional and performance characteristics of the "ground" post-fire subsystem for precise mapping of the devastated areas after the fire season are also commented.

1 INTRODUCTION

The SITHON Project was successfully competed and funded in 2003 under the Operational Program of Competitiveness of the Ministry of Development-GSRT-Action 4.5.1: Natural Environment and Sustainable Development. The project was originally entitled "Application and evaluation of terrestrial and airborne telemetric methods for rapid detection- early awareness and real time monitoring of wildfires". The project was a three-year funded effort which initiated in July 2003. Between the objectives of the project was a) to foster collaboration between the private service sector, technological partners and research community and b) demonstrate the synergy of evolving technologies (terrestrial, airborne and EO) for increasing the information content of the collected data and enhance the timeliness in data collection, processing and transmission in respect to an efficient management of wildfire suppression actions. There were five main focused elements of collaborative effort:

1) A research and development element which specifically focused on advancing the development of a remote sensing airborne imaging infrared system for real time monitoring of fire fronts and in time detection of hot spots.

2) A technological element which focused on the installation and synergetic use of a number of terrestrial optical cameras.

3) A technological element which focused on the establishment of reference data bases providing support to wildfire fighting and suppression activities.

4) An application, demonstration and validation element which focused on test bedding and demonstrating the benefit from the synergetic use of the R&D and technological developments of the project.

5) In parallel to SITHON developments, a fifth R&D element focusing on automatic change detection in the devastated areas, delineation of burn scars and assessment of fire impact was developed, tested and evaluated. In the following a presentation of elements (1) and (5) above is given.

2 BACKGROUND

In the last decade, there have been advancements in technologies that support wild land fire management and emergency response *(Ambrosia V. G. et al., 2003, Light D., 2001, Hutton J. and Melihen A, 2006, Sifakis N. et al, 2001)*. These advancements include: a) improved capability for remote sensing towers, aircrafts and satellites; b) Geographic Information Systems; c) image processing and image geo-referencing; d) Global Positioning System (GPS) in combination with Inertial Navigation Systems (INS); and e) fire behavior models. Fast fire detection and real time monitoring of a fire (fire spread, location of hot spots) are crucial for the success of the initial attack on and containment of a fire. Infrared sensors have been viewed, as detection and monitoring systems, but are better viewed as equipment of a detection/monitoring system. Uncooled forward looking infrared cameras provide an opportunity for lower cost fire detection and monitoring. On this basis it was decided in the frame of SITHON project: a) to conduct further R&D in the area of using new smaller and less expensive IR uncooled cameras for fire detection and monitoring; b) to conduct further R&D in the area of image processing coupled with GIS, GPS and INS technologies to assist in the dynamic translation of the raw image data to usable products (coordinates/maps of hot spots and fire fronts, isothermal contour lines, geo-referenced/projected videos and thermal images).

3 FIRE DETECTION AND MONITORING - SITHON AIRBORNE SUBSYSTEM

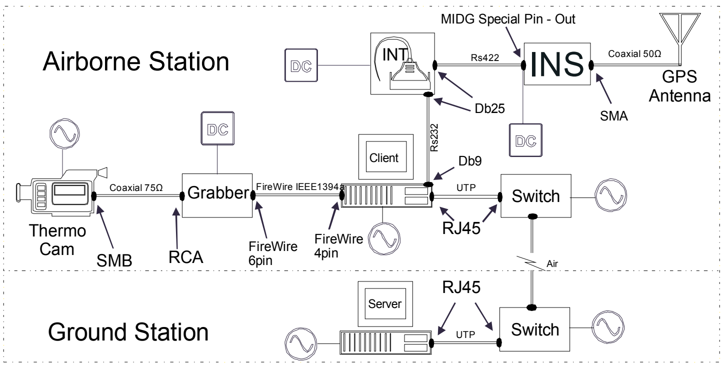
3.1 *Major elements of imaging payload*

The imaging payload in its current version is for a low-cost system. The infrared camera Thermovision R 570 was flown on a CESNA 3100 two-engine aircraft own and operated by AEROPHOTO Ltd. The integration of the camera was facilitated by the design elements of the plane, equipped with a gyro-stabilized camera mount on which the infrared camera body was mounted and fixed. The Thermovision R 570 is a light weigh, high performance IR camera. It uses advanced uncooled Focal Plane Array (FPA) micro-bolometer technology and stores images and data to memory cards. Significant software developments were made to allow remote control and operation of the camera system by the payload engineer on board. The infrared camera Thermovision R 570 characteristics are summarized in table 1. The camera has been laboratory calibrated to resolve fire intensities up to 500 ^{o}C. For this range of temperatures discrimination was approximately 1.0 ^{o}C per digital count with a systematic shift (bias) of 6 ^{o}C. This was adequate because in the frame of the SITHON project the interest is more focused on mapping relative temperature differences between points than estimating absolute temperatures. To recover the camera's interior orientation that is the principal point (*xp, yp*) and the principal distance (*c*), an analytical 3-D camera calibration (bundle adjustment with self calibration) using a 3-D calibration test field was performed. The resulted interior camera orientation expressed in pixels is reported also in table 1. Direct image geo-referencing was based on the combination of GPS for position and inertial measurements for the camera's orientation angles. This GPS/INS combination allowed the real time determination of both attitude (pitch, roll, yaw) and position (X, Y, Z) of the camera at the time of exposure. The MIDG II GPS/INS system of Mi-

Table 1: AGGA Thermovision R570 Infrared camera

FOV	*24^ox18^o/0.5m built in*
IFOV	*1.3 mrad*
Detector type	*Focal Plane Array / uncooled*
Spectral range	*7.5-13 μm*
Video output	*CCIR/PAL Composite and S-video*
Image resolution	*12 bit images stored on PC-Card hard disc*
Interior orientation	*x_o=16.0452, y_o=31.6923, c=0.5329*

Figure 1. The SITHON airborne system configuration



crobotics was used. It is a low-cost, light weight, small size and low power package which integrates an internal GPS receiver that collects GPS positions and velocity information and passes it to the data fusion processor to be combined with the inertial data to generate the state vector. The MIDG II device provided position data with the rate of 10Hz and velocity, attitude and acceleration information with the rate of 50Hz. The attitude data accuracy was of 1^o. The payload components (camera, GPS and INS units) were controlled by a laptop PC (Pentium IV, 2GHz) onboard the airplane. The camera system was capturing thermal images in user specified time intervals. The time interval was set to be in the range of 3 to 7 seconds depending on flight conditions (flight height and cruising speed). For every new acquisition the corresponding GPS and INS data were automatically saved together with the image data to create a new data package. The data package was forwarded to a server PC system (Pentium IV, 2GHz) where it was decoded and transformed to useful products before the next camera frame was captured. On the server the following operations were performing in real time: a) image geo-referencing and projection, b) image processing to identify temperature alarms, c) display of the geographic coordinates of the detected hot spots and fire fronts. During the operations the payload engineer was provided with interfaces showing dynamically a) the status of system's components and subcomponents, b) the data ingested to the system (images, GPS and INS data), c) the status of communication between the two PCs (system controller and data server), and d) the output products (geo-referenced image, geographic coordinates of the hot spots detected, the id of the data package processed, etc). The SITHON airborne system configuration is shown in figure 1.

Figure 2a. Dynamic representation of the thermal image acquisitions during the operations

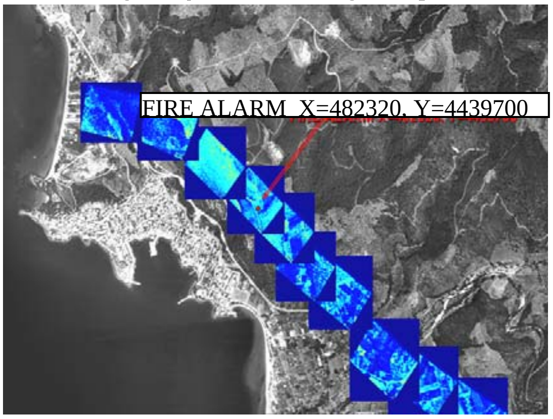
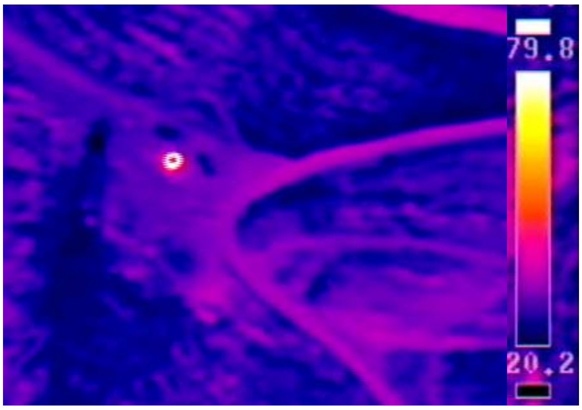


Figure 2b. A hot spot detected from 2.000 m ABS



3.2 *System demonstration*

Several demonstration campaigns of the SITHON airborne imaging platform were conducted during the project lifecycle. The first experiments were conducted in May 2005 and they have driven the further R&D developments to enhance the system's capabilities and meet operational functionality requirements. The system in its final configuration was flown several times over the Sithonia Peninsula of Chalkidiki. The system's sensing and imaging capability was evaluated in different conditions by changing the flight height, the size and the intensity of the fires which were subject of detection. The demonstration campaigns showed that the SITHON infrared platform was sensitive to detect fires of a few square meters on the ground from the height of 1.500m to 2.000m ASL. Real time direct image geo-referencing using input only from the GPS-assisted INS, performed well and produced sufficiently accurate (~30-50m) relationships between the captured images and the terrain system. Figure 2a illustrates the system's capability for dynamic representation and projection of the geo-referenced images onto a reference base map of the study area. An example of a small size fire of about 2mx2m on the ground detected from 2.000m ASL is given in figure 2b.

4 POST-FIRE IMPACT ASSESSMENT – GROUND (POST-FIRE) SUBSYSTEM

Satellite images of high spatial resolution (Landsat, SPOT-4/5, IRS, etc) in combination with land cover data (CLC-2000) and ground truth evidence are used for post-fire impact assessment. The operations provide seasonal burn scar maps and tables with burnt area information such as location, locality, size, and types of land cover changes. The method relies on automatic tools for a) change detection, b) change area mapping and c) burn scars identification. Supervised clustering is applied on the image data to highlight areas with typical after-fire signature. Unsupervised clustering is invoked in the change vector feature space using combinations of image bands and vegetation indices. In the post-processing refinement phase several aggregations of burn scar polygons are performed using photo-interpretation logic, ground truth data and user provided evidence on the reported fire events.

At least three images are used corresponding to: a) pre-fire season, c) during fire season (mid summer) and c) post-fire season. The change detection technique is based on the principles of the change vector analysis (CVA) *Chen et al. 2003*. A synthetic image is created by coupling image bands with vegetation indices. Using as reference the synthetic image corresponding to the pre-fire season and combining it with the other two images corresponding to mid-summer and after-summer seasons, the algorithm a) defines the change vector between any two dates, b) calculates the change vector magnitude together with the change vector elements (direction and sign of direction) and c) performs unsupervised clustering of the change vector data to obtain change clusters including those corresponding to burnt sites. Once the clustering operations are successfully terminated the operator examines the clustering output and sets the appropriate label to the burnt area clusters. The method proved to be an effective solution in the frame of operational projects. It limits considerably the time of data processing and classifies with high accuracy (88%-96% overall accuracy) the burnt areas and the types of change categories in the devastated areas (Kontoes C., 2007).

5 CONCLUSIONS

The R&D developments in the frame of SITHON project resulted in the delivery of an efficient and cost-effective airborne imaging system capable to detect and monitor wildfires in real time. The demonstrations showed that this system can lead to a significant improvement in tactical fire imaging from the air and can reduce the fire information ingestion process to few minutes, thereby minimizing the potential loss of resources, personnel, and property during fire event. On the other side the ground subsystem allows precise burnt area mapping and supports the effective management of the affected zones after fire. It assists the rapid mapping of the devastated areas and provides the solution to the problem of large time delays between the end of the fire season and the time to deploy the available cartographic capacities on site (aerial campaigns, field surveys).

6 REFERENCES

Ambrosia, V.G., Wegener, S.S., Sullivan, D.V., Buechel, S.W., Dunagan, S.E., Brass, J.A., Stoneburner J., Schoenung S.M. 2003. Demonstrating UAV-acquired real-time thermal data over fires. *Photogrammetric Engineering and Remote Sensing*: 69:391-402.

Chen, J., Gong, P., He, C., Pu, R., Shi, P., 2003. Land-use/Land-cover change detection using improved change-vector analysis. *Photogrammetric Engineering and Remote Sensing*: 69:369-379.

Hutton, J., Melihen, A. 2006. Emergency response remote sensing evolves in the wake of experience. *Photogrammetric Engineering and Remote Sensing*: 72:977-981.

Kontoes, C. 2007. Operational land cover change detection using change vector analysis. *International Journal of Remote Sensing.* Under final review.

Light, D. 2001. An airborne direct digital imaging system. *Photogrammetric Engineering and Remote Sensing*: 67:1299-1305.

Sifakis, N., Paronis, D., Kontoes, C. 2001. Operational application of satellite observations in monitoring of forest fires in quasi real time and guidance of firemen to impassable mountain areas. *Proceedings of the Conference on "Integrated development in mountain areas: Theory and Action"*. Metsovo Greece (in Greek).

7 ACKNOWLEDGEMENTS

The authors acknowledge the contribution of Prof. M. Santamouris (Institute of Accelerating Systems and Applications-University of Athens) in providing the Infrared camera Thermovision 570.

We acknowledge the participation of Mr P. Doukas in the preparation and realization of the airborne campaigns over the Sithonia Peninsula.

We are grateful to Dr. P. Konstantinides and Dr. G. Tsiourlis (Forest Research Institute-NAGREF) for their valuable efforts in managing the SITHON project and ensure its proper and undisturbed continuation in the three-years project lifecycle.

We thank the pilot Mr P. Boutsoukis, and the owners Grigoris and Giannis Noitsis of AEROPHOTO ltd for providing us their valuable help and technical support to fly the airborne infrared imaging system over the Sithonia Peninsula in Chalkidiki.

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MONITORING

airborne

SITHON

Temperature Range: –20ºC to 500ºC (2000ºC)

Infrared camera Thermovision R570

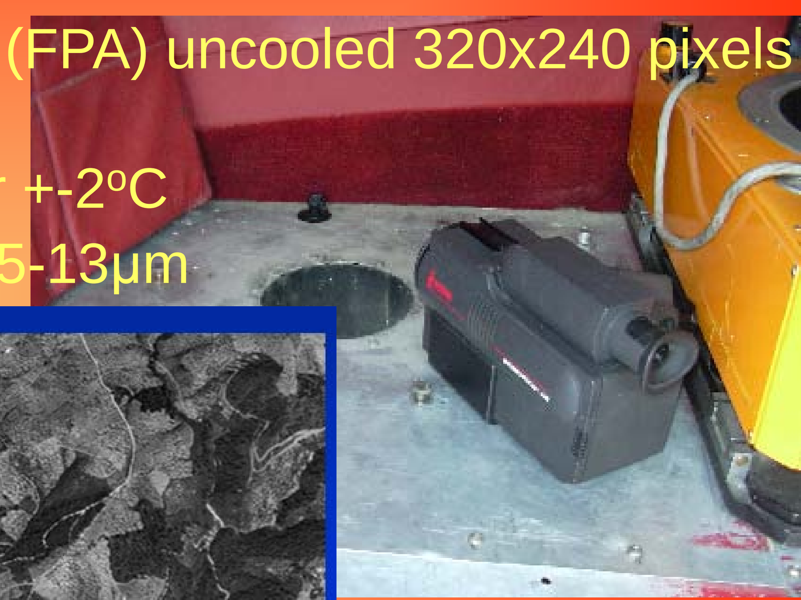
Instantaneous Field of view: 1,3 mrad

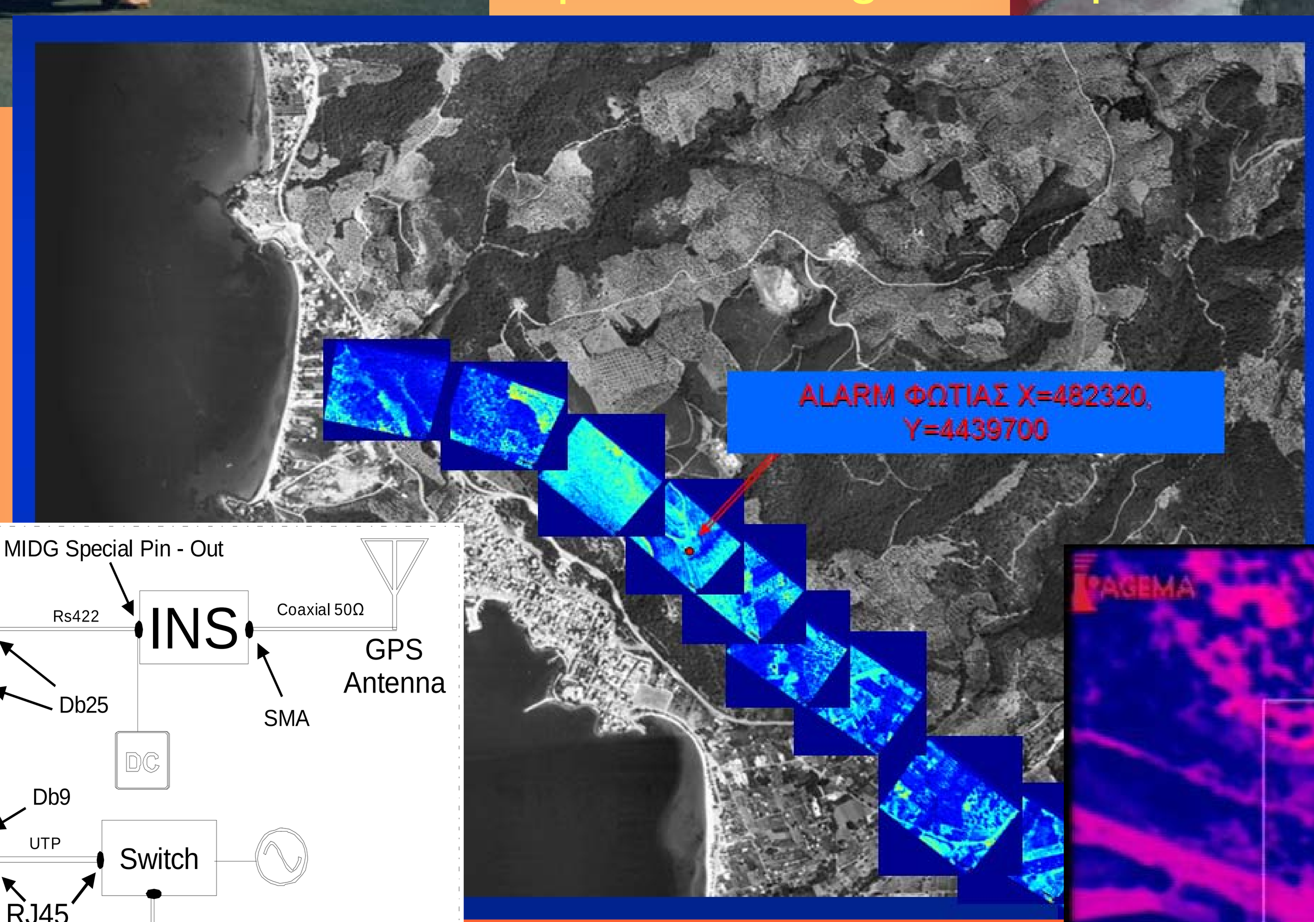
Thermal Sensitivity: 0,1ºC at 30ºC

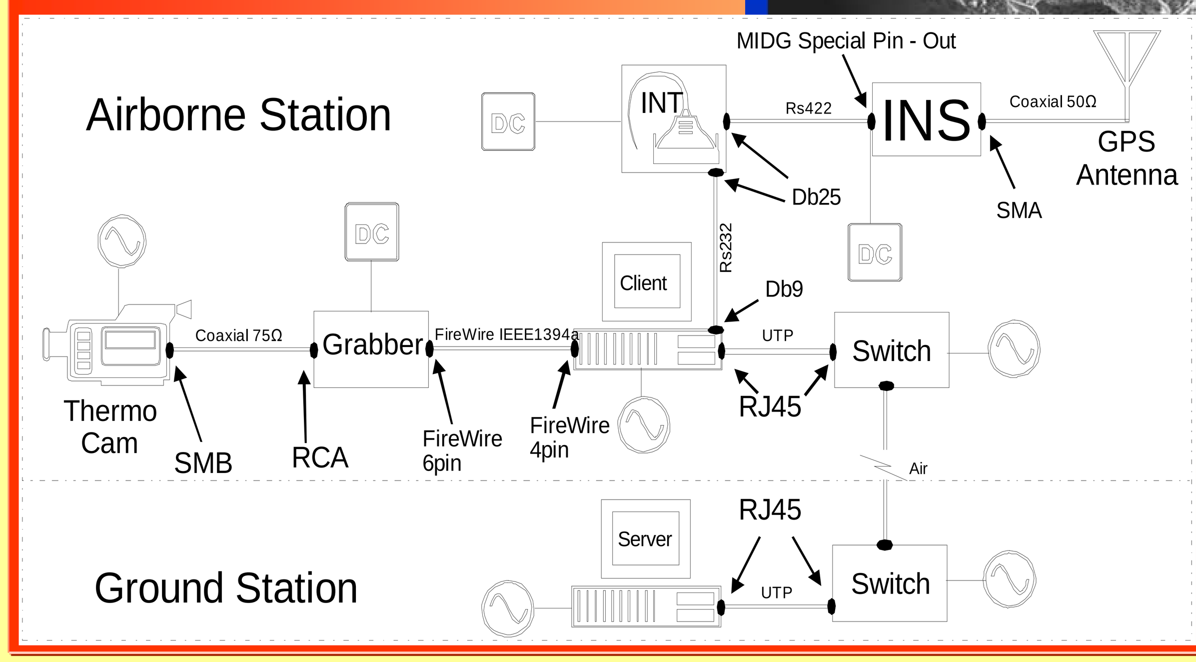
Focal Plane Array (FPA) uncooled 320x240 pixels (24ºx18º)

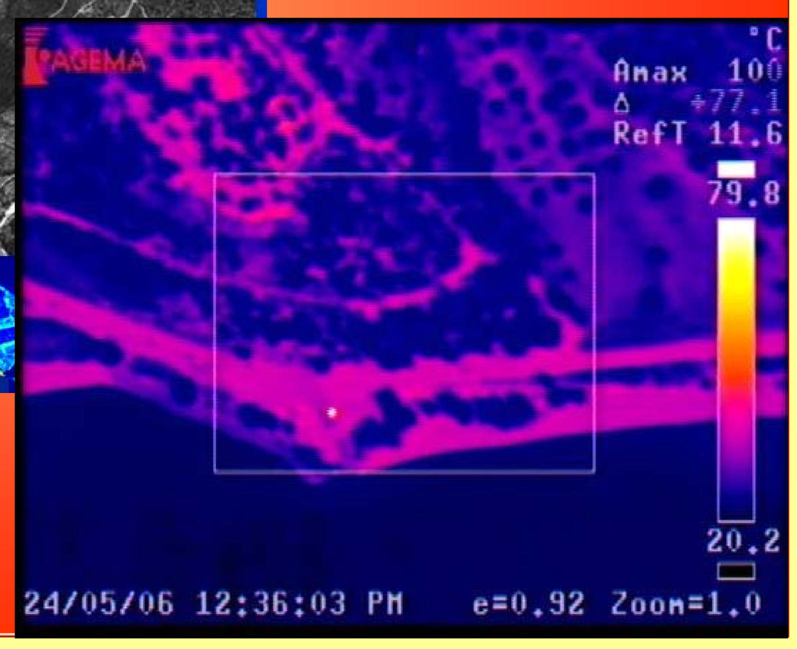
Accuracy: +-2% or +-2ºC

Spectral Range 7,5-13μm







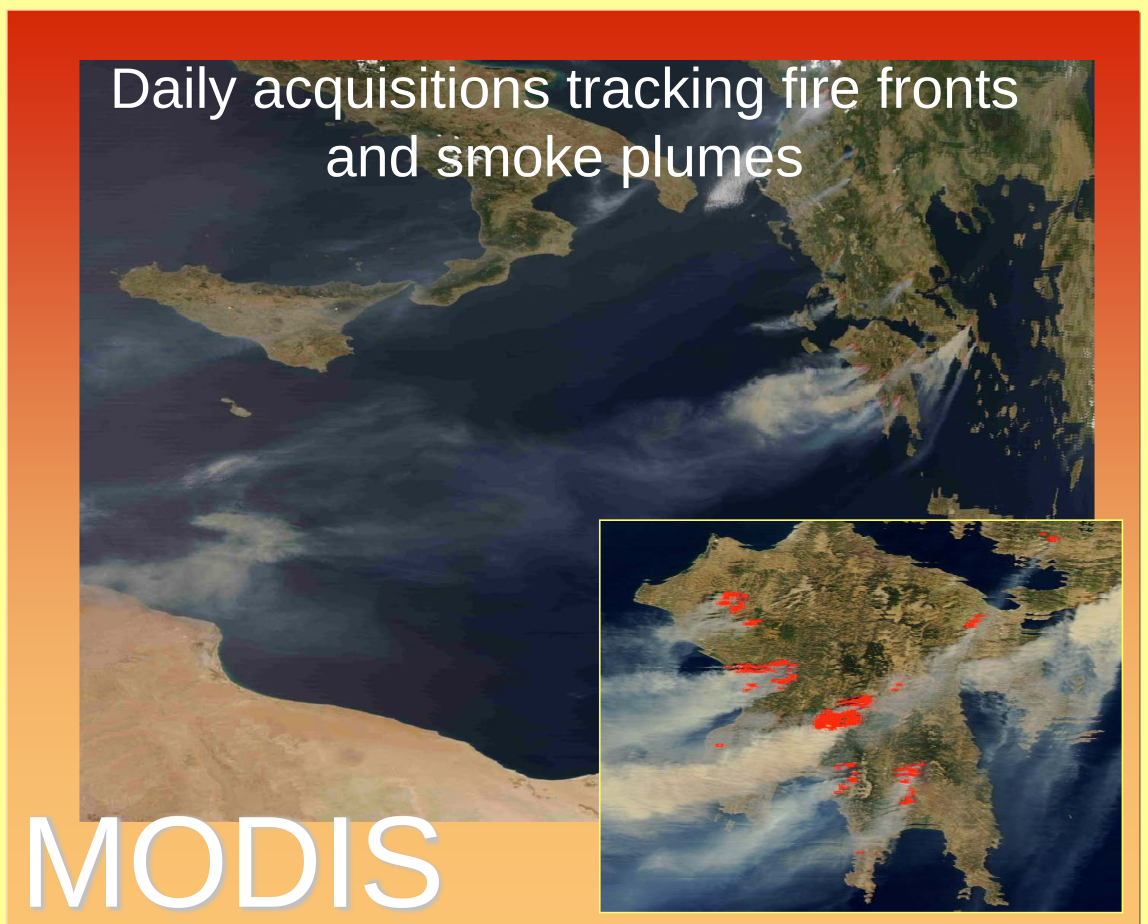


satellite

Images acquired by a geostationary satellite every 15 min at NOA-ISARS

SEVIRI MIR 25/7 15:30 UTC - ISARS-NOA

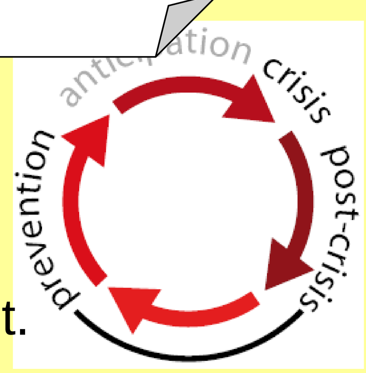
Daily acquisitions tracking fire fronts and smoke plumes



RISK-EOS SERVICE EXTENSION TO GREECE

GEOINFORMATION SERVICES FOR NATURAL DISASTERS

RISK-EOS is a service element within the Global Monitoring for Environment and Security (GMES) program funded by ESA and the European Commission. The crisis response services within RISK-EOS provide a full time on-duty staff. For most RISK-EOS services, service delivery to users is organized decentrally, to ensure proximity to the users and adequacy to their needs.



1. Fire Rapid Mapping

This service delivers rapid mapping products for large fire events. It complements "Burn Scar Mapping", by providing fire extent and impact maps during and shortly after the event. The central service of rapid fire mapping is supporting the "International Charter Space and Major Disasters"

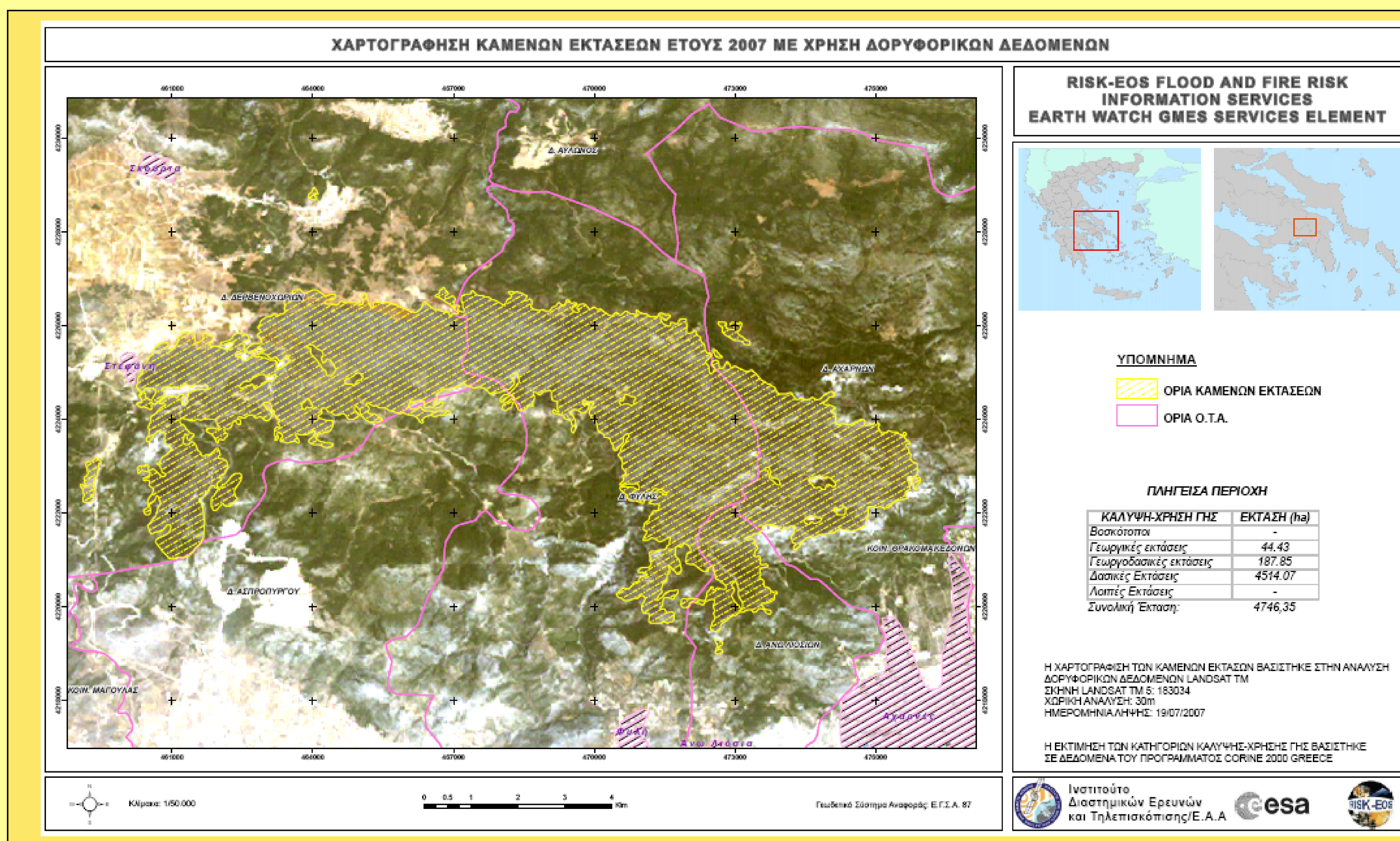
Product	Updating Frequency	Localisation Accuracy	Resolution	Format
Near Real Time Fire Extent rapid mapping FRM1	8 to 12h after image acquisition	Depends on EO data	30 meters	Raster
Non Real Time Fire Extent rapid mapping FRM2	2 weeks after image acquisition	Depends on EO data	30 meters	Raster & Vector
Non Real Time Fire damage assessment FRM3	2 weeks after image acquisition	Depends on EO data	30 meters	Vector

2. Burn Scar Mapping

Service main objectives:

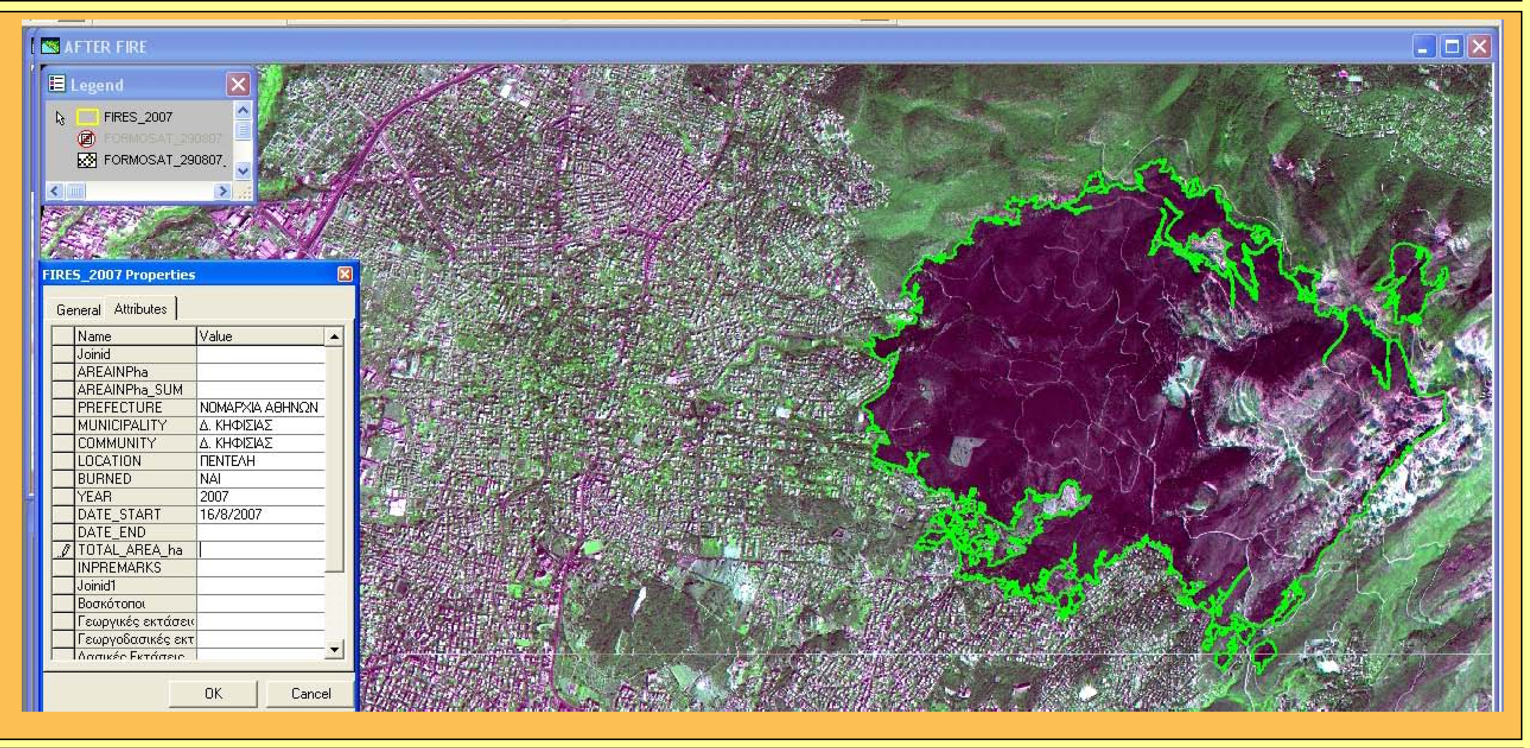
- to provide post-crisis information for the areas burnt by fires
- to assess the damage and
- to monitor vegetation recovery and man-made changes

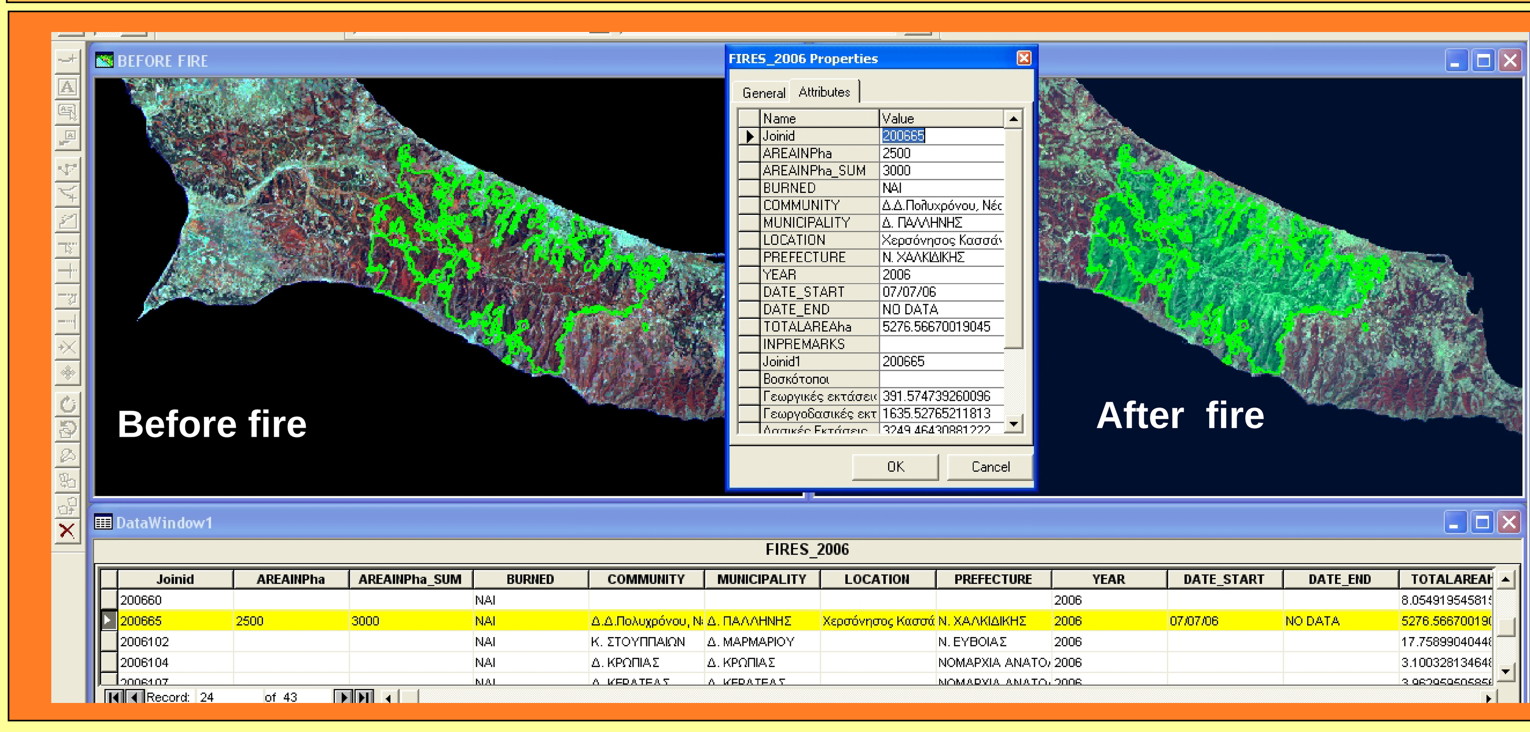
Product	Updating Frequency	Resolution	Format
Burn Scar Maps BSM 1	Yearly	From 2 to 30m depending on EO data (compatible with a scale 1:10.000/ 1:50.000	Vector
Burnt Area Maps BSM 2	Yearly	From 2 to 30m depending on EO data (compatible with a scale 1:10.000/ 1:50.000	Vector
Cloud & water/urban mask BSM 3	Yearly	From 2 to 30m depending on EO data (compatible with a scale 1:10.000/ 1:50.000	Raster
Post Fire Images BSM 4	Yearly	From 2 to 30m depending on EO data (compatible with a scale 1:10.000/ 1:50.000	Raster
GIS File integrated product	Yearly	From 2 to 30m depending on EO data (compatible with a scale 1:10.000/ 1:50.000	Raster & Vector



Map showing the burnt area on Mount Parnitha after the catastrophic fire of July 2007. Landsat data has been used to map the burnt area. The extent of the burnt area is masked and provides input for further processing and integration in a GIS system.

The "GIS-File Integrated product" shows the burnt area after the catastrophic fire of 16.08.2007. It is based on FORMOSAT-2 data. The spatial resolution is 2m and the map scale is 1:10.000





The "GIS-File Integrated product" provides information on the area affected by fires in Kassandra Peninsula in 2006. The burnt area includes forest, tourist and agricultural zones.