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WILDFIRE REMOTE SENSING MONITORING AND K LINE METHOD VALIDATION

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Summary

Introduction

Remote sensing sensors find historically many application: agriculture, environment, geology, etc. The detection and monitoring of wild fire thermal characteristics is relevant at small and large scale. At small scale, real-timand near-real-time observations are important for the identification and the localization of the front of fire during the crisis phase allowing to plan the actions for fire suppression [Stearns et al 1986]. On large scale, the Global satellite-based monitoring of biomass burning, permits to understand the role of fires in the global change [Vodacek, et al 2002, Kaufman et. al. 1998, Prins and Menzel 1992] The typical spectral ranges used to the fire detection are in the 3.5- 5micron and 8-14 um [Dozier,1981]. *In the NIR range Thomas and O, 1993, suggested to use the NIR 1.0-2.5 um.* Moreover, ground and laboratory observation revealed that natural fire presents an optical emission doublet of the K respectively at 766.5 nm and 769.9 nm [Latham, 1998]. This technique has been tested by Vodacek using AVIRIS (Airborne Visible Infrared Imaging Spectrometer) images acquired over Cuiaba (Brasil) on 25 July 1995. Because of limited temporal or the spatial resolution existing satellite sensors are not suitable to support the crisis phase. Therefore, this technique has not been further investigated. In the frame of AIRFIRE project (ESA contract CN/20090) a sensor realized by Selex SAS Galileo was mounted on a ultralight plane and tested on small scale wild fire. The main objective of the project was to test the systems and to validate and to assess the results obtainable through the most relevant satellite observation techniques, against the high resolution fire mapping information derived from a dedicated SIM-GA spectral airborne campaign.

Thanks to the very good spectral and spatial resolution of the SIM-GA another important result was reached. The validation and evaluation of K line method was realized.

1. System set-up Description

SIM-GA, this is the name of the sensor, is a modular avionic spectral image spectrometer. It consists of two Electro-Optical Heads (EOH) integrated in a single box: a Visible Near Infrared (VNIR) covering the spectral range 400-1000 nm with the spectral resolution 1.2 nm and a SWIR one, covering the spectral range 1000-2500 nm with the spectral resolution 5.4 nm.

The two EOHs are physically separated but placed side by side on a common alignment plate and enclosed in a protecting box. The “modular” philosophy at the base of SIM-GA allows a flexible arrangement of instrument accommodation and therefore the possibility to put it on small platforms changing the mechanical interface. The complete image is built up by subsequent acquisitions, in push broom mode and nadir pointing. The final result is a three-dimensional data set (named Data Cube) that correlates each on ground pixel with its corresponding spectrum [Piccioni et al, 2000].

The frame rates are selected taking into account the airplane velocity and its altitude to avoid the under-sampling of the images. The flight data, coming from a dedicated GPS/INS unit, are logged continuously in order to derive geo-registered images. The GPS and inertial sensors are part of the SIM-GA system.

The mounting operations of the instrument and the proximity electronics was carried out at Laboratorio Tevere. Laboratorio Tevere is one of the main Italian operators of professional airborne services for remote sensing and TV broadcasting. The aircraft, fantasy Air Allegro ultra-light vehicle, was equipped with the Kell AWAIR navigation terminal for precise positioning.

SIM-GA was mounted on the right side of the plane in nadir configuration using a deployable mechanical support for the optical head (Figure 1) The proximity electronics and acquisition interface took place at the second passenger place by a custom rack using vibration damper in order to be easily operated by the pilot.

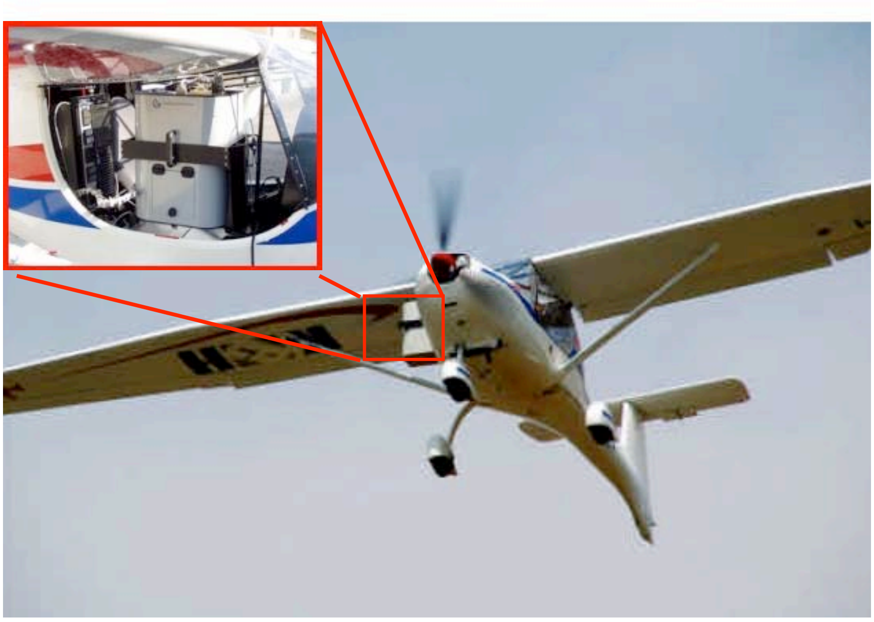

Figure 1. The fantasy Air - Allegro2000 ultra-light aircraft (I-7886) lodges the SIM-GA (by Selex SAS Galileo) on the right passenger side (picture courtesy of KELL S.r.l.).

The following table (Table 1) shows the technical characteristics of the SIM-GA spectral sensor.

Instrument Characteristics	**VNIR Spectrometer**	**SWIR Spectrometer**
Spectral Band	400-1000nm	1000-2400nm
Spectral Sampling	1.2nm	5.4nm
Detector	500 pixel (Spectral direction) x 1024 pixel (Spatial direction) (CCD)	256 pixel (Spectral direction) x 320 pixel (Spatial direction) (MCT)
	pixel width= 12μm	pixel width= 30μm
Optical Objective	F=17mm (focal length)	F=22.5mm (focal length)
IFOV	0.7mrad	1.3mrad
FOV	±19deg	±12deg
Digital Resolution	12bits	14bits

Table 1. SIM-GA optical characteristics as given by Selex SAS Galileo.

2. Airfire Data Acquisition

2.1 Campaign description

The AIRFIRE campaign [Aversa F, 2006] was required to provide support to both validation of fire monitoring system based on imaging spectrometer data and to definition of technical concept for high temperature event monitoring capability [Stearns, J.R., 1986].
The area of interest was the Latium region. The time window of the campaign was August based on previous years statistics on occurrence of wild fire events in Latium area. Unfortunately, the summer 2006 was a relatively rainy season and half of wildfires occurred in the same area on 2005 were registered.

The strategy for the operational activity was the following: the aircraft was ready to fly by receiving an event communication in three different ways.

● The Civil Protection National Unified Command for operations of airborne fire fighting (COAU), coordinating all the aircraft (Canadair CL 205 and CL 405) operating in Italy provided by mobile the locations of events occurring in the area of interest. For example the fire of 16/08 was communicated by COAU.

● Several helicopter bases, operated by private companies contracted by the Latium Region were in touch with the base to communicate an event as soon as an operation started. For example the fire of 14/08/2006 (about 15:00 local time) was communicated by helicopter pilots.

● The aircraft, in particular the ultra light, patrolled the northern Latium area in search of fires during the part of the day (13:00 -15:00) when most fires start. This strategy led to the discovery of some event, mainly of limited size. For example the second fire of 14/08/2006 (about 17:00 local time) in a remote forest area was discovered by direct observation from air.

The alert mechanism arranged by the campaign team enabled recording of most fires that occurred in the area and the period of interest.
Since this campaign was demonstrative of SIM-GA potentiality also satellite data were considered but they will not treated in the present work.

2.2 SIM-GA data acquisition

The system was kept standing ready to operate for the whole month of August 2006. When an event occurred, a real time fly took place. The instrument was operated by the pilot who could change some settings and parameters (e.g. calibration procedure selection; integration time selection, etc.).
The SIM-GA collected about 30 hours of fly with 300 Gbyte of acquired data flying over the Latium region. A total of 10 wildfires were registered [Fiorani et al, 2007]. In the present work, the analysis was concentrated on four fires occurred on different kind of vegetation.

Date	Site	LAT LON	Way point TIME GMT+2	Canopy type
14/08	*First event:* Fire in **Magliano/ Campagnano**. Mixed vegetation (high and low) *Second event:* Fire in **Manziana / Oriolo**, trees with high flames. Flight duration: 2 hours	N 42° 08' 41.641" E 12° 25' 50.237 N 42° 11' 28.329" E 12° 08' 47.061"	16:32:30→17:15:56 17:41:50 → 7:46:50	**brushes** **broad-leaved wood**
16/08	Fire in **Nemi** (Frascati). Northern lake border. Flight duration: 1 .5 hours	N41° 43' 17.121" E12° 42' 15.237"	16:55:50 → 7:01:30	**leaved wood.**
19/08	Fire in **Cerveteri**. Electric cables damaged from fire. Flight duration: 1 hour		15:19:30→15:33:47	**orchard and cropped fields**

Table 2. The table shows the details of the four selected four wildfire.

The CORINE LAND COVER database of ARPA (Italy) characterize the canopy typology of Italian surface. By overlapping the land cover maps of interest, with the SIM-GA and Google Earth referenced image it was possible identify four different canopy types for the four of the measured wildefire (figure 2) .

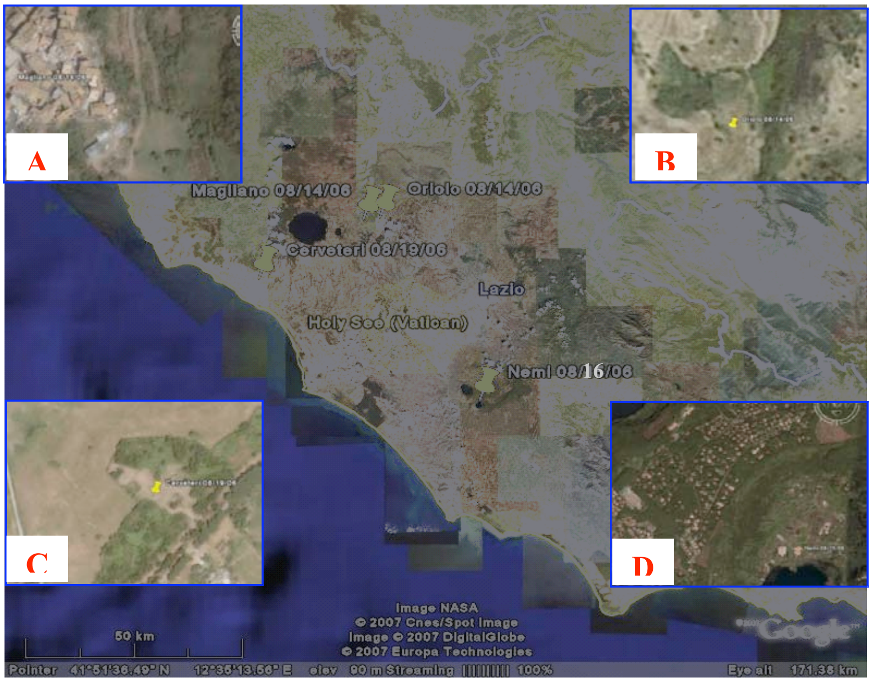

Figure 2. Location of 4 different canopy type wildfire : A) Magliano,–canopy type: brushes; B) Oriolo-canopy type: broad-leaved wood; C) Cerveteri, orchard and cropped fields; D) Nemi- canopy type: leaved wood.

3. Data Analysis

3.1 SIM-GA data reduction

The SIM-GA data analysis consisted in different steps.
The first phase, is the *quick look* of the data. The data saved by on board acquisition system in HDF format, were visually analysed in order to select the “good data”, point out any problem that can affect the following step, and provide a image short quality comment .
Secondly, a *pre-processing* phase, consists in applying, geometrical correction, geocoding (for the data set were it was possible) and data calibration.
The third phase is the *product generation* and results evaluation (Figure 3).
A quick look library of the data was realized to evaluate data and to define an image classification according to the acquisition date, the target, integration time, line and fire position.
The SIM-GA data were further corrected for the dark current contribution taking into account the different integration time; the instrument transfer function (different for VIS and SWIR) was applied to obtain data expressed into physical unit.

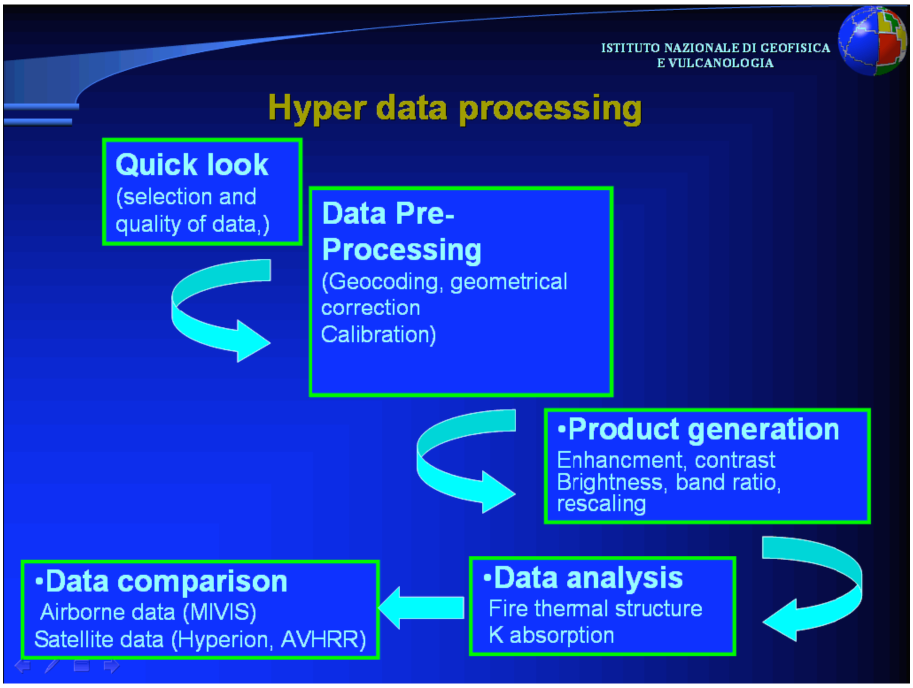

Figure 3. Logical flow diagram of SIM-GA data processing.

3.2 K-method verification

K method is based on the properties of this element. It is an omnipresent nutrient in the soil and is incorporated in the tissues of the plants. Due to its low excitation energy, a significant portion of K in the burning biomass may be ionized producing a strong and narrow emission lines [Vodacek et al., 2002].
The expected two K emission picks in the visible spectral range, are respectively at 766.5 nm and 769.9 nm, near the 762nm O_2 absorption band.
The first step consisted in verifying the performances of SIM-GA for the K- method.
Because of low image spatial distortion, the wildfire occurred near Oriolo village (42° 11' 28.329" 12° 08' 47.061") on 14 August 2006 was firstly analyzed.
Since K emission is specific to flaming combustion of biomass, it is potentially possible to detect flaming area and according to Vodacek study, the scene at 589 nm points out smoke from fire while the 770 nm image shows a good penetration from smoke .
This consideration was applied on data acquired on Oriolo village area (17:36 GMT) and the result is showed in figure 4.
Since the study was devoted to investigate improvement due to the good spectral performances of SIM-GA sensor respect on the previous work of Vodacek, a grey image centred respectively in the bands (766.5nm and 769.3 nm) corresponding to the duplet were performed. (Figure 5). In these images is possible to see the flaming sources of wildfires due to the K excitation.
The data were subsequently visualised in the typical RGB visual bands (R =621nm, G=569nm, B=511nm) and the spectral profile analysed (Figure 6).
It was possible to distinguish the duplet that in the Vodacek experiment was not possible; The K duplet is well resolved in correspondence of flaming area; attenuated K duplet is evident also in smoky area. This result suggest that an improved K lines band ratio technique for flaming area detection, may be implemented.
The AVIRIS data allowed to detect the K line but not to solve the duplet: this was limit for the application of K method pointed out by Vodaceck himself.

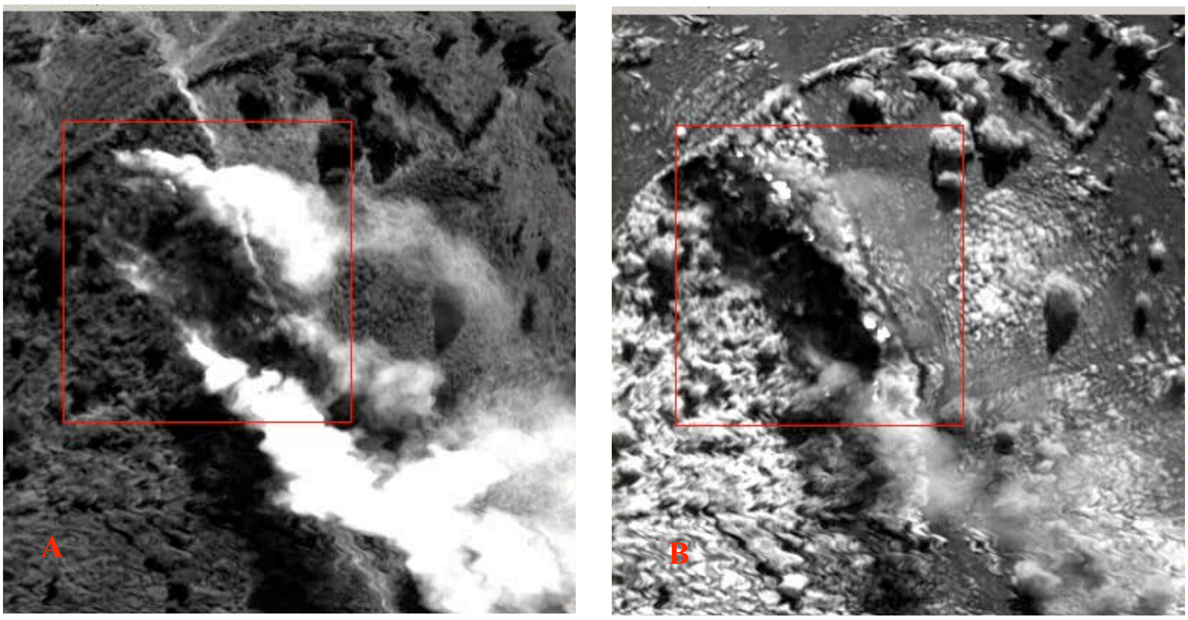

Figure 4. August 14 2006 on Oriolo 17:36 GMT- 42° 11' 28.329" 12° 08' 47.061" A) 589 nm and B) 770 nm image.

The band 770 is in correspondence of K emission peak and was used by Vodacek because of spectral resolution of AVIRIS (9 nm). Due to the very high SIM-GA spectral resolution it is possible to show the images at 766.5 and 769.3 (SIM-GA bands) almost in correspondence of K lines (766.5 nm and 769.9 nm) really corresponding to flaming area (Figure 5 A and B).

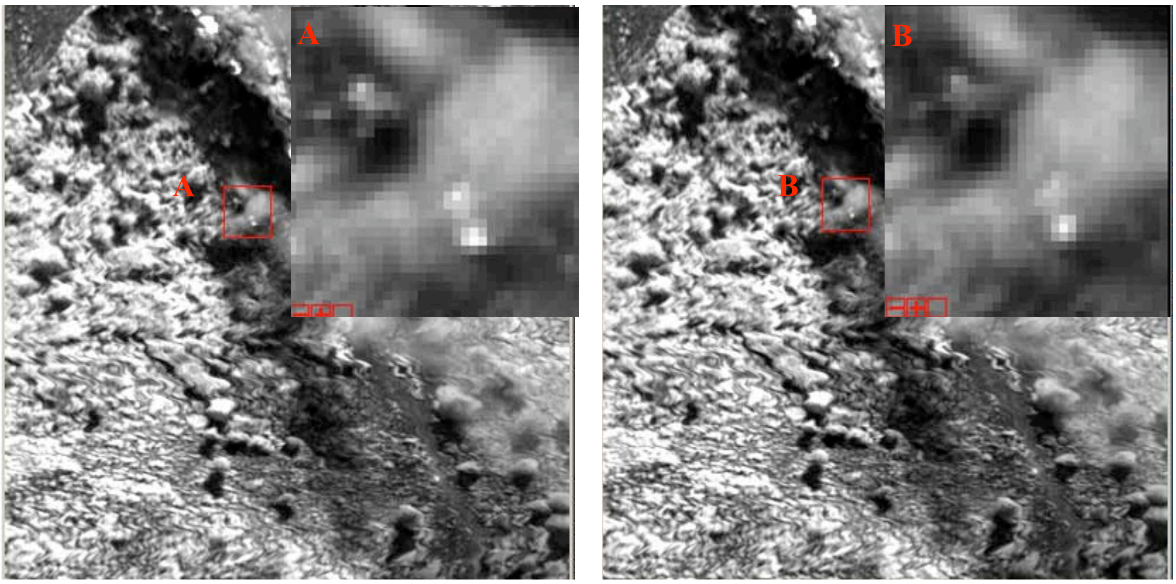

Figure 5. August 14 2006 on Oriolo:17:36 GMT A) 766.5nm and B) 769.3 nm image.

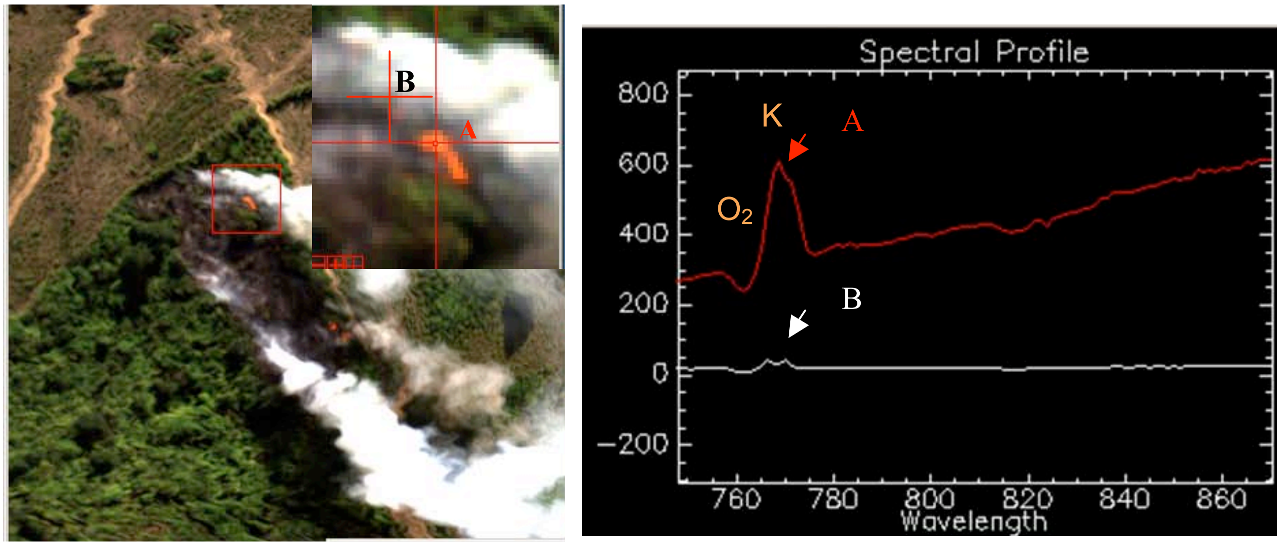

Figure 6. The left side picture shows the R=621nm,G =569nm, B=511nm, of Oriolo wildfire, on the right picture the spectral profile and the K duplet is showed in correspondence of two different points. A visible flaming area and B flaming area under the smoke.

3.3 Band ratio application

Rationing is an enhancement process in which the DN value of one band is divided by that of any other band in the sensor array. If both values are similar, the resulting quotient is a number close to 1. If the numerator number is low and denominator high, the quotient approaches zero. If this is reversed (high numerator; low denominator) the number is well above 1.
Certain ratios can point to certain tonal anomalies that are diagnostic of special conditions. The band ratio was applied in order to point out the fire active sources.
The bands ratio algorithm at 766.5 and 769.3 (named *Advanced K Band Ratio, AKBR*) was applied on each of four wildfire events four wildfires described on table 2 . The linear or square root enhancement and the red colour table were applied. The RGB images (R=621nm,G =569nm, B=511nm) were compared with the image resulting from the AKBR algorithm. (Figure 7, 8, 9 and 10 respectively).

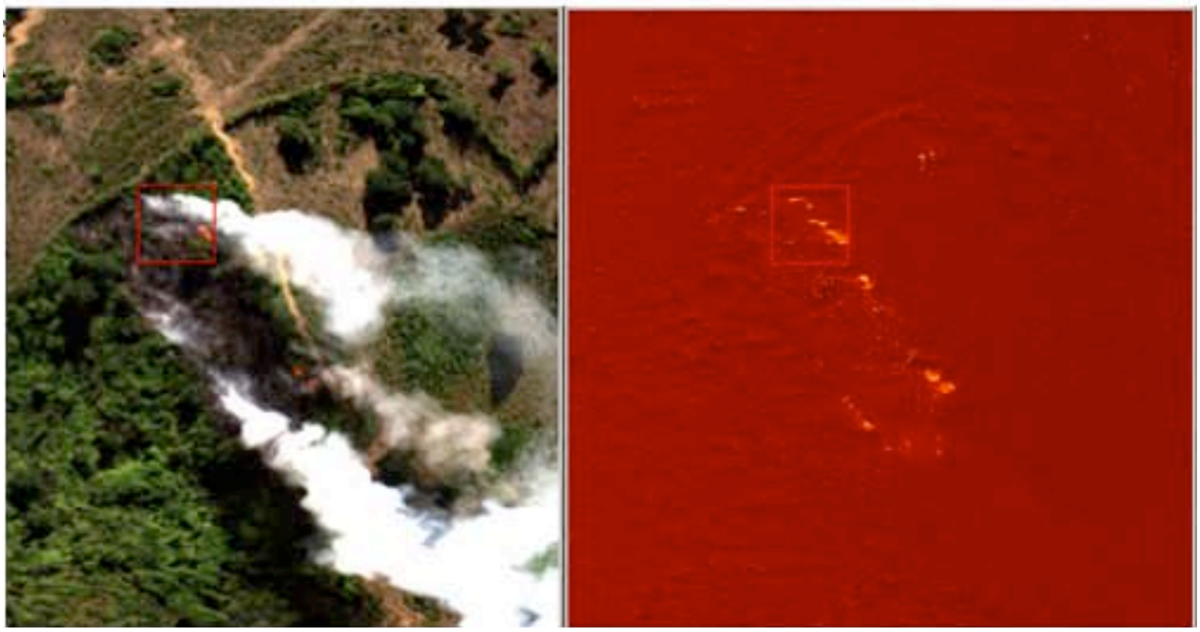

Figure 7. Oriolo wildfire shows high presence of smoke, the band ratio point out the flaming area also under the smoke.

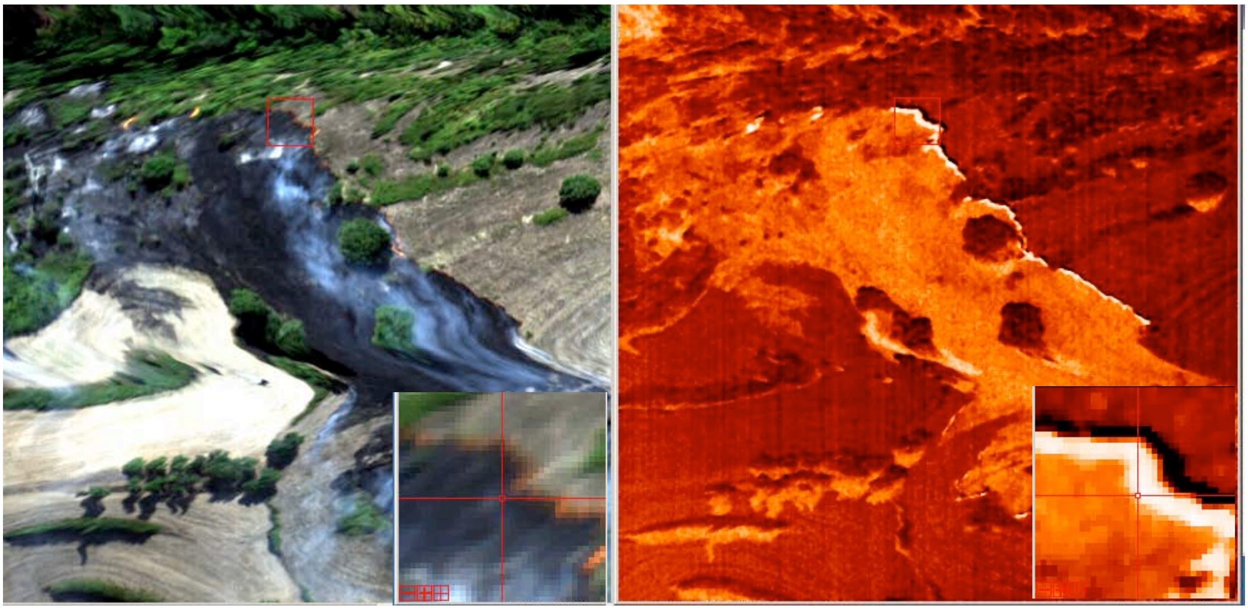

Figure 8. Magliano wildfire: the band ratio shows point out the flaming area and the front of fire.

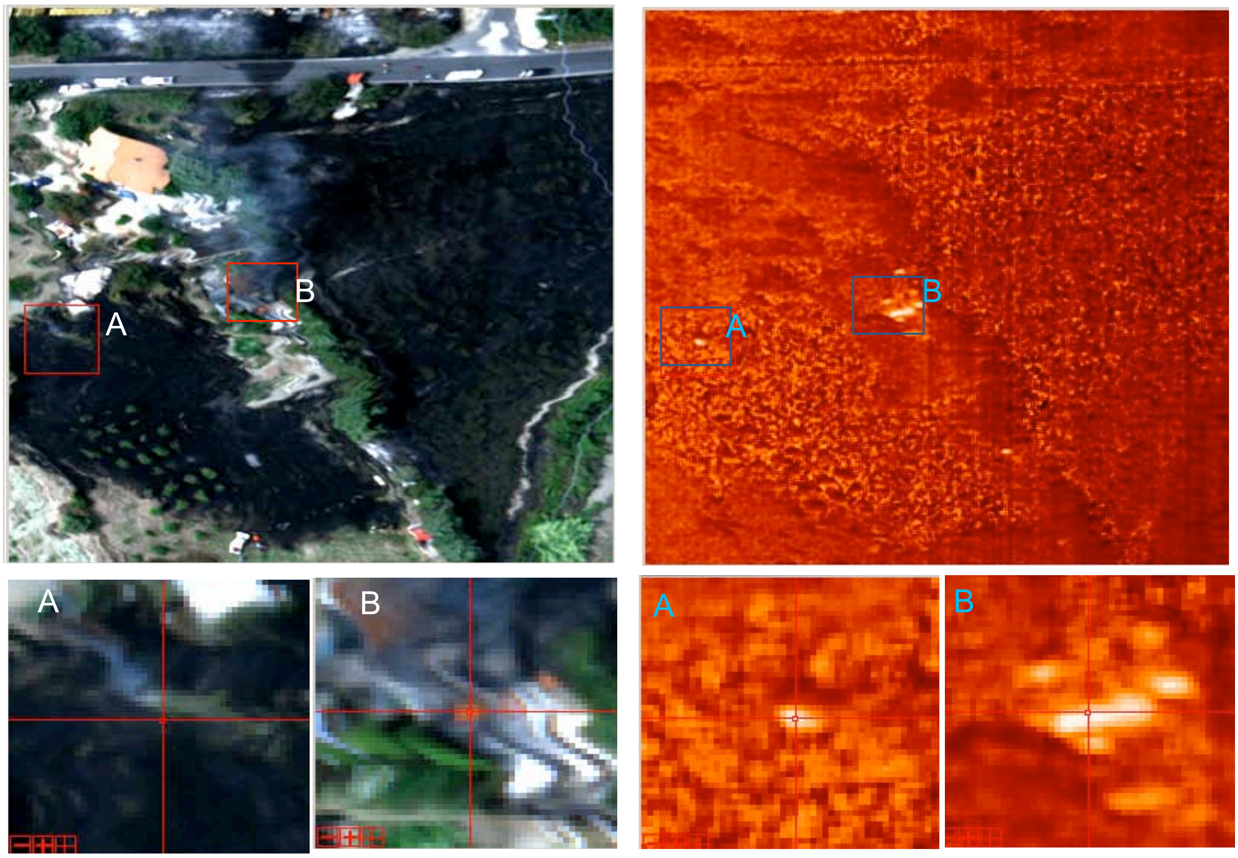

Figure 9. Cerveteri wildfire: the band ratio shows the flaming area (A) under the smoke, the flaming source in a smouldering area is pointed out in correspondence of point B.

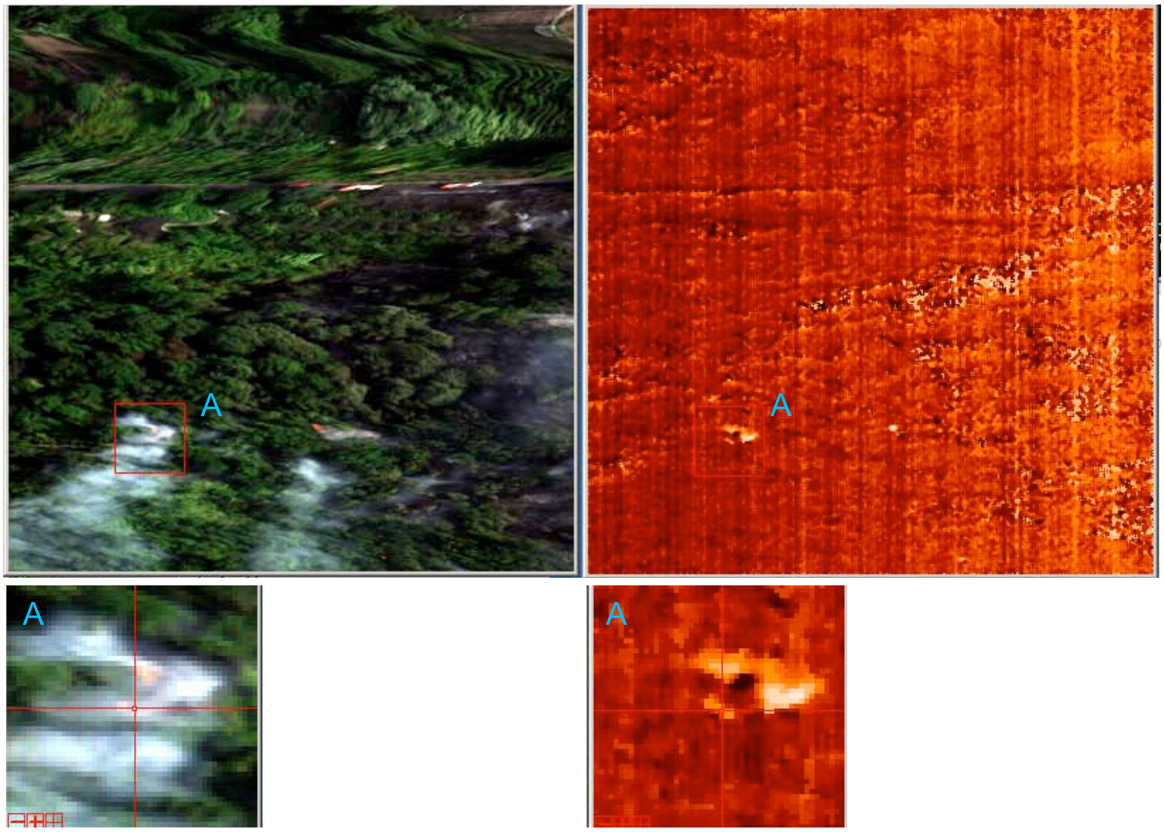

Figure 10. Nemi Cerveteri wildfire: the band ratio shows also in the presence of plants the flaming area.

The images obtained by applying the AKBR, point out the flaming area in correspondence of value greater than 1. A more quantitative investigation is under study.

3.4 SIM-GA SWIR –VNIR comparison

SWIR range is used in the scientific analysis of High Temperature events because of high contrast between fire and background and because of the minimal clutter in emissive spectra [Dozier et al., 1981.]. Full range sensors that operate into the SWIR provide the capability of detecting hot spots as well as estimating their temperature.
In order to validate the K-method emission analysis, a comparison between the two different spectral range was performed.
The chosen image, is that acquired on 14 August 2006 (time17:36 GMT) that presented low spatial geometrical distortion.
Since spatial resolution of SIM-GA in the Visible EOH is about double of that one in the SWIR EOH, the VISIBLE data set was spatially resampled to the spatial resolution of the SWIR HEO in order to be compared with the corresponding SWIR data.
A spatial filtering operation was performed to suppress the random noise and the smoothed SWIR image at 1975.0nm, was compared with the K lines band ratio (766.3nm/769.5 nm) (figure 11a).
A scatter plot, of 766.3 (x) vs 769.5 (y) and 1975.0vnm (x) vs 1104.nm (y) respectively was realised to point out two different classes (figure 11b): flaming area (due to K lines) and smoldering and hot spot typical of SWIR. The resulting classes were plotted on the image and the results compared. Since the high level of noise, especially around 2200nm spectral range, it was considered acceptable to choose the band 1975nm : in fact the fire saturates the pixels and the values are very high compared to the S/N ratio due to the H_2O absorption.

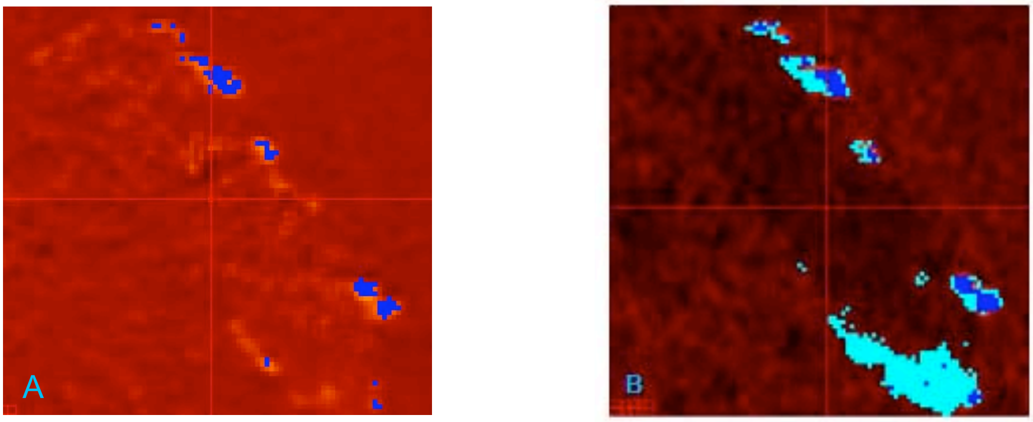

Figure 11a). (A) the spatial AKBR resampled image (30 m/px), is compared (B), with the corresponding SWIR image at 1243.24nm; the red colour table is applied to A and B.

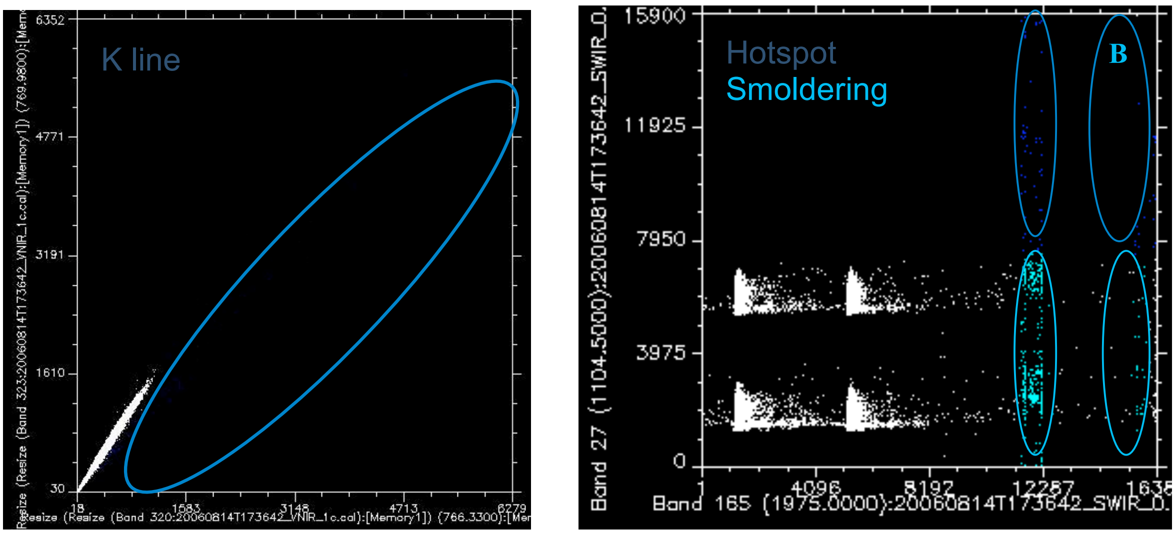

Figure 11 b). Scatter plot (A), of 766.3nm (x) vs 769.5nm (y) and 1975.0nm (x) vs 1104.nm (y) respectively was realised to point out two different classes: flaming (K line) /hot spot and smoldering.

The comparison between K line pixels (figure11a, A) and the hot spot pixels (figure 11a, B) shows an high correlation between them. “Smoldering” area in correspondence of high saturation is in light blue (figure 11a, B).
The K line method offers the opportunity to detect the exact position of flames also in presence of smoke, if the performance of the sensor are adequate, being helpful in fire suppressing actions. Further, separating smoldering from flaming vegetation is important to quantifying the release of gases and aerosols from biomass burning that impact atmospheric chemistry because some important gases .

Conclusions

The aim of the project was that to test the spectral performances of SIM-GA verify the feasibility of using alternative spectral range respect to the more common used SWIR -TIR bands. The visible EOH of SIM-GA showed very good performances compared to the SWIR EOH one. Very noisy bands and the needs to select proper integration time for SWIR acquisition were pointed out.

On the other side the Visible EOH of SIM-GA allowed to investigate and verify the K-line method.
Further, the very high spectral resolution (1.2nm) allowed to resolve the K duplet, compared to previous experiment carried out by Vodacek on 2002 by using AVIRIS sensor.
By comparing the data acquired by both EOHs a good capacity of SIM-GA to detect flaming pixels by using K-method was pointed out.

Future Work

Future steps will consist in investigate the possibility to apply K method on data acquired by satellite sensor and evaluate spectral and signal requirements.

Acknowledgments

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