# Spectral features of open fires for detection and burn scar

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**Workshop Data Exploitation della missione PRISMA, precursore delle missioni iperspettrali nazionali,**
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Image source Nurallao, Joseph Loddo

# Acknowledgements

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- Landsat 7 ETM+ from EarthExplorer
- ERS-2, ASAR & ALOS PALSAR data as part of Category 1 Project 2999 PI Dr. Kamie Kitmitto
- AIST Japan nuova collaborazione -HSUI

# Overview

- Problem
- Metodology
- Input data
- Algorithm -> product
- Work in progress
- Impact

# Problem

## Economic

loss of infrastructure, natural and
cultural resources, insurance
Fire suppression high costs

1

## Scientific

Transport gas to atmosphere
climate change
Fire regime, biodiversity

2

## Social

Transport gas to atmosphere
climate change

3

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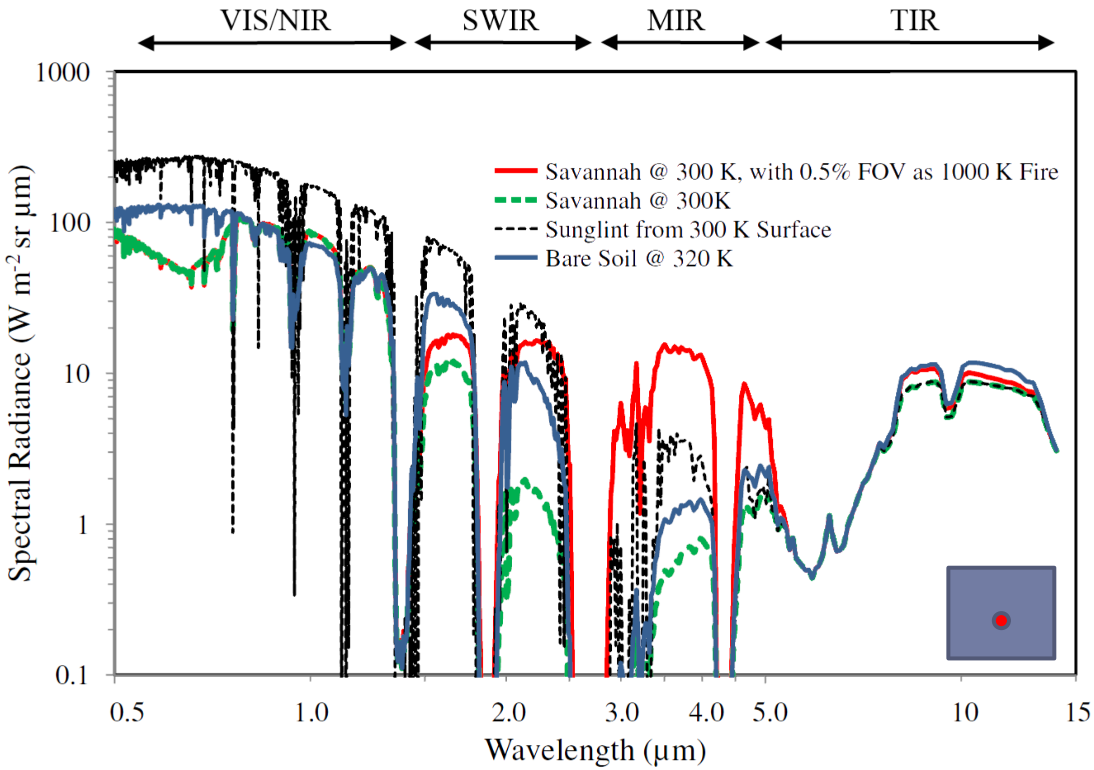
1 http://www.sardiniapost.it/cronaca/incendio-vicino-olbia-spento-subito-grazie-un-continuo-bombardamento-dacqua/, consulted on jan 2016
2 http://earthobservatory.nasa.gov/IOTD/view.php?id=81431, consulted on jan 2016
3 http://www.wri.org/blog/2014/03/fires-indonesia-spike-highest-levels-june-2013-haz, consulted on jan 2016

# Need for research

- **Pre-fire** Measurements that can be correlated to fire behaviour
- **Active fire** Localization, flame/ smouldering, evaluation of Parameters for modelling, Linking Energy to Emissions and Air Quality
- **Post- fire** burn scar delineation, Vegetation Mortality, Ecosystem Recovery, Land use change

# Metodology: detection methods

- Vegetation fires involve **high temperatures**, so thermal remote sensing is suitable to its identification and study
- Actively burning **fires emit IR** so strongly, especially at MIR (**3–5 μm)** wavelengths that can be identify by Earth orbit
- ***Fixed –threshold approach*** algorithms which provide 'hotspot' counts and fire location maps (e.g. MODIS products Justice et al., 2002, Giglio et al., 2003, Denisson et al., 2006.)



Top-of-atmosphere spectral radiance simulated at four different target) using the MODTRAN 5 radiative transfer code.
**Simulations for a savannah surface at 300** K;t he same surface but with a 1,000 K **fire covering 0.5 % of the ground field-of-view (FOV),** specularly reflected sunglint from a 300 K surface; and solar-heated (320 K) bare soil.
**The pixel containing the sub-pixel fire shows a signal highly elevated in the MIR (3–5μm)** spectral region compared to all other targets, equivalent to a brightness temperature of around **400 K** ( Wooster et al. 2012 )

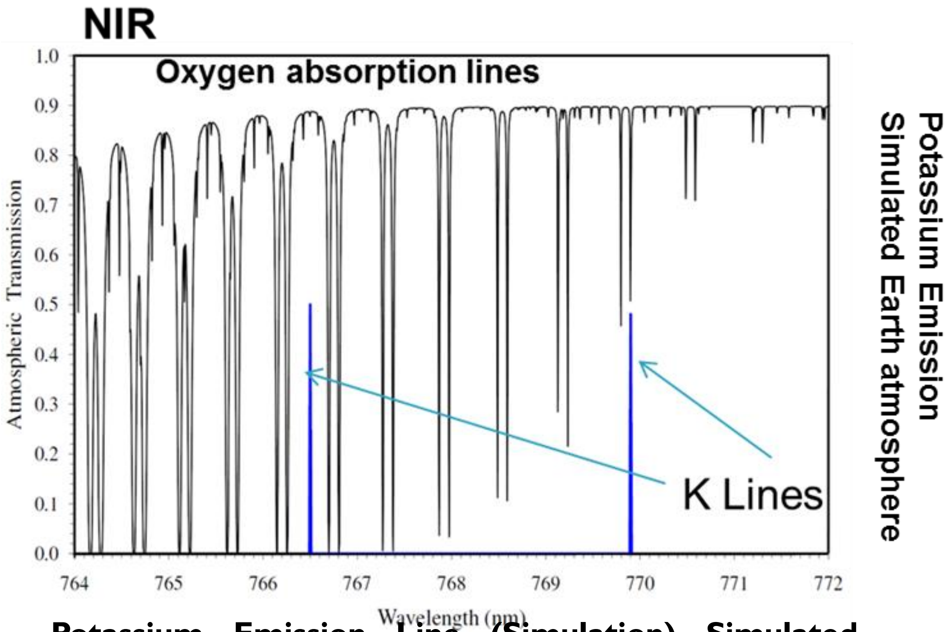
# Caratteristiche spettroscopiche dei fuochi: emissione del Potassio

- Fuel biomass is largely composed of **Carbon (~45%), Hydrogen (5.5%), Oxygen (41%),** and **Nitrogen (3.5%),** and the molecular combustion products are dominantly CO2, H2O, CO, CH4, and various nitrogenous compounds (Levine, 1991)
- ✓ In addition 'trace' elements: K: up to 7%, Na: 0.1%, P: up to 1%, Ca: up to 5%
- ✓ When ionized alkalies can make transitions resulting in very strong emission lines.
- ✓ At high temperatures associated with flaming combustion, trace elements like K are mobilised. This produces a sudden increase in reflectance at **766.5nm and 7.69.9nm,** which very narrow band (hyperspectral) sensors detect as a sharp emission peak or line**.**(Vodacek 2002).

**Advantages:**

being specific to flaming combustion a K emission approach theoretically allows for the **separation of smouldering from flaming** areas of vegetation and **active fire detection.**

**Potassium low excitation energy - 4.34 eV**

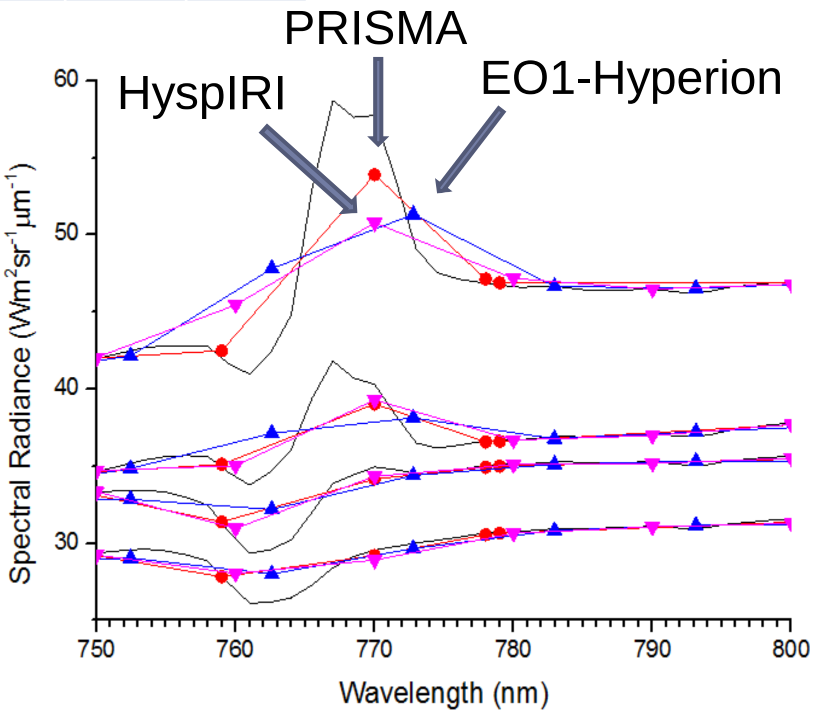


**Potassium Emission Line (Simulation) Simulated Earth atmosphere.**
Transmission was calculated as viewing the Earth from100 km elevation at nadir and assuming a US 1976 Standard Atmosphere and a 23 km rural aerosol. Simulation was conducted at 0.1 $cm^{-1}$ wavenumber resolution using the high spectral resolution mode of MODTRAN 5.2 (Berk et al., 2008)

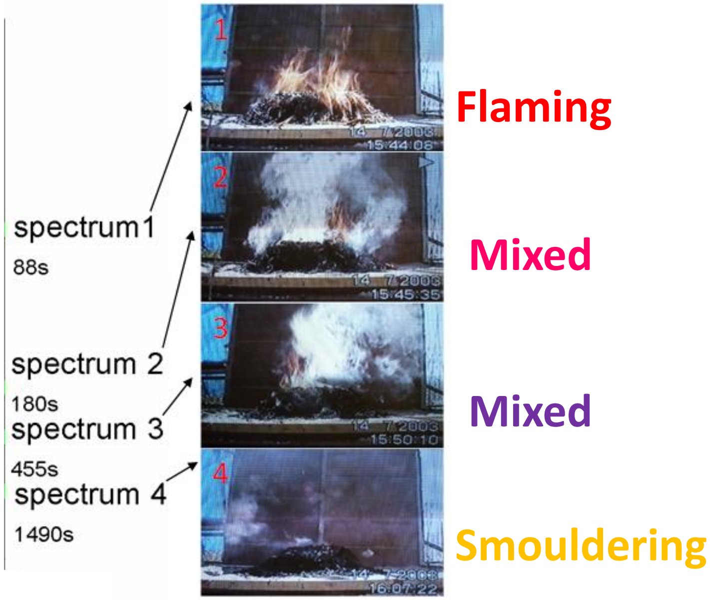
# Input data: Laboratory scale

| Sensor | Sptial resolution | Central band |
|---|---|---|
| Hyperion | 30m | 772nm |
| HyspIRI | 60m | 770nm |
| PRISMA | 30m | 770nm |

**How different sensors see the K emission?**

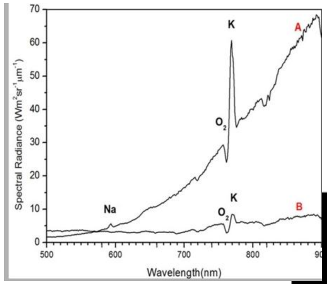


*S Amici , M.J. Wooster, A. Piscini RSE 2011, Hyper- SiMGA data courtesy Leonardo*



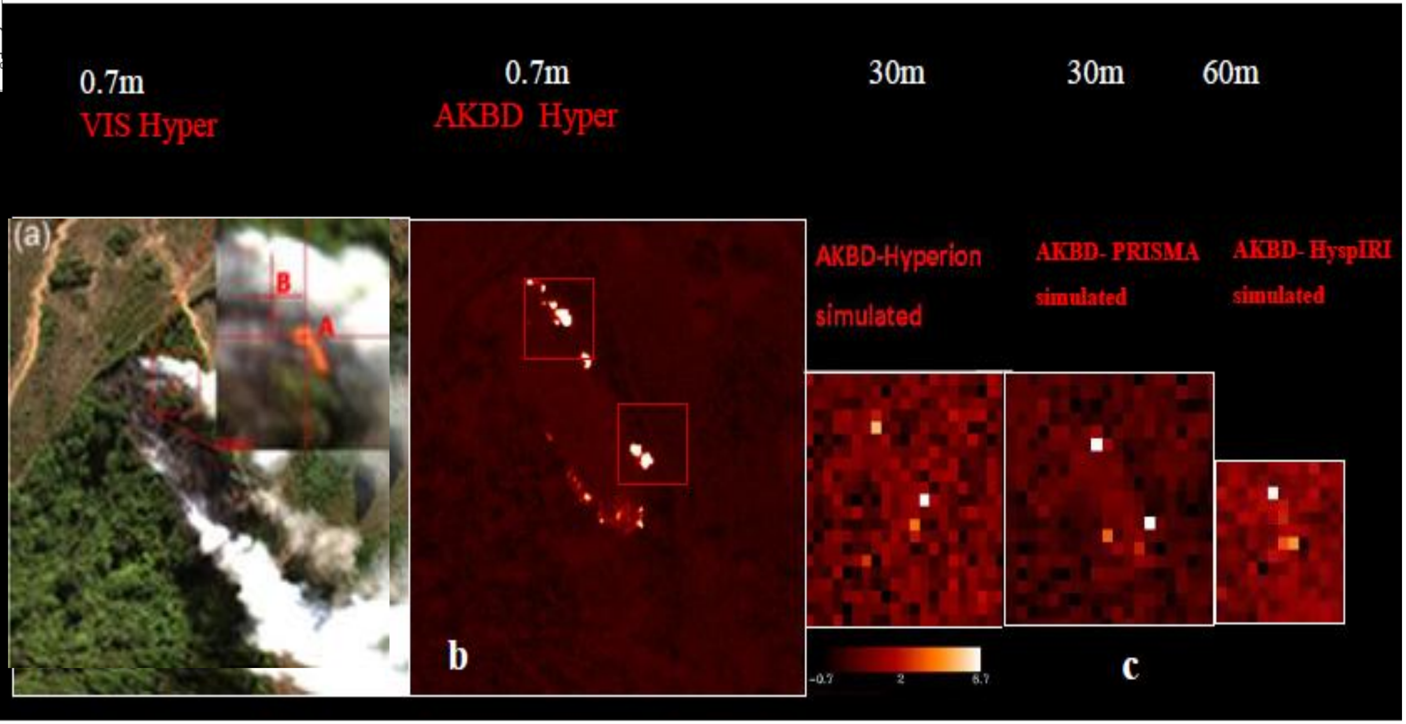
Data courtesy Prof. M. Wooster

# Airborne data: Mediterranean land cover



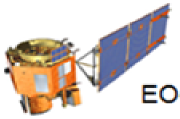
**Advanced K Band Difference (AKBD) = Max|BandJK$_i$|-BKG**

True colour composite



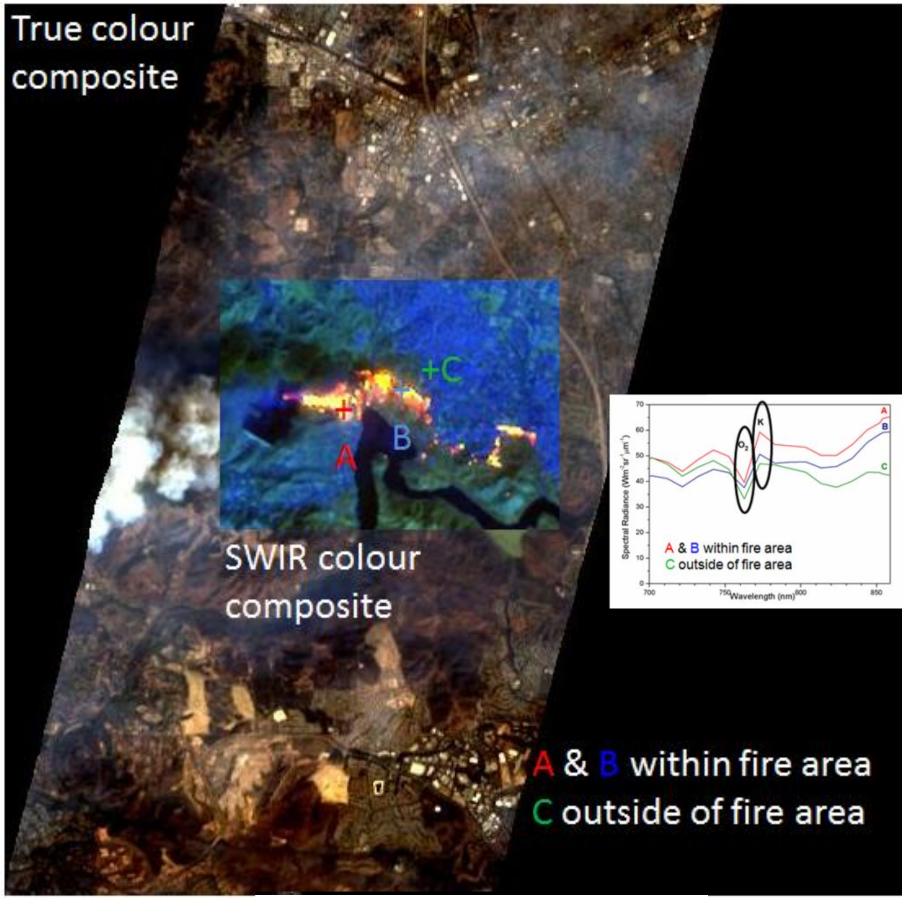
*S Amici , M.J. Wooster, A. Piscini RSE 2011, Hyper- SiMGA data courtesy Leonardo*

# Satellite scale: EO1Hyperion: AKBD and CDI

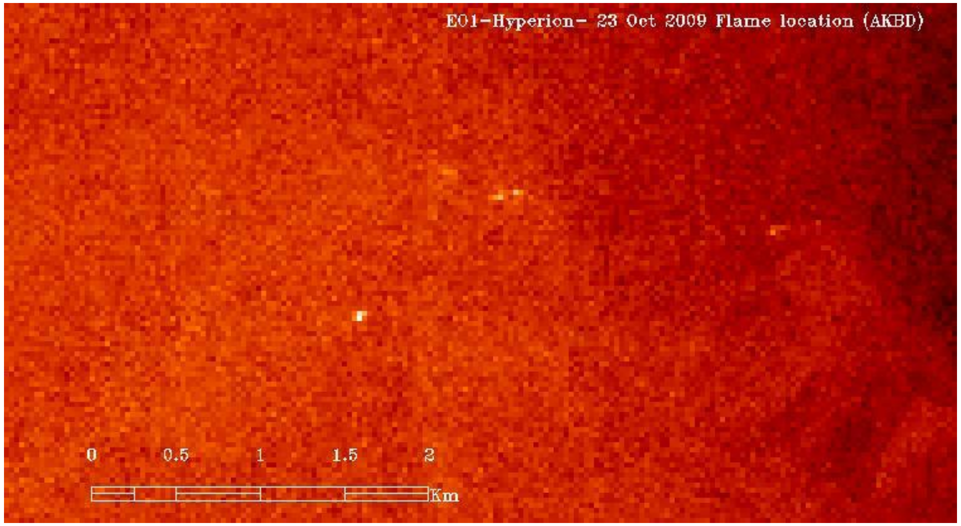


EO-1 Satellite

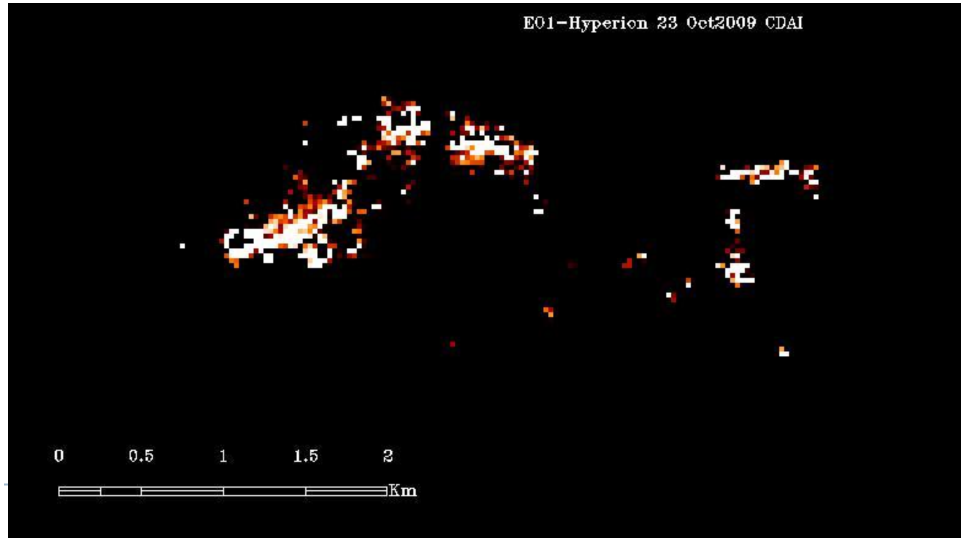
- South –California 23October 2007



(lat. 33.0 ° N, lon. 117.2 ° W)

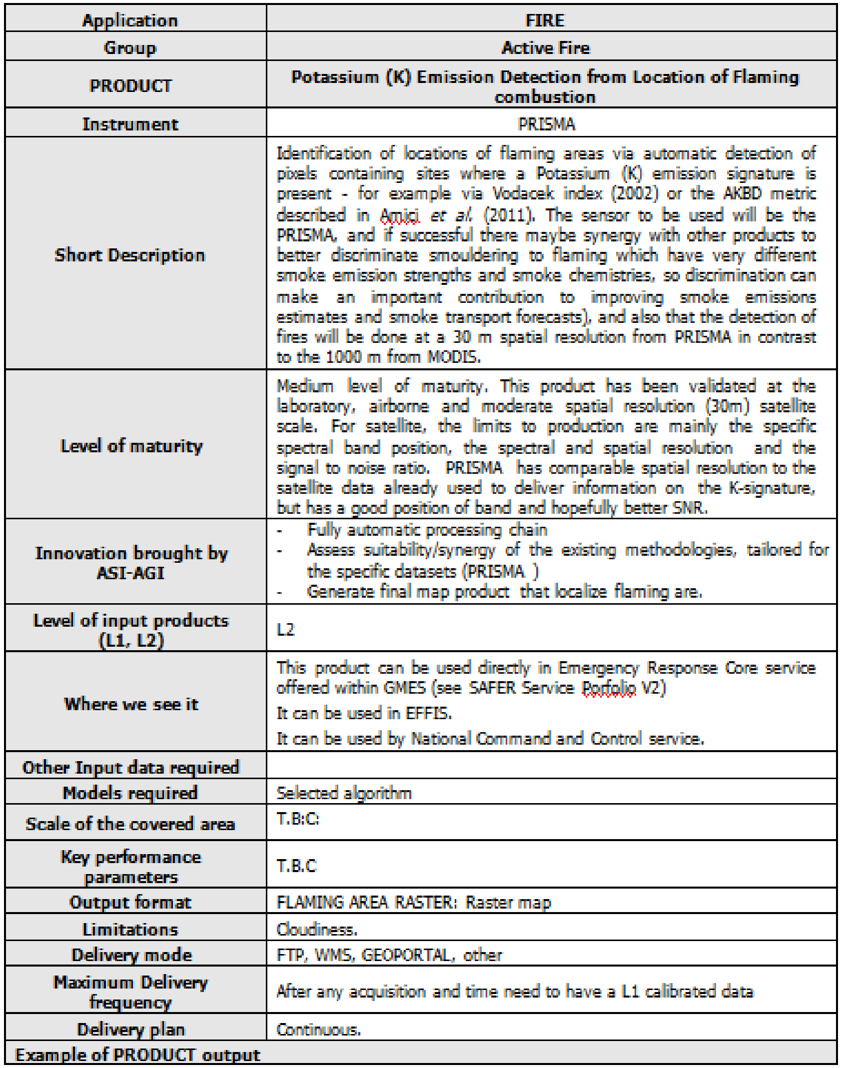


E01-Hyperion- 23 Oct 2009 Flame location (AKBD)

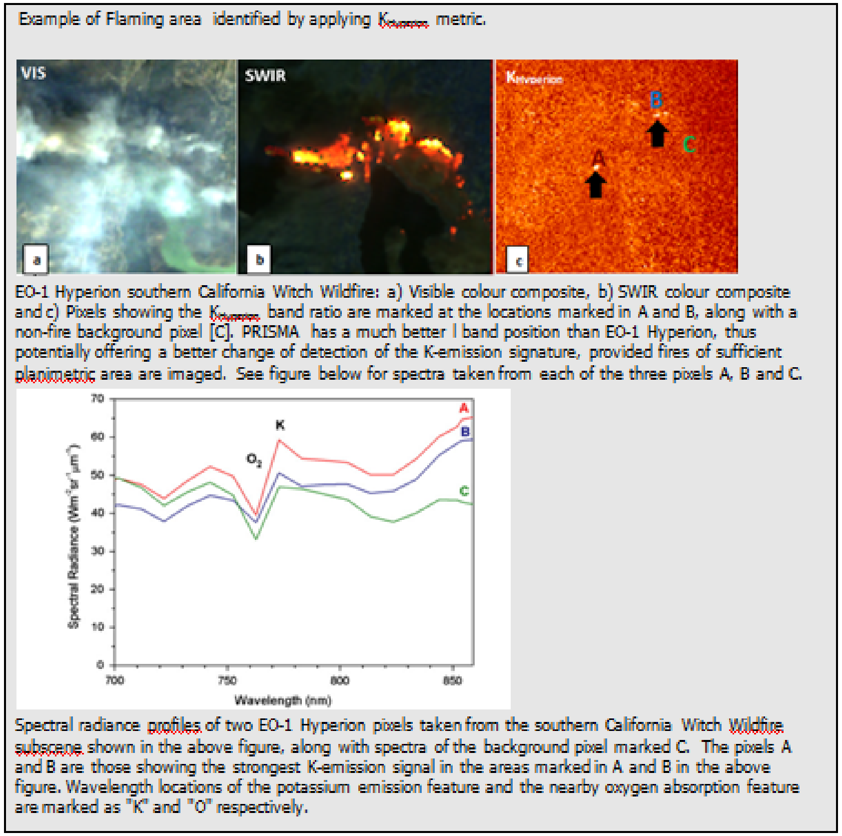


E01-Hyperion 23 Oct2009 CDAI

# Solution: ASI-AGI (flaming location product)



| Application | FIRE |
|---|---|
| Group | Active Fire |
| PRODUCT | Potassium (K) Emission Detection from Location of Flaming combustion |
| Instrument | PRISMA |
| Short Description | Identification of locations of flaming areas via automatic detection of pixels containing sites where a Potassium (K) emission signature is present - for example via Vodacek index (2002) or the AKBD metric described in Amici *et al.* (2011). The sensor to be used will be the PRISMA, and if successful there maybe synergy with other products to better discriminate smouldering to flaming which have very different smoke emission strengths and smoke chemistries, so discrimination can make an important contribution to improving smoke emissions estimates and smoke transport forecasts), and also that the detection of fires will be done at a 30 m spatial resolution from PRISMA in contrast to the 1000 m from MODIS. |
| Level of maturity | Medium level of maturity. This product has been validated at the laboratory, airborne and moderate spatial resolution (30m) satellite scale. For satellite, the limits to production are mainly the specific spectral band position, the spectral and spatial resolution and the signal to noise ratio. PRISMA has comparable spatial resolution to the satellite data already used to deliver information on the K-signature, but has a good position of band and hopefully better SNR. |
| Innovation brought by ASI-AGI | - Fully automatic processing chain<br>- Assess suitability/synergy of the existing methodologies, tailored for the specific datasets (PRISMA )<br>- Generate final map product that localize flaming are. |
| Level of input products (L1, L2) | L2 |
| Where we see it | This product can be used directly in Emergency Response Core service offered within GMES (see SAFER Service Porfolio V2)<br>It can be used in EFFIS.<br>It can be used by National Command and Control service. |
| Other Input data required | |
| Models required | Selected algorithm |
| Scale of the covered area | T.B:C: |
| Key performance parameters | T.B.C |
| Output format | FLAMING AREA RASTER: Raster map |
| Limitations | Cloudiness. |
| Delivery mode | FTP, WMS, GEOPORTAL, other |
| Maximum Delivery frequency | After any acquisition and time need to have a L1 calibrated data |
| Delivery plan | Continuous. |
| Example of PRODUCT output | |



Example of Flaming area identified by applying $K_{Hyperion}$ metric.

EO-1 Hyperion southern California Witch Wildfire: a) Visible colour composite, b) SWIR colour composite and c) Pixels showing the $K_{Hyperion}$ band ratio are marked at the locations marked in A and B, along with a non-fire background pixel [C]. PRISMA has a much better I band position than EO-1 Hyperion, thus potentially offering a better change of detection of the K-emission signature, provided fires of sufficient planimetric area are imaged. See figure below for spectra taken from each of the three pixels A, B and C.

Spectral radiance profiles of two EO-1 Hyperion pixels taken from the southern California Witch Wildfire subscene shown in the above figure, along with spectra of the background pixel marked C. The pixels A and B are those showing the strongest K-emission signal in the areas marked in A and B in the above figure. Wavelength locations of the potassium emission feature and the nearby oxygen absorption feature are marked as "K" and "O" respectively.

# Work in progress- **Post fire effect: peatland UK**
## Peak District National Park (PDNP) case study

Peak District National Park (PDNP) case study

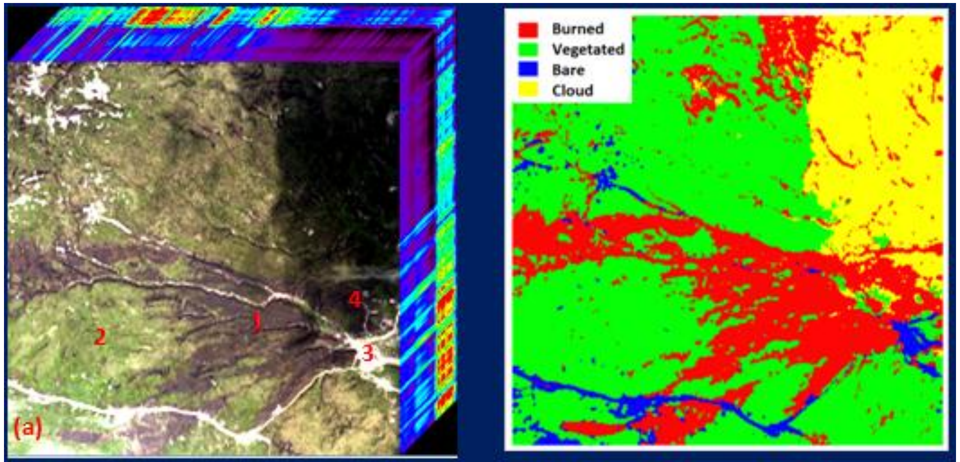
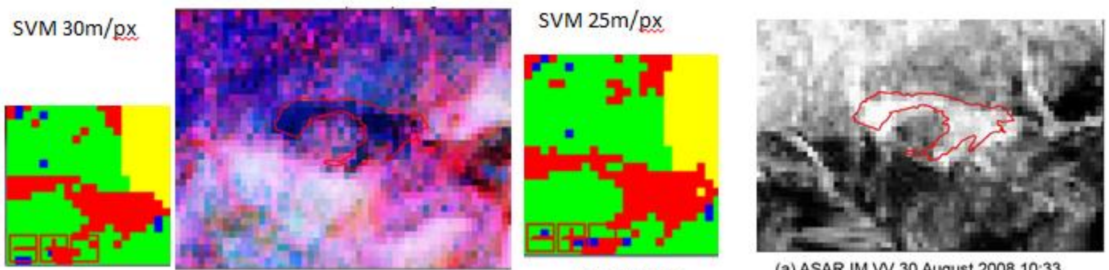


Fig 2 (a) True colour colour composite and hyperspectral cube showing location of land cover types; (b) SVM classification obtained using four classes to delineate the burn scar (1.5 m/pixel).



© USGS/ EROS 2008

(d) Landsat 7 27 September 2008
DS3 R=b31, G=b41, B=b52 - 30m pixel spacing

© ESA 2008

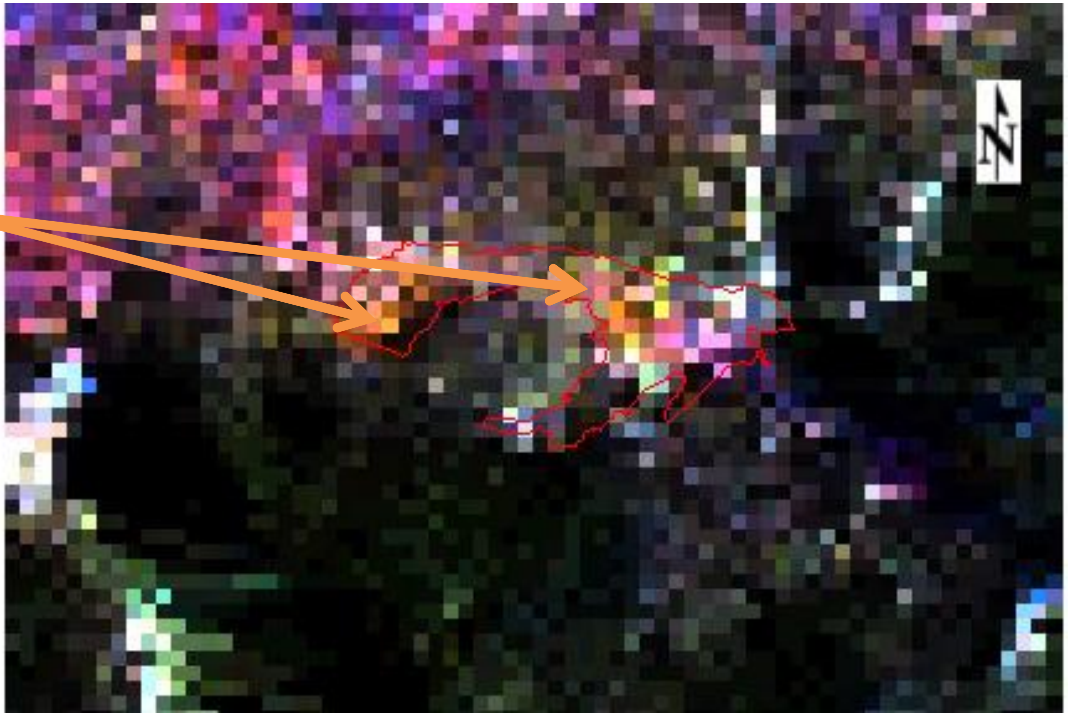
(a) ASAR IM VV 30 August 2008 10:33
C-band - 25m pixel spacing

Figure 2 burn scar delineation resulted by SVM against Landsat and ASAR respectively.

**Decorrelation Stretch** (DS) applied to L7 to remove highly correlated data, which is commonly found in multi-spectral images.

Amici, S., Millin-Chalabi, G., Danson, M., Mcmorrow, J., & Agnew, C. (2016). *Aerial high resolution hyperspectral data for validation of the Edale upland peat moorland burn scar derived by SAR and Optical satellite imagery*. Poster session presented at ESA Living Planet Symposium, Prague, Czech Republic.. Publication link: 2f0b411d-724b-46df-9d58-8c5c080a8495

# First Attempt: Data Fusion



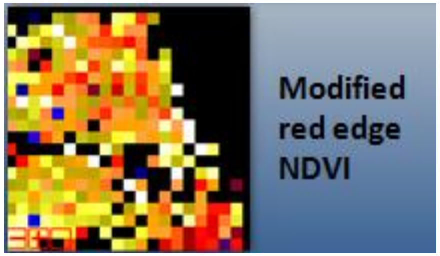
ERS-2 30/08/08

Landsat 7 ETM+ 27/09/08

Orange areas highlighting most severely burnt locations

**NEXT steps:**

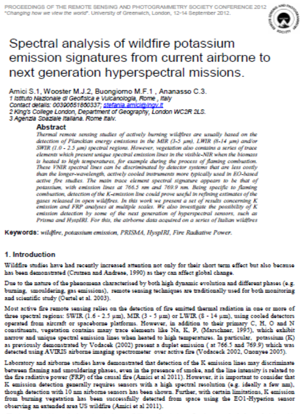
- Validate the fusion interpretation by using
- NERC ARSF, Eagle Hyperspectral data ( 01/07/08)
- and in situ data
- Use the hyperspectral data to apply classification methods and validate L7/ SAR classification results



Amici, S., Millin-Chalabi, G., Danson, M., Mcmorrow, J., & Agnew, C. (2016). *Aerial high resolution hyperspectral data for validation of the Edale upland peat moorland burn scar derived by SAR and Optical satellite imagery*. Poster session presented at ESA Living Planet Symposium, Prague, Czech Republic.. Publication link: 2f0b411d-724b-46df-9d58-8c5c080a8495

# Impact

10 Conference contributions
6 inviting talk
6 papers
6 projects contributions
Network and collaborations



PROCEEDINGS OF THE REMOTE SENSING AND PHOTOGRAMMETRY SOCIETY CONFERENCE 2012
"Changing how we view the world". University of Greenwich, London, 12-14 September 2012.

Spectral analysis of wildfire potassium emission signatures from current airborne to next generation hyperspectral missions.

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*Contact details: 00390651860337; stefania.amici@ingv.it*
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**Abstract**

*Thermal remote sensing studies of actively burning wildfires are usually based on the detection of Planckian energy emissions in the MIR (3-5 µm), LWIR (8-14 µm) and/or SWIR (1.0 - 2.5 µm) spectral regions. However, vegetation also contains a series of trace elements which present unique spectral emission lines in the visible-NIR when the biomass is heated to high temperatures, for example during the process of flaming combustion. These VNIR spectral lines can be discriminated by detector systems that are less costly than the longer-wavelength, actively cooled instruments more typically used in EO-based active fire studies. The main trace element spectral signature appears to be that of potassium, with emission lines at 766.5 nm and 769.9 nm. Being specific to flaming combustion, detection of the K-emission line could prove useful in refining estimates of the gases released in open wildfires. In this work we present a set of results concerning K emission and FRP analyses at multiple scales. We also investigate the possibility of K emission detection by some of the next generation of hyperspectral sensors, such as Prisma and HyspIRI. For this, the airborne data acquired on a series of Italian wildfires*

**Keywords:** *wildfire, potassium emission, PRISMA, HyspIRI, Fire Radiative Power.*

**1. Introduction**

Wildfire studies have had recently increased attention not only for their short term effect but also because has been demonstrated (Crutzen and Andreae, 1990) as they can affect global change.

Due to the nature of the phenomena characterised by both high dynamic evolution and different phases (e.g. burning, smouldering, gas emissions), remote sensing techniques are traditionally used for both monitoring and scientific study (Oertel et al. 2003).

Most active fire remote sensing relies on the detection of fire emitted thermal radiation in one or more of three spectral regions: SWIR (1.6 - 2.5 µm), MIR (3 - 5 µm) or LWIR (8 - 14 µm), using cooled detectors operated from aircraft or spaceborne platforms. However, in addition to their primary C, H, O and N constituents, vegetation contains many trace elements like Na, K, P, (Marschner, 1995), which exhibit narrow and unique spectral emission lines when heated to high temperatures. In particular, potassium (K) as previously demonstrated by Vodacek (2002) present a duplet emission ( at 766.5 and 769.9) which was detected using AVIRIS airborne imaging spectrometer over active fire (Vodaceck 2002, Ononyee 2005).

Laboratory and airborne studies have demonstrated that detection of the K emission lines may discriminate between flaming and smouldering phases, even in the presence of smoke, and the line intensity is related to the fire radiative power (FRP) of the causal fire (Amici et al 2011). However, it is important to consider that K emission detection generally requires sensors with a high spectral resolution (e.g. ideally a few nm), though detection with 10 nm airborne sensors has been shown. Further, with certain limitations, K emission from burning vegetation has been successfully detected from space using the EO1-Hyperion sensor observing an extended area US wildfire (Amici et al 2011).

The interest in this method consists in the possibility to discriminate flaming area, both day and night, with a limited sensitivity to false alarm. Furthermore, the technology involved in silicon CCD detector used in optical sensor is low cost compared to active cooled MIR to LWIR thermal imaging sensor.

1

2011

2012

RSPSOC
EGU

HyspIRI 2013

2014

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1 INGV,
2 the Univ. Mancester,
3Salfornd Univ.

RSPSOC

SPIE
2015

2016

Tmax

**New areas**
Peatland
Landuse change
Fire regime
Burn scar
Model propagation
Regrowing map

2017

Miniworkshop for global wildfire prevention16-01-2017-AISTAIST

# Thanks for listening

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it.linkedin.com/pub/stefania-amici-phd/24/5b6/794/