MULTI-SENSOR RAPID FIRE DAMAGE ASSESSMENT OVER MEDITERRANEAN AREA

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Abstract – Several studies have clearly demonstrated the capability of suitable algorithms based on satellite images to detect fires scars by using optical and radar data. In the near infrared region (0.7-1.3 micron) green vegetation shows high reflectance values compared to the most other natural surfaces. In general this region of the spectrum contains the most useful information on burned surface detection. After a fire occurs, in fact, a strong reflectance decrease can be found in the burned area. Generally, in a burned surface, the reflectance falls to a low level (5-15 %) because of the presence of ash and carbon over the soil. For this reason the NIR is the more appropriate spectral region for burned areas detection, allowing high contrast between burned and unburned surfaces. Taking the advantage of using the synthetic aperture radar (SAR) for mapping forest volume or above ground biomass in big area, within the burned area, this instrument has been used to detect deep fire scars in order to provide more information on the fire event .

Keywords: Fire Damage Assesment, Biomass, SAR, NDVI

1. INTRODUCTION

Forest fires represent the main cause of forest degradation in the Mediterranean area. This phenomenon, progressively increasing, reached an average of 57,000 fires per year in the period 2000-2008 with the destruction of almost 450,000 ha of vegetated areas in southern European countries. Fires occurring in the Mediterranean area are rarely significant in terms of pollution or greenhouse gases released to the atmosphere. Nevertheless, they have a dramatic impact on forest and scrub in regions with relatively sparse vegetation, as well as on human lives and infrastructure. The most effective, passive remote-sensing methods for detecting and mapping burn scars in vegetated areas, rely upon the observation of near-infrared (NIR) and short-wavelength infrared (SWIR) bands, with wavelengths comprised between 0.8 and 2.3µm.
An innovative method to separate reflectance variation due to vegetation damages from changes due to other factors influencing the at-satellite reflectance is that of identifying pseudo-invariant features to be used as reference targets in different scenes. On the other hand, SAR seems to be another good candidate for fire assessment, because of sensitivity of backscattering to the geometric structure of targets and surfaces, particularly during the fire, when the smoke makes the approach with optical sensors not feasible. The incident wave is influenced by several target's parameters, such as moisture, orientation, roughness.
When a fire occurs, the landscape is modified dramatically; the grassland, the leaves and bushes are completely burned, while the trunks can disappear depending on the fire intensity. The backscattering of a vegetated area is mainly dominated by a volumetric scattering mechanism, with the backscattered wave is highly depolarized; after a fire, when all the vegetation has been burnt, the backscattering is dominated by a surface scattering mechanism (burnt soil) or by the double bounce mechanism (by the presence of scattered burnt trunks). By means of multi-temporal SAR observation, it is possible to assess fire damage (burnt surface and burnt biomass estimation) and to monitor the forest re-grown. A synergic approach of automatic rapid mapping fire scars is presented by the use of high-resolution optical imagery (ALOS-AVNIR, SPOT-5) and C and L band radar images (single and dual-pol) applied on the major forest fires occurred in Sardinia during the 2009 summer season.

2. BACKGROUND

Several studies have clearly demonstrated the capability of suitable algorithms based on satellite images to detect fires scars by using optical and radar data.
Methods based on optical multi-temporal images (before and after fires), acquired by a variety of aerial and satellite sensors (AVHRR, ATSR, MODIS, SPOT-VEGETATION, TM/ETM+) [1], [2], commonly rely upon the analysis of the behaviour of visual near-infrared (VNIR), short-wavelength infrared (SWIR) and thermal infrared (TIR) data, combined to compute a set of spectral indices such as the NDII (Normalised Differential Infrared Index) [3], the BAI (Burned Area Index) [4], the GEMI (Global Environmental Monitoring Index) [5], the VI3 index [6], the NBRTI (thermally enhanced versions of the Normalized Burn Ratio index) [7], and the MIRBI (Mid-infrared Bispectral Index) [8].
Of course, any method should be able to distinguish quantitatively between reflectance changes – originating from temporary or local image acquisition conditions – and reflectance changes due to the actual vegetation changes in biomass, chlorophyll absorption and water content.
The spectral signal of burned surface differs from pre-fire vegetation signature, such as fuel loading and canopy structure, and also as consequence of varying fire behaviour, that affects the severity of the fires effects. In the visible spectrum (0.4-0.7 micron), the reflectance of vegetation is normally low, depending on the level of chlorophyll present, with a peak at 0.55 micron (green). After the fire passage two particular products can be seen: the white ash due to a complete combustion of the biomass and black ash like carbon, produced by combustion during low oxygen conditions.
The first case is common in the dry grass burning while the second in case of live biomass burned like forest and shrub-lands. Without a detailed analysis conducted at local basis, it is hence difficult to deduce that burned surfaces lead to an increase or a decrease of the reflectance in the visible range.

In the near infrared region (0.7-1.3 micron) green vegetation shows high reflectance values compared to the most other natural surfaces. In general this region of the spectrum contains the most useful information on burned surface detection. After a fire occurs, in fact, a strong reflectance decrease can be found in the burned area. Generally, in a burned surface, the reflectance falls to a low level (5-15%) because of the presence of ash and carbon over the soil, [9].

For this reason the NIR is the more appropriate spectral region for burned areas detection, allowing high contrast between burned and unburned surfaces.

Taking the advantage of synthetic aperture radar (SAR) for mapping forest volume or above ground biomass in big area, many studies have been carried out to extract forest parameters information from SAR data. The techniques suitable for forest volume or biomass extraction include C-band InSAR ([11], [12] [13]), L- and P-band intensity ([14], [15]) and L-band ([16], [17]) and P-band [18] polarimetric interferometry SAR (POLinSAR). C-band InSAR coherence has been observed using ERS Tandem data to have good correlation with volume density, and the higher the volume density the lower the InSAR coherence. However, the relationship between L-band InSAR coherence is much more complex and needs to be further investigated. C-band SAR intensity saturates at very low biomass level, so only L- and P-band intensity were thought as suitable for forest biomass estimation.

In case of SAR intensity only, P-band is the best for biomass estimation with the highest saturation level. Normally, L-band intensity saturates at 120-160 ton/ha of biomass. In the case of POLinSAR technique, many successful observations have been carried out using L-band data. ALOS PALSAR can provide dual-polarization (HH, HV) intensity data and quad-polarization data, so the potential applications of these data for forest parameters extraction include dual-polarization intensity, multi-temporal dual-intensity, polarimetry, InSAR coherence and POLinSAR. In this test site, only two ALOS PALSAR dual-polarimetric data was acquired together with a short multi-angle Envisat ASAR single Polarimetric Wide Swath images, therefore POLinSAR was not covered in this.

Focusing on RADAR sensitivity to geometrical characteristic of the target, SAR dual polarimetric data is a good data source for better understanding the forest fire damage, extension and evolution. In particular at L Band, the radar signal interacts with the first leaf layer and trunks, allowing the forest classification inside the burned area. While Optical data is useful for the precise segmentation of the fire scar, radar can provide information of what has been destroyed by the fire events, if trunks have been completely destroyed or if only the leaves have been burned.

The emphasis of this work is on precise mapping of the burned zones on which the ban prescribed by the law is to be applied. This requires the processing of high spatial resolution images (AVNIR-2, SPOT). To the above ends, many images must be managed, requiring adoption of an approach which is as automatic as possible. The application of a robust, unsupervised change detection method will be of considerable advantage. In second instance the type of vegetation burned shall be analyzed by exploiting the RADAR data.

All the results have been compared and validated with the ground-truth analysis performed by the CFVA (Corpo Forestale e Vigilanza Ambientale) which has adopted, for the ground perimetration a GPS instrument.

3. DATA AND METHOD

The fire studied has occurred in Sardinia on the Monte Arci the 23th July 2009, burning over 2200 hectares of Mediterranean shrub land and oak forest. During the same day over 20.000 hectares of vegetation burned in the only Sardinia Region resulting the worst day of the whole fire season in Italy.

Figure 1. The wasting fire seen from the North side of the mountain at 17:00 GMT.

Monte Arci is an old volcano famous for being one of the Mediterranean central places where obsidian was found and worked for cutting tools and arrowheads in prehistoric age. Even now the volcanic glass can be found on the sides of the mountain. Currently it is part of a regional naturalistic park

The fire considered triggered at 13:00 by human unintentional action, when the wind was blowing from SW at 40 km/h and the temperatures were above 36-37 Celsius degrees. The event has been extinguished after 48 hours of operations carried out by the Fire Corps of the Sardinia Region. Several aerial interventions have been necessary together with terrestrial operations to extinguish the fire. As mentioned above, in the same days more than ten huge fires were devastating the region causing unfortunately two fatalities and resetting the entire intervention system. For these reasons the objective information coming from the satellites has proven to be very useful during the coordination phases, in the post-crisis event.

In previous papers the validity of integrated systems exploiting both optical and radar data in forest fire management has been demonstrated, [10]. For instance, the first optical data acquired by MODIS was available after two hours from the ignition of the fire showing an already critical situation.

Because of the particularly predisposing meteorological conditions, the fire quickly burned the forest and shrubs, completely destroying the trunks in the wind area and rapidly burning only the undergrowth in the high wind zone, leaving many tree canopies intact.

While Optical data detects accurately the spectral signature of the scar ensuring a precise perimetration, the exploitation of RADAR data allows to detect those areas partially burned, identifying the biomass partially destroyed. For the optical processing few cloud-free images have been processed, in particular one SPOT-5 image before the fire and one acquire just 5 days after the disaster. The processing has concerned first the calibration and the orthorectification of the optical images with SRTM data.

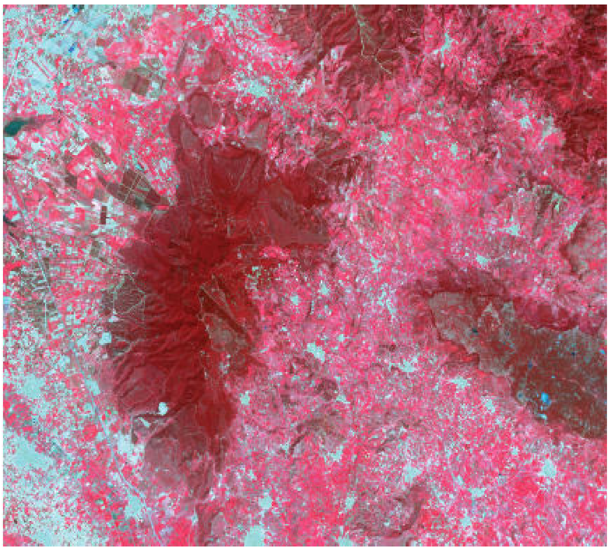

Figure 2. SPOT-5 image acquired in May 2009

In order to increase the precision of the image-registration a set of 50 GCPs spread in the image has been used. As shown in Fig.2 and Fig.3 the burned scar is quite evident by applying a simple change-detection technique based on the NIR channels. In particular the heavy burned areas are quite distinguishable, and detectable automatically by edge feature detection, while the partially burned zones show a minor contrast with the unburned surfaces.

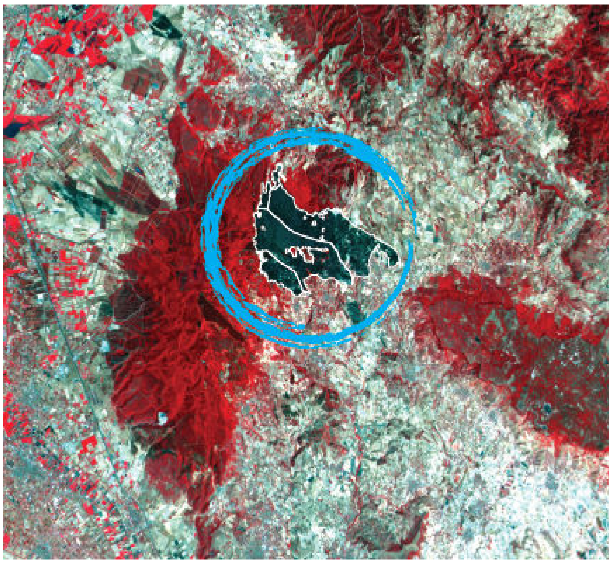

Figure 3. SPOT-5 image acquired the 26 July 2009

SAR images (ALOS dual-pol data before and after the fire) have been first calibrated and, to synergistically use both optical and SAR information, all data have been orthorectified and co-registered on a common reference Fig-5.

Using the image stack, textural information of GLCM (Gray-Level Co-occurrence Matrices) has been extracted and used in the segmentation together with the original data (both radar and optical). Based on statistic of the segmentation result, a clusterization algorithm has been triggered, in order to merge homogeneous polygons. Envisat ASAR single Polarimetric Wide Swath data have been used in a second processing step, for cross-compare the obtained results (Fig. 7).
The accuracy of the detected burned areas compared to the ground truth, which was available after more than four month, is above the 90%, Fig. 6.

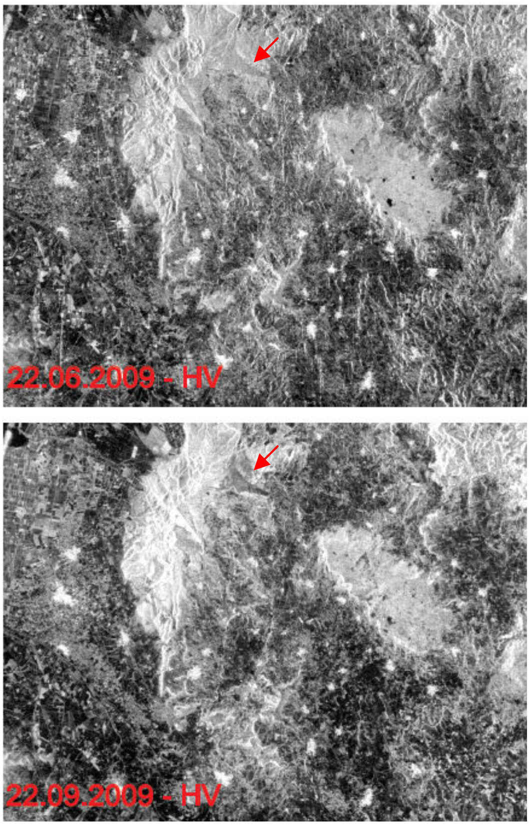

Figure 5. ALOS-PALSAR

4. CONCLUSIONS

The proposed algorithm showed good performances in rapid fire damage assessment and precise scar detection. The exploitation of multi-source EO data for tactical post event-crisis management has been demonstrated as a prompt and appropriate information source. Indeed the precise ground-base validation data are often available after several months from the event, above all during particular severe fire season. For this reason the proposed method is found to be very encouraging.
Radar data showed interesting results in providing basic information for forest fire classification. The sensitivity of Radar signal to geometrical structure of the target allows to classify the fire scar: where the fire completely burned the multi-temporal HV signal drastically decreases, this due to the destruction of the randomly oriented stable structures (trunks) and leaves, the targets producing a strong backscatter in the HV channel; where the fire rapidly burned the forest, without destroying the trunks, the backscattering in the HV channel

softly decreases; bushes or grass fire is not detected due to not relevant changes in the target geometrical structures: in L band, low biomass targets, such as understory, bushes or grass, are strongly influenced by the soil condition (roughness, soil moisture, etc…), parameters not significantly influenced by the fire events and below the sensor sensitivity.

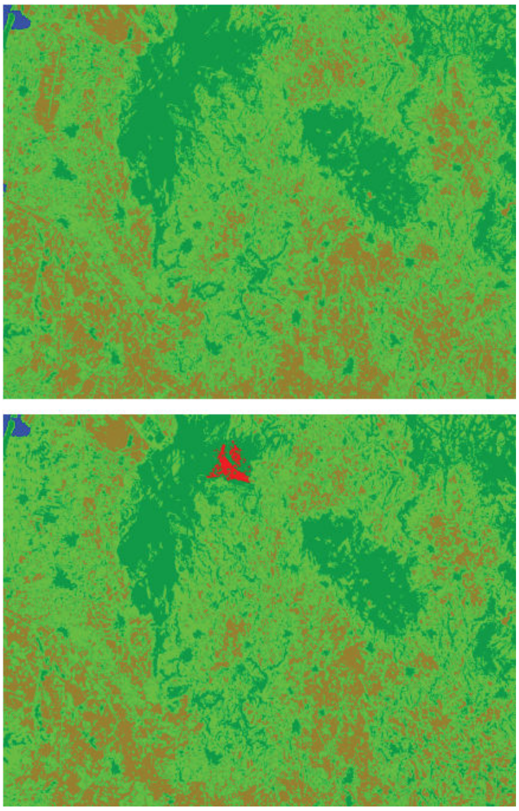

Figure 6. Resulting clustered Image before and after the fire

5. REFERENCES

[1] Barbosa, P. M., Gregoire, J. M. and Pereira, J. M. C., 1999. An algorithm for extracting burned areas from time series of AVHRR GAC data applied at a continental scale. Remote Sensing of Environment, 69, pp. 253-263.

[2] Giglio, L., Justice, C., Korontzi, S., and Roy, D. ,2000a. MODIS Fire Product. User's Guide (MOD14).

[3] Fensholt, R. and Sandholt, I., 2003. Derivation of a shortwave infrared water stress index from modis near- and shortwave infrared data in a semiarid environment. Remote Sensing of Environment, 87, 111–121.

[4] Chuvieco, E., Riano, A. I., and Cocero, D. , 2002. Estimation of fuel moisture content from multitemporal analysis of landsat thematic mapper reflectance data: applications in fire danger assessment. International Journal of Remote Sensing, 23, 2145–2162.

[5] Pereira, J. M. C. ,1999. A comparative evaluation of NOAA/AVHRR vegetation indexes for burned surface detection and mapping. IEEE Transactions on Geoscience and Remote Sensing, 37, 217–226.

[6] Barbosa, P. M., Gregoire, J.-M., and Pereira, J. M. C. ,1999. An algorithm for extracting burned areas from time series of AVHRR GAC data applied at a continental scale. Remote Sensing of Environment, 69, 253–263.

[7] Holden, Z. A., Smith, A. M. S., Morgan, P., Rollins, M. G., and Gessler, P. E., 2005. Evaluation of novel thermally enhanced spectral indices for mapping fire perimeters and comparisons with fire atlas data. International Journal of Remote Sensing, 26, 4801–4808.

[8] Trigg, S. and Flasse, S., 2001. An evaluation of different bi-spectral spaces for discriminating burned shrub-savanna. International Journal of Remote Sensing, 22, 2641–2647.

[9] Arino, O. et al. Methods of Mapping Burned Surfaces in Vegetation Fires, 2001. Global and Regional Vegetation Fire Monitoring from space, 227-255.

[10] Ferrucci, F. Laneve, G., Cadau E.G., 2009. SIGRI - An Integrated System for Detecting, Monitoring, Characterizing Forest Fires and Assessing damage by LEO-GEO Data, 7th International Workshop on "Advances in RS and GIS applications in Forest Fire Management Towards an Operational Use of Remote Sensing in Forest Fire Management''.

[11] Luckman, A., Baker, J., & Wegmuller, U. 2000. Repeat-pass interferometric coherence measurements of disturbed tropical forest from JERS and ERS satellites. Remote Sensing of Environment. 73, 350-360

[12] Fransson, J., Smith, G., Askne, J., & Olsson, H. (2001). Stem volume estimation in boreal forests using ERS-1/2 coherence and Spot XS optical data. International Journal of Remote Sensing, 22(14), 2777-2791.

[13] Paulliainen, J., Engdahl, M., & Hallikainen, M. (2003). Feasibility of multi-temporal interferometric SAR data for stand-level estimation of boreal forest stem volume. Remote Sensing of Environment, 85, 397-409.

[14] Le Toan T., Beaudoin A., Riom J., & Guyon D. Relating forest biomass to SAR data. IEEE Trans. Geosci. Remote Sensing, 1992, 30: 403-411.

[15] Ranson K. J., Sun G. Mapping biomass of Northern forest using multifrequency SAR data. IEEE Trans. Geosci. Remote Sensing, 1994, 32: 388-396.

[16] Papathanassiou K P, Cloude S R. 2001. Single baseline polarimetric SAR interferometry. IEEE Trans. Geosci. Remote Sens., 39(11): 2352-2363

[17] Cloude S R, Papathanassiou K P. 2003. Three- stage inversion process for polarimetric SAR interferometry. IEE Proc. Radar Sonar Navig, 150 (3): 125-134

[18] Dubois F. P., Angelliaume S., Souyris J. C., Garestier F., Champion I., The Specificity of P band POLINSAR data over vegetation, 2007, POLINSAR Workshop, ESRIN Italy.

[19] Erxue Chen, Zengyuan Li, Feilong Ling, Ying Lu, Qisheng He , Fengyun Fan, *Forest Density Estimation Capability of ALOS PALSAR Data over Hilly Region,* POLINSAR 2009, Frascati, Italy