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Fire Damage Assessment in Sardinia: the use of ALOS/PALSAR data for post fire effects management

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Abstract
Fires in the Sardinia Island are one of the most important environmental factors controlling the ecosystem´s function and structure. The evaluation of fire effects by means of remote sensing is economically and practically the best way to assess fire damage, before going to the field. The use of alternative techniques for fire effects assessment is needed, in particular to characterize the biomass loss at the regional level. Radar remotely sensed data can provide great advantages with respect to optical sensors. The paper is devoted to show the results obtained by applying a semi-automatic algorithm to the images of the L-band SAR sensor PALSAR, on board of the ALOS satellite, for the estimate of the burned area. To assess the quality of the estimate, the radar based results have been compared with those obtained from optical data and ground based information.
Keywords: SAR, Forest Fires, burned area, Mediterranean, optical data.

Introduction
During year 2009, the Island of Sardinia, suffered 684 fires of important size, affecting 37104 ha of which 12270 ha were wooded vegetation, as reported by the JRC 2009. According to historical data, the island is burned every year with important impacts in the loss of wooded vegetation. It is thought that longer dry weather periods, can negatively contribute to the biomass loss, as fuels gets drier and more susceptible to burn [Bajocco et al., 2007]. Related to this, there is a growing concern in the conservation of wooded areas as sinks of carbon and, on the other hand, to avoid high frequency fires, as they contribute to the release of extra greenhouse gas emissions to the atmosphere. Therefore the estimation of burned areas and the quantification of biomass loss is a critical parameter to understand how fires contribute

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to the consumption of different vegetation types, and how this is related to the loss of carbon stocks and its release to the atmosphere. Some research papers reported the utility of Synthetic Aperture Radar (SAR) data for providing information on patterns of disturbance by detecting fire scars [Bourgeau-Chavez et al., 1997; Cahoon et al., 1994, Kasischke et al., 1993; Kasischke et al., 1997], and for studying fire effects in forested areas [Tanase et al., 2010]. The ability to detect burned areas with SAR, as for any ecological process, will depend firstly on defining the optimal system parameters, including microwave frequency, polarization, incidence angle, resolution, and sampling frequency [Kasischke et al., 1997]. These characteristics will determine the type of backscatter mechanisms over forested terrains, and related to these, the type of effects produced by the fire disturbance. The ALOS/PALSAR sensor is a L-band microwave frequency (23cm) radar which has a deep penetration capability under the canopy, interacting with large branches, tree stems, and even has some interaction with the ground [Le Toan et al., 1992]. It is expected that the effect of fire on the reduction of the canopy structure, can produce a decrease of the backscatter signal, depending on the polarization mode. Optimal polarization in burned area detection was found to be the HV cross-polarized configuration (Transmit horizontal, receive vertical) [Keiko et al., 2009], since exhibits good sensitivity to biomass, and being least affected by forest types and ground conditions [Le Toan et al., 2004]. The incidence observation angle of the radar beam will also affect on the proportion of the backscatter signal, as different angles result in exposure of different branch structures and orientations. Therefore, the overall pattern of the post-fire canopy structure, and the optimal SAR system parameters, will determine the interpretation of the associated fire effects. For Mediterranean pine forest, Tanase reported good agreements for L-band and HV polarization to burn severity assessment. In this work, we intend to demonstrate the ability of ALOS/PALSAR data to estimate the effect of fire over different Mediterranean vegetation types and land covers, and to develop a methodology for burned area estimation from SAR data, validated by using traditional optical burned area estimation methods and ground truth data.

Material and Methods

Study Area

The Island of Sardinia is characterized by Mediterranean climate with hot and dry summers, and a rainy season concentrated during winter and spring seasons. The heterogeneity of topographic forms comprises hilly regions and interior valleys. Along the coast and river valleys, vegetation is dominated by sclerophyllous shrubs, thermo Mediterranean Quercus ilex forests, and agricultural lands. Inland areas are characterized by forest stands combined with pastures and shrublands. The principal forest formations include mesomediterranean Quercus ilex and Quercus suber forests. At higher elevations the sclerophyllous oak forests merge with broadleaved forests of Quercus congesta and Quercus ichnusae [Bajoco et al., 2007]. In the Sardinia Island wild fires are one of the most important environmental controls affecting the ecosystems functioning and structure, being responsible for the actual shape of landscapes and vegetation forms. Nevertheless, changes in the natural fire regime have led to a higher frequency and intensity of fires, representing a factor of degradation, with significant impacts on forest stands. In this work we analyzed a fire occurred the 23d of July of 2009 in Sardinia island, in the locality of Pardu along the municipalities of Pau, Villaurbana, Usellus and Villa Verde (lat: 39 49 35.3 N lon: 8 48 02.8 E). The fire affected a total of 2242 ha. as reported by the reports of the CFVA (Corpo Forestale e di Vigilanza

Ambientale) of the Regione Autonoma della Sardegna, from which 50% of the area was wooded vegetation (Fig. 1).

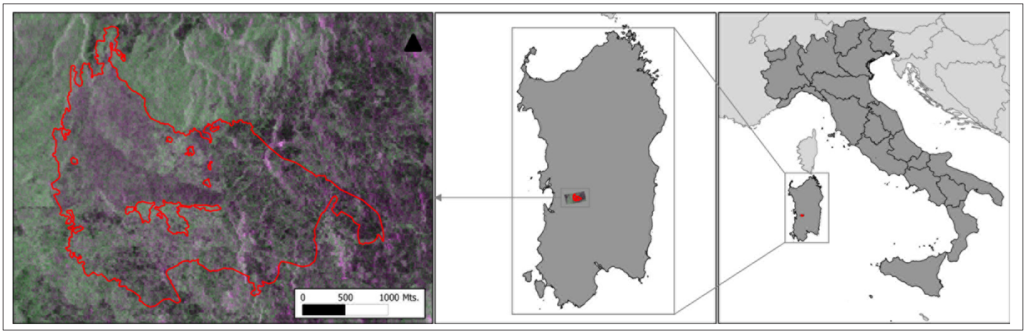

Figure 1 - The island of Sardinia and the Study area with detail of the burned perimeter. ALOS image represented in RGB: HH, HV, HH.

SAR data

The SAR data used in this study corresponds to the Advanced Land Observing Satellite (ALOS) Phased Array Type L-band SAR (PALSAR) (Fig. 2). Images were acquired in the pre and post fire dates of the fire event, the 22 of June 2009 and 22 of September 2009 respectively. The pre-fire date is 31 days prior to the fire, and the post fire image was acquired 61 days after the event. ALOS images were calibrated by using NEST software* in order to retrieve σ_0 (dB), and then co-registered on a common reference (Geographic WGS-84).

SAR -Statistical Analysis

Mean dB values of pre and post fire sites were extracted for the different vegetation types affected by fire. Statistical analysis was made separately for each of both HH and HV polarization modes. Negative differences in dB between the pre and post fire events for each vegetation types were interpreted to be related to fire effect (Student's Test).

SAR-Burned Area estimation

The analysis was made using a subset of the entire image around the burned perimeter (The ground truth perimeter was obtained from Regione Autonoma della Sardegna). We calculated the difference between pre and post fire imagery only for HV polarization mode (ΔHV). The resulting image was filtered with an "Enhanced Frost" adaptive filter with an 11x11 window size, with the purpose of isolating positive values related to higher damage levels. Subsequent positive values were selected as burned and transformed to a binary map (fire /non fire) (Fig. 2).

Optical data

We use an optical SPOT-4 image of the post fire event (27/07/2009). A simple threshold methodology was developed to retrieve the burned perimeter based on Normalized Difference Vegetation Index (NDVI), Normalized Burn Ratio (NBR) and Near Infrared (NIR) band 3 as main inputs (Fig. 3). Optimal thresholds were obtained from visual interpretation for the 3 inputs independently, avoiding commission errors as much as possible.

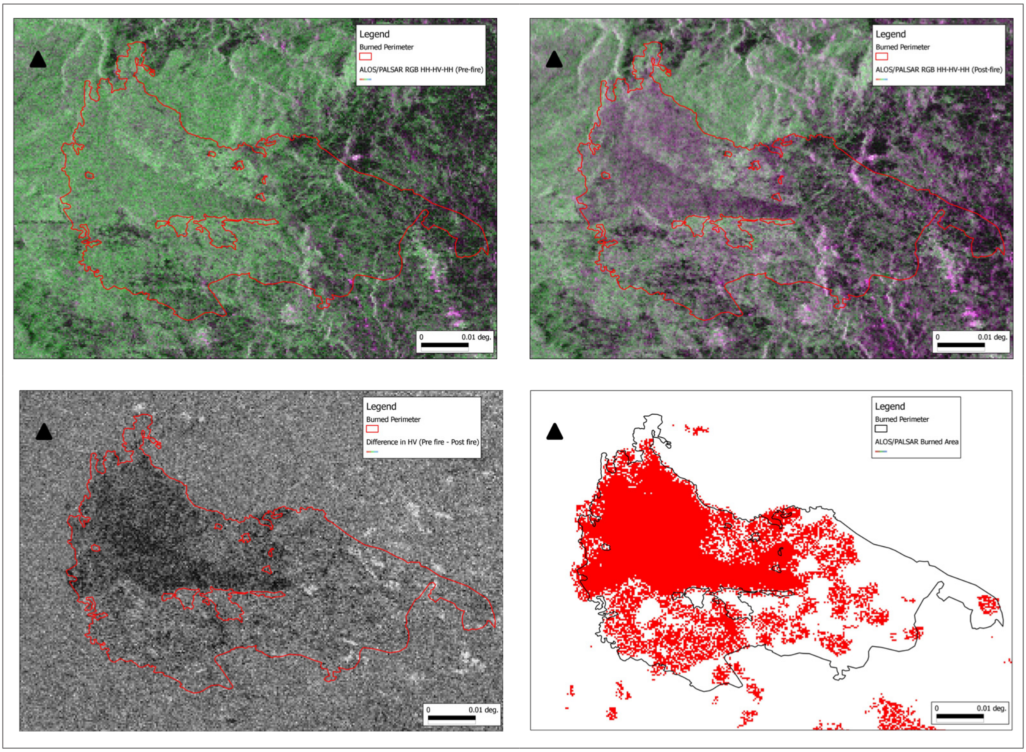

Figure 2 - ALOS/PALSAR data, Pre-fire event at top left, Post-fire event, top right, Difference in HV polarization, down left, and the Burned area estimated from positive threshold values from the ΔHV SAR data.

Complementary data

Burned vegetation types were recognized with the Corine Land Cover 2006 map**. Data sample extraction was assessed with an Ortofoto image mosaic obtained on line by a WMS server. Four Vegetation types and land covers were identified to be affected by the Pardu fire: Coniferous forest, Natural Grasslands, Sclerophyllous vegetation and Agricultural areas.

Results and Conclusions

HH Polarization exhibits a similar and continuous effect of increased backscatter over the different vegetation types for the post fire event (Fig. 4b). It has been proved that the effect of the increased backscattering response for the post fire event with HH polarization is attributed to local dielectric properties of the scatterers, with higher soil moisture content [Tanase et al., 2010]. Nevertheless, for the HV polarization it is observed mayor variability in the response of backscatter signals for the different vegetation types, with a more evident reduction for the woody vegetation types (Fig. 4a).

Assuming dB data is normally distributed; sclerophyllous vegetation presented the greater reduction in mean dB values (Mean reduction= 3.4dB, n=1412, p< 0.001), suggesting a more structural damage in comparison to the other vegetation types.

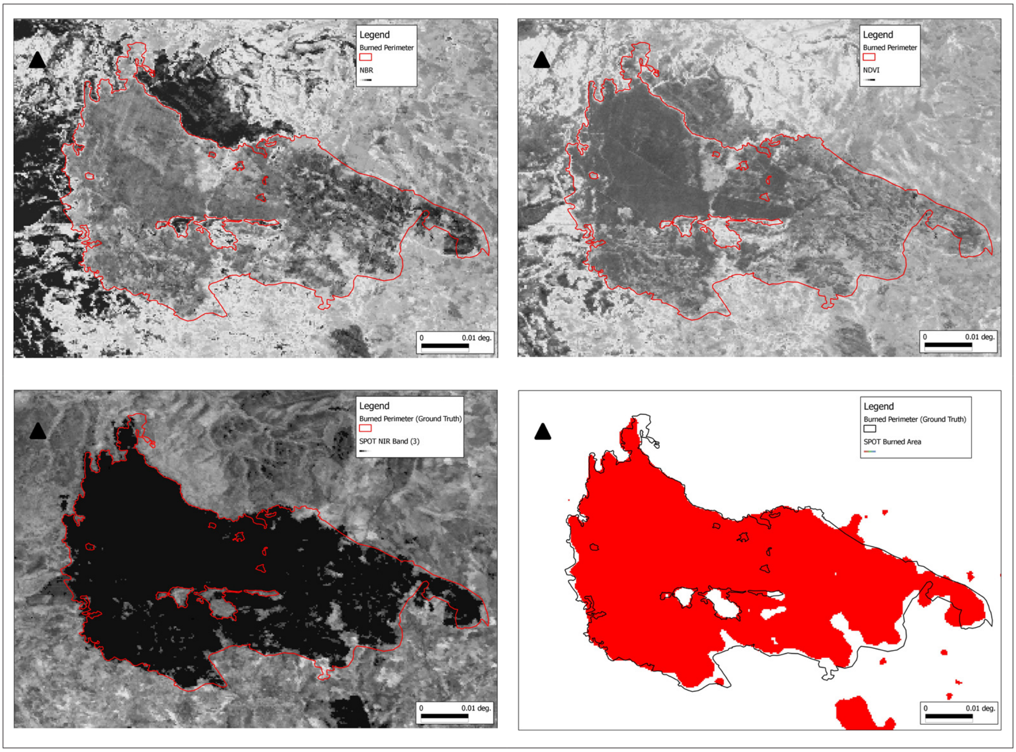

Figure 3 - SPOT4 Optical data, Normalized Burn Ratio (NBR) top left, Normalized Difference Vegetation Index (NDVI) top right, Near Infrared (NIR) down left, and the Burned area estimated from thresholds of the indices and spectral NIR data.

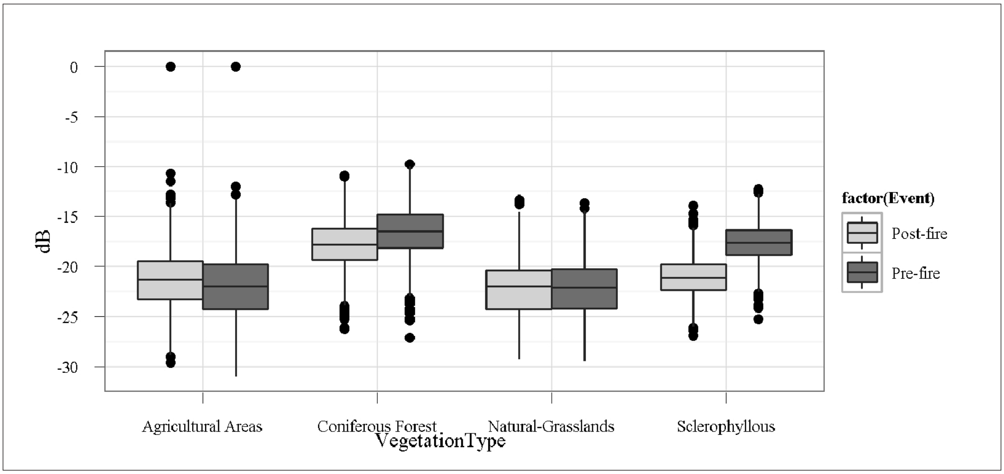

Figure 4a - Interactions between pre and post fire SAR data with HV cross polarized mode.

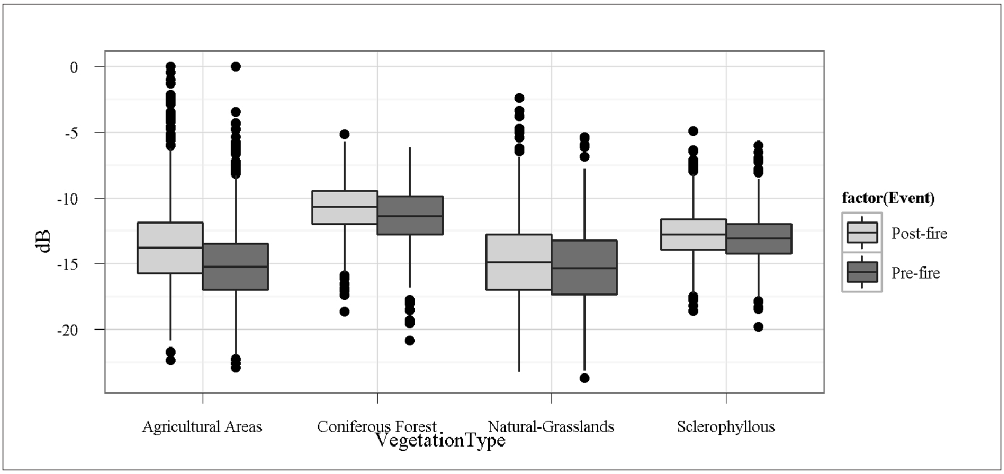

Figure 4b - Interactions between pre and post fire SAR data with HH polarized mode.

Coniferous forest also showed a significant reduction in mean dB values (Mean reduction= 1.2dB, n=951, P<0.001), but with a less mean difference in comparison to Sclerophyllous vegetation (Tab. 1).

Table 1 - Statistical Analysis for the pre and post fire events (Student's Test), considering the effect of different polarizations over diverse vegetation types.

	Polarization									
	HH					**HV**				
	Post-fire		**Pre-fire**			**Post-fire**		**Pre-fire**		
Vegetation Types	Mean dB	S.D	Mean dB	S.D		Mean dB	S.D	Mean dB	S.D	
Agricoltural Areas	-13.66897	3.032	-15.131	1.909	***	-21.267	2.996	-21.882	3.419	
Coniferous Forest	-1081376	1.854	-11.465	2.206		-17.858	2.412	-16.619	2.616	***
Natural Grasslands	-14.64136	3.279	-15.235	3.173	***	-22.179	2.752	-22.276	3.031	
Sclerophylous Vegetation	12.81717	1.740	-13.098	1.724	***	-21.084	1.857	-17.687	1.883	***

Natural Grasslands were insensitive to the signal of HV polarization, meaning that there is probably no utility in using HV polarization mode to verify fire effects on herbaceous types for these typical Mediterranean regions. Nevertheless it either could be also possible, that grasslands recovery is faster after 60 days, and structural damage is almost repaired. Agricultural Areas presented a similar increasing behavior as seen with the HH polarization mode, remaining less clear what are the principal interactions involved. The burned area estimation methodology was based on the fact that HV polarization resulted to be more sensitive to fire effects in wooded vegetation. The difference in HV (Pre-Post) evidenced a spatial correlation with the wooded vegetation types, with higher dark dB values related to structural damage (Fig. 3). The application of the enhanced frost adaptive filter was done in a trial and error basis, reaching the 11x11 window which showed the better separability between burned/unburned values (Fig. 3). Results show an agreement between 70 and 80% of the burned area for Coniferous and Sclerophyllous vegetation as compared to the ground truth perimeter. The Agricultural and Grassland areas presented a low agreement between 25-35% (Fig. 5). Other studies in tropical forest showed similar results for Agricultural mixed areas [Hoekman, 1999]. Omission errors were evaluated for each vegetation type, according to their relative proportion inside the ground truth perimeter: Agricultural Areas had the higher omission error (0.74) followed by Coniferous Forest (0.65). Natural Grasslands (0.27) and Sclerophyllous types (0.21). There were no commission errors according to the information of the ground truth perimeter. It is conclusive that the shrubby vegetation type can be more exposed to fire flames, with the consequent total destruction of the structural components of the canopy, more suitable to be detected with SAR data (See example in Figure 6). The less reduction of mean dB values for Coniferous forest in comparison with the sclerophyllous types may be related to the height of the trees, which are in less contact with fire flames. These results indicate the possibility of using ALOS/PALSAR L-HV imagery for fire Damage Assessment in forested Mediterranean Regions, especially under challenging weather conditions. A mixed optical-SAR data methodology could be explored for better discriminations of all types of vegetation structures.

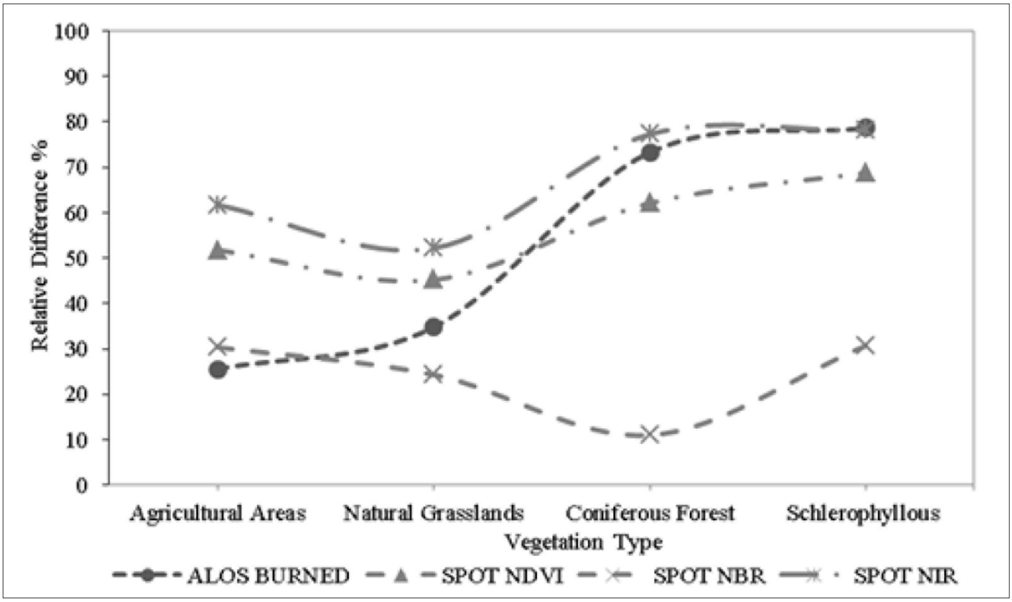

Figure 5 - Total agreement for the different vegetation types from optical reflectance data and SAR data.

Figure 6 - Burned Vegetation Types from Monti Arci area.

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References
Bajocco S., Ricotta C. (2007) - *Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer?* Landscape Ecol (2008) 23: 241-248. doi: http://dx.doi.org/10.1007/s10980-007-9176-5.

Bourgeau-Chavez, L. L., Harrell, P. A., Kasischke, E. S., French, N. H. F. (1997) - *The detection and mapping of Alaskan wildfires using a spaceborne imaging radar system.* International Journal of Remote Sensing, 18: 355-373. doi: http://dx.doi.org/10.1080/014311697219114.

Cahoon D.R., Stocks B.J., Levine J.S., Cofer W.R., Pierson J.M. (1994) - *Satellite Analysis of the Severe 1987 Forest-Fires in Northern China and Southeastern Siberia*. J. Geophys. Res.-Atmos., 99(D9): 18627-18638. doi: http://dx.doi.org/10.1029/94JD01024.

Hoekman D. (1999) - *Monitoring tropical forests using Synthetic Aperture Radar.* Invited paper presented at the International MOFEC-Tropenbos and NWO Workshop: The balance between biodiversity conservation and sustainable use of tropical rain forests, Balikpapan, Indonesia Dec. 6-8 1999.

Kasischke E.S., Melack J.M., Dobson M.C. (1997) - *The use of imaging radars for ecological applications - a review.* Remote Sensing of Environment 59: 141-156. doi: http://dx.doi.org/10.1016/S0034-4257(96)00148-4.

Kasischke E., French N., Harrell P., Christensen Jr. N., Ustin S., Barry D. (1993) - *Monitoring of wildfires in Boreal Forests using large area AVHRR NDVI composite image data.* Remote Sensing of Environment, 45 (1): 61-71, ISSN 0034-4257. doi: http://dx.doi.org/10.1016/0034-4257(93)90082-9.

Keiko Masanobu S., Osamu I., Kazuo I. (2009) - *Detecting an area affected by forest fires using ALOS PALSAR*. 3rd ALOS Joint PI Symposium, Nov. 2009, Kona, Hawaii.

Laneve G., Castronuovo M. M., Cadau E.G. (2006) - *Continuous Monitoring of Forest Fires in Mediterranean Area Using MSG*. Transactions on Geoscience and Remote Sensing, IEEE, Oct. 2006. 44:(10) Part 1.

Laneve G., Cadau E., Ferrucci F., Rongo R., Guarino A., Fortunato G., Him B., Di Bartola C., Iavarone L., Loizzo R. (2012) - *SIGRI - an Integrated System for Detecting, Monitoring, Characterizing Forest Fires and Assessing damage by LEO-GEO Data*. Italian Journal of Remote Sensing, 44: 19 - 25. doi: http://dx.doi.org/10.5721/ItJRS20124412.

Le Toan T., Beaudoin A., Riom J., Guyon D. (1992) - *Relating forest biomass to SAR data*. Geoscience and Remote Sensing, IEEE Transactions on, Mar 1992. 30 (2): 403-411 doi: http://dx.doi.org/10.1109/36.134089.

Le Toan (2004) - *Relating radar remote sensing of biomass to modeling of forest carbon budgets.* Climatic Change 67: 379-402. doi: http://dx.doi.org/10.1007/s10584-004-3155-5.

Tanase M., Santoro M., de la Riva J., Pérez-Cabello F., Le Toan T. (2010) - *Sensitivity of X-, C-, and L-Band SAR Backscatter to Burn Severity in Mediterranean Pine Forests.* IEEE Transactions of Geoscience and Remote Sensing. 48(10). doi: http://dx.doi.org/10.1109/TGRS.2010.2049653.

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