ITALSCAR, Burned Forest Mapping from Space
An Earth Observation service demonstration project in Italy

funded by the Data User Programme of the European Space Agency
requested by the Italian Civil Protection Authorities

Executive Summary

Abstract - ITALSCAR is a "*Burned Forest Mapping from Space*" project requested by the Italian Department of Civil Protection (DPC) and funded by the European Space Agency under the framework of its Data User Programme (DUP), with the primary aim of developing operative answers to National Civil Protection Agencies needs regarding Burn Scars Mapping. The main goal of the project was the generation of Burn Scars Maps (BSM) and the associated catalogue, over the entire Italian territory for 4 consecutive years, with the objective to support the operational Fire Disaster Management in Italy. The project aimed also at providing a reference framework for similar European initiatives to be undertaken at national and at regional levels. This Executive Summary highlights the major particulars and findings of the project, and evidences the way forward for developing a regional burn scar mapping service in the Mediterranean countries.

I. Forest Fires In The Mediterranean Countries

One of the most critical issues that affect forest fire management is the lack of appropriate mapping on burnt land, which makes difficult the evaluation of forest fire environmental impacts as well as the introduction of appropriate measures to prevent soil erosion and help vegetation recovery. This also reduces drastically the efficacy of the implementation of the national laws regarding forest fires fighting. Most of the Mediterranean countries that are mainly affected by forest fires do not have proper data on fire incidences. Forest fires are in most cases not mapped and only general statistics derived from the intervention records of the Forest Guards and of the Fire Brigades are made available. A well-structured decision making system for an efficient management of forest fires requires a complete, detailed and accurate spatial database of burnt areas.

II. Italian Legislation Framework

The ITALSCAR project is to be positioned in the light of the Italian firefighting laws and regulations. Prior to the initiation of the ITALSCAR project in 2000, an extensive redrawing of the Italian framework for forest fire fighting was approved by the Italian Parliament. In spite of a prohibition of land use change within burnt areas that is in force since 1975, no cartographic archives of burnt areas exist in Italy. Mapping of burnt areas was seldom done, only upon initiative of a few individual administrations and by use of heterogeneous techniques. The current historical archive of wildfires relies upon the so-called AIB (*Area Incendio Boschivo* – Forest Fire Area) card sets from the Italian Forest Guards. These AIB card sets are not always geo-referenced and don't contain any contour information of the burn scars.

III. DPC User Requirements

The user requirements for the ITALSCAR service demonstration project were challenging requirements that have been compiled by the European Space Agency in close collaboration with the Italian Civil Protection Authorities:

(1) Covering the entire Italian territory with a particular attention to the Italian regions that are at high fire risk during the summer season;

(2) Initially limited to four consecutive years (1997, 1998, 1999 and 2000);

(3) Limited to forest classes as defined in the CORINE Land Cover nomenclature;

(4) Covering the summer fire season (June – September);

(5) Detecting burnt forest scars with, as a minimum, 1ha surface extent;

(6) Using a proven and reliable methodology based on proven research pilot projects;

(7) Associating product quality information (Product Confidence Level) to the final product;

(8) Ensuring an extensive product quality control;

(9) Using forest fires information collected by other means (e.g. Fire Brigades reports, Forest Guards AIB reports);

(10) Validating the products across regions and across years, with in-situ field surveys on at least 3 Italian provinces.

IV. ITALSCAR PROJECT TEAMS

The European Space Agency awarded, in late 2000, industrial contracts to two Italian Consortiums:

- A first contract was awarded to a Consortium lead by **VITROCISET** (It) for the detailed definition and pre-validation of the ITALSCAR processing model, for the products specification and for the validation of the ITALSCAR products;

  The VITROCISET Consortium was composed of Vitrociset (It) as a Prime Contractor, Cesia – Accademia dei Geogofili (It), MESTOR Software and Consulting (It) and SARMAP (CH), supported by scientific experts, Prof. E. Chuvieco from the University of ALCALA (Sp) and Prof. G. Gallo from the University of CATANIA (It).
- A second contract was awarded to a Consortium lead by **TELESPAZIO** (It) for the design, development, testing and integration of the ITALSCAR processing chain, for the production of the Burn Scar maps at a national and regional levels, and for the service demonstration.

  The TELESPAZIO Consortium was composed of Telespazio (It) as a Prime Contractor, and INTECS HRT as the unique sub-contractor.

Such a project organisation structured around two independent teams, one team assigned to the definition and to the validation phases and a second team in charge of the implementation, the production and the service demonstration, was meant to put in place a work organization that should have better responded to the stringent requirements of the ITALSCAR project.

The decomposition of the ITALSCAR activities aimed also at ensuring the best integration of the Burn Scar Mapping (BSM) algorithms into a robust and reliable operational system as well as at developing cost effective services for the future operational provision of BSM products to the Italian public administrations.

Finally the Italian Department of Civil Protection, played an important role in the genesis and in the initial phases of the ITALSCAR project through the active participation of Prof. Fabrizio Ferrucci (University of Calabria, and consultant at the Italian Civil Protection Agency) who has been instrumental in bringing forward this project and in providing the necessary advises during the initial phases of the project.

V. ITALSCAR METHODOLOGY

The main challenge of the project was to develop a solid and reliable processing methodology based on satellite imagery that would produce Burn Scar Maps with the same quality on a wide spectrum of environmental scenarios representing the heterogeneous characteristics of the Italian landscape, and consequently applicable to the European Mediterranean countries.

The core system of the ITALSCAR processing model, depicted in *figure 1*, includes two major elements:

(1) *Core burned pixels identification,* by means of multi-temporal and multi-threshold analysis of LANDSAT TM/ETM satellite images and;

(2) *Burned areas shape refinement,* by means of proven image processing techniques (i.e. Seed Region Growing).

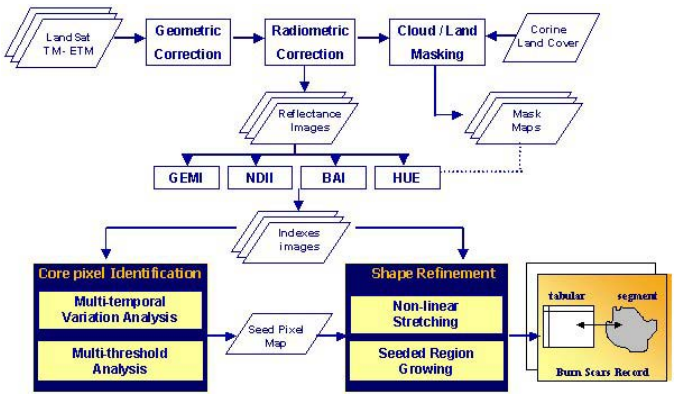

Figure 1: ITALSCAR processing model

The ITALSCAR processing model is organized along a 6–stage procedure that includes the following key steps:

- **Pre-processing**, to prepare the reflectance images and all ancillary information (i.e. cloud and land maps) that are used as input by the ITALSCAR core system. It includes a geometric correction, a radiometric correction using an image-based atmospheric correction algorithm (*Chavez 1996*), the masking of areas (i.e. water bodies) that would affect the statistical analysis and the mapping of cloud-affected areas.
- **Spectral Enhancement**, that calculates a set of spectral indices chosen among the most suitable for the burned areas identification: the NDII Normalised Differential Infrared Index, the BAI Burned Area Index (*Martin 1998*), the GEMI Global Environmental Monitoring Index (*Pinty 1992*), the HUE component of the HIS transformation (*Koutsias 2000*).
- **Burned Core Pixel Identification**, for the extraction of pixels with a very high probably of being burned. The function applies a Land Cover change analysis based on a multi-threshold and multi-temporal approach to identify the pixels candidates to be used as seeds for the burned areas shape refinement phase.

  The multi-temporal Land Cover analysis uses a 3-input approach that performs both inter-annual and intra-annual comparisons on LANSAT TM/ETM images acquired before and after the summer fire seasons. A 2-input solution has also been experienced in various cases to assess cost-effective solutions, as well as the robustness of the methodology in the absence of input data with sufficient quality (e.g. cloud-free, sensing date).
- **Shape Refinement**, for the precise definition of the perimeter of the burned areas, starting from the burned core pixels and applying a seeded region growing algorithm.
- **Shape File transformation**, for the conversion of the burned scars raster data into vector format, associating an appropriate level of confidence to each BSM polygon.
- **Image Photo-interpretation**, for the visual inspection, the quality control and possibly the manual adjustment of the burned areas to all BSM polygons that would fall below a pre-defined confidence level.

VI. THE ITALSCAR PRODUCTS

The ITALSCAR burn scar maps are packaged in administrative products that can be delivered either at Regional level or at National level.

The ITALSCAR Products *at Regional level* includes the following information:

- Year;
- Burn Scars Maps (for surfaces greater than 1 hectare);
- Cloud mask ;
- Boundary of LANDSAT frames used and their dates of acquisition;
- Administrative limits (Region, Province, Municipality);
- Information associated to each Burn Scar Map with the following indications:

  - polygon identifier
  - Surface burned (in hectares)
  - Perimeter of the Burn Scar (in meters)
  - Level of Confidence (values from 0 to 100)

The Level of Confidence is automatically generated in the ITALSCAR core processing and estimates the degree of certainty regarding the identification of the forest area as burned.

The ITALSCAR geospatial information is geo-referenced in the Cartographic system defined by:

- Projection: UTM
- Fuse: Following regional standard
- Ellipsoid: WGS84
- Datum: WGS84

The Fuse standard is **32** for the following Italian regions:

Piemonte, Valle d'Aosta, Liguria, Lombardia, Trentino Alto Adige, Veneto, Emilia Romagna, Toscana, Sardegna;

The Fuse standard is **33** for the following Italian regions:

Friuli Venezia, Giulia, Marche, Lazio, Umbria, Campania, Abruzzo, Molise, Basilicata, Puglia, Calabria, Sicilia.

The ITALSCAR Product *at National level* is projected in the UTM Fuse 32 Cartographic System and includes the same information as the Regional Level Products, at the exception of the Administrative Municipalities Limits.

VII. ITALSCAR PRODUCTION

The Italian territory is covered by 34 LANDSAT frames, as depicted in figure 2. A total number of 272 satellite images have been acquired and processed during the project:

- 52 LANDSAT-7 Enhanced Thematic Mapper (ETM);
- 220 LANDSAT-5 Thematic Mapper (TM)

Out of the 136 frames (34 frames x 4 years) that had to be processed, 86 frames have been executed with the 3-input multi-temporal approach, 46 frames with a 2-input approach, and 4 frames have not been processed due to the lack of post-season images compliant with the input data quality criteria (i.e. cloud coverage and date of acquisition).

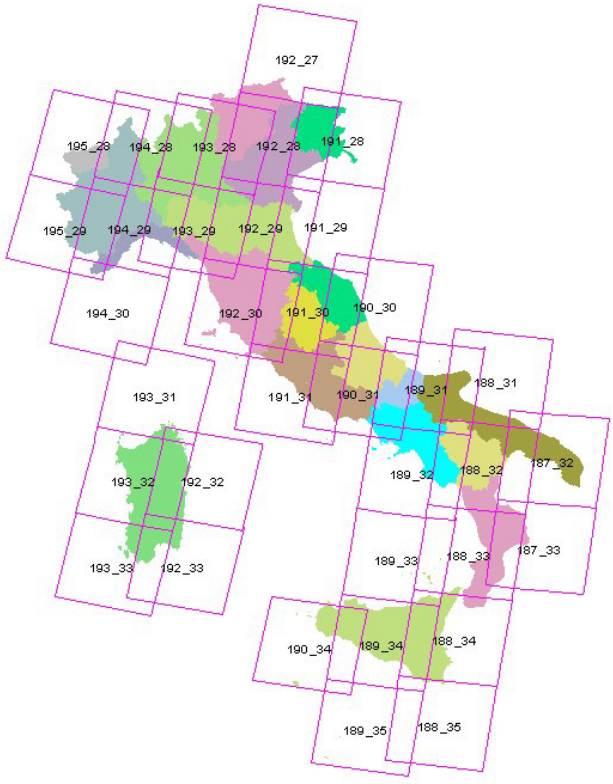

Figure 2: coverage of Italy by LANDSAT TM/ETM frames

The LANDSAT frames that have not been processed due to a lack of post-fire season image were:

- frame 193-32 (1997 - 1998) and;
- frame 193-28 (1997 - 1998).

The criteria used for the selection of the satellite input images were threefold:

- Acquisition Dates:

  In order to have a sun zenith angle sufficiently high, the following constraints were imposed on the dates of satellite imagery acquisitions:

  Pre-Fire season image acquisition date: preferably in May, in any case after the end of March

  Post-Fire season image acquisition date: preferably in late September, in any case before mid October

- Cloud Coverage:

  The maximum acceptable cloud coverage was 20% of the land area (i.e. sea excluded). A higher percentage of cloud coverage (up to 30%) was preferable to a very low sun zenith angle.

- Satellite Sensors:

  Both LANDSAT-5 TM and LANDSAT-7 ETM could be acquired, with a preference to LANDSAT-T ETM since it shows better spectral and spatial characteristics.

VIII. ITALSCAR RESULTS

The results of the summer burned forested areas mapped by ITALSCAR in the various Italian regions are summarized in the *figures 3 to 6* .

Italian Regions	Burned Forest Surfaces (ha)			
	1997	1998	1999	2000
Abruzzo	273	812	57	2,254
Basilicata	713	755	286	2,696
Calabria	6,426	19,646	3,416	11,984
Campania	2,480	1,429	332	8,053
Emilia Romagna	18	0	4	16
Lazio	910	2,164	647	4,497
Liguria	0	1,002	1,046	255
Lombardia	22	0	0	0
Marche	6	46	75	135
Molise	0	657	11	360
Piemonte	0	6	23	16
Puglia	825	1,502	166	3,296
Sardegna	1,825	4,019	5,573	10,660
Sicilia	6,151	23,289	4,018	9,912
Toscana	327	1,615	65	204
Umbria	0	0	0	80
Valle d'Aosta	52	0	0	0
Veneto	0	20	0	0
Total burned surface	**20,028**	**56,962**	**15,719**	**54,418**

Figure 3: Total surfaces[1] (ha) of the burned forested areas mapped by ITALSCAR, organised by Italian regions and yearly seasons.

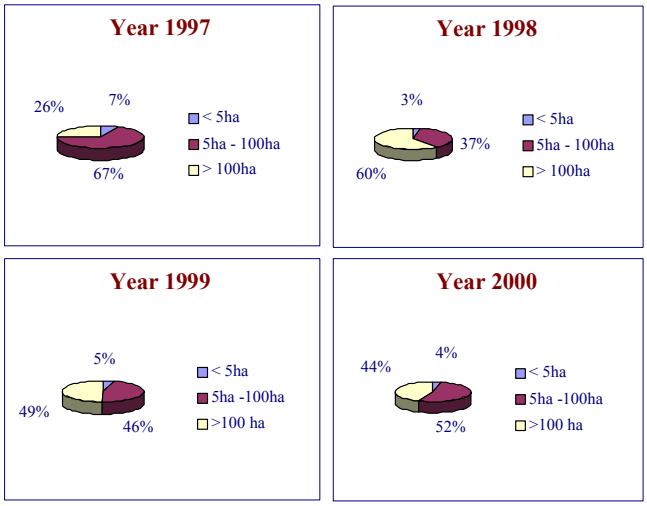

Figure 4: Percentage of the burned forested areas mapped by ITALSCAR for different size ranges (<5ha, 5-100ha, >100ha).

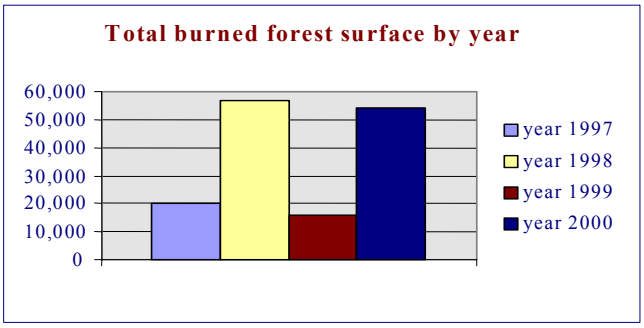

Figure 5: Comparison of the total burned forested areas in Italy (in ha) for the years 1997-2000.

	Year							
	1997		1998		1999		2000	
Polygon size	**Polygons #**	**Surface (ha)**	**Polygons #**	**Surface (ha)**	**Polygons #**	**Surface (ha)**	**Polygons #**	**Surface (ha)**
< 5ha	517	1,326 ha	608	1,612 ha	274	741 ha	761	2,015 ha
5ha –100ha	706	13,582 ha	875	21,208 ha	377	7,177 ha	1,204	28,572 ha
>100 ha	28	5,120 ha	106	34,141 ha	28	7,801 ha	94	23,831 ha
Total number	1,251		1,589		679		2,059	
Total surface	**20,028 ha**		**56,962 ha**		**15,719 ha**		**54,418 ha**	
Mean surface	16 ha		36 ha		23 ha		26 ha	

Figure 6: Summer fires statistics over the entire Italian territory for the years 1997-2000.
The table shows the number of ITALSCAR polygons and the total surfaces of the burned areas mapped by ITALSCAR for each year and for different sizes of forested areas (less than 5 ha, between 5ha and 100ha, greater than 100 ha)

[1] The above numbers give the total surface of the burn scars for forest fires that occurred during the time window of cloud-free (below a predefined level of cloud coverage) LANDSAT TM/ETM images acquired before and after the summer season. The 97 and 98 numbers for Sardegna are underestimated due to a missing LANDSAT frame (193-32).

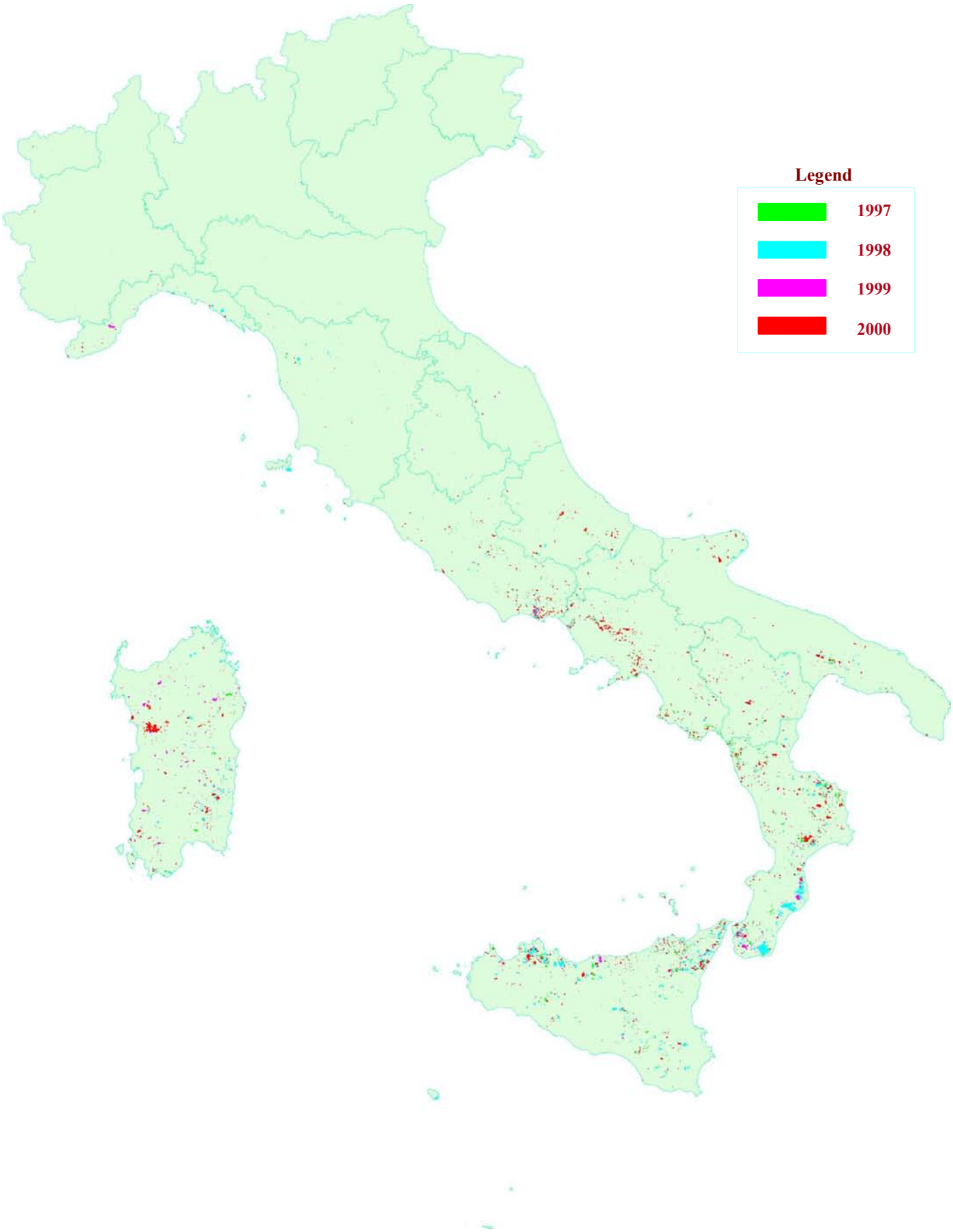

Figure 7: Burn Scars of the Summer Forest Fires in **Italy** for the years 1997-2000

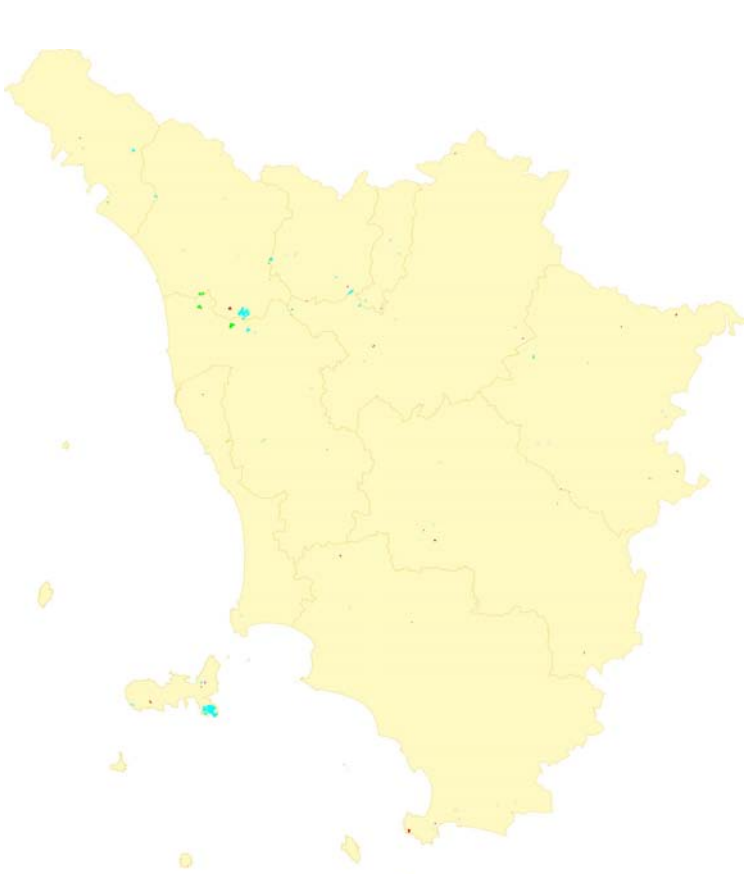

Figure 8: Burn Scars of the Summer Forest Fires in **Tuscany** for the years 1997-2000

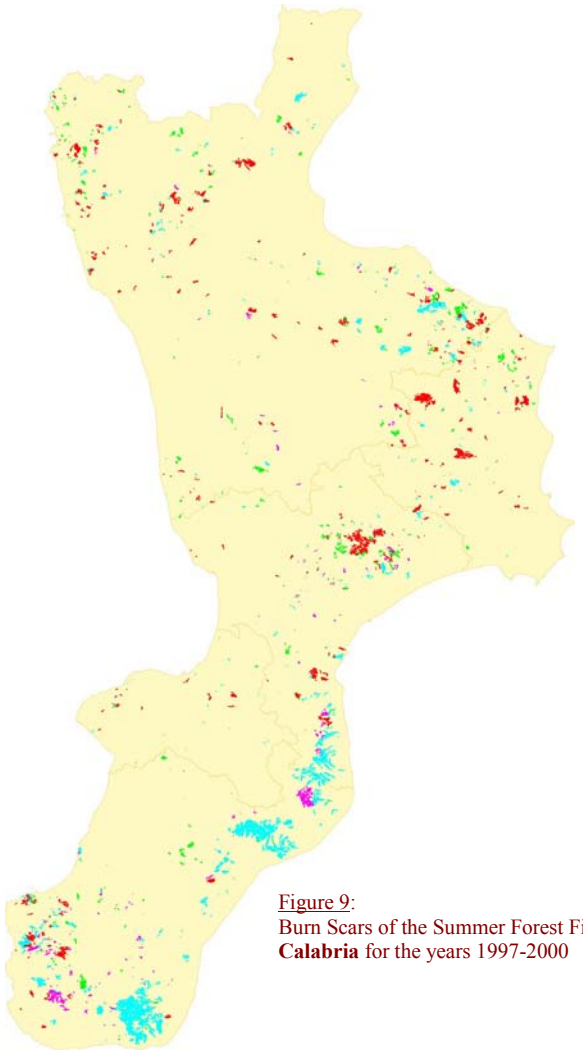

Figure 9:
Burn Scars of the Summer Forest Fires in **Calabria** for the years 1997-2000

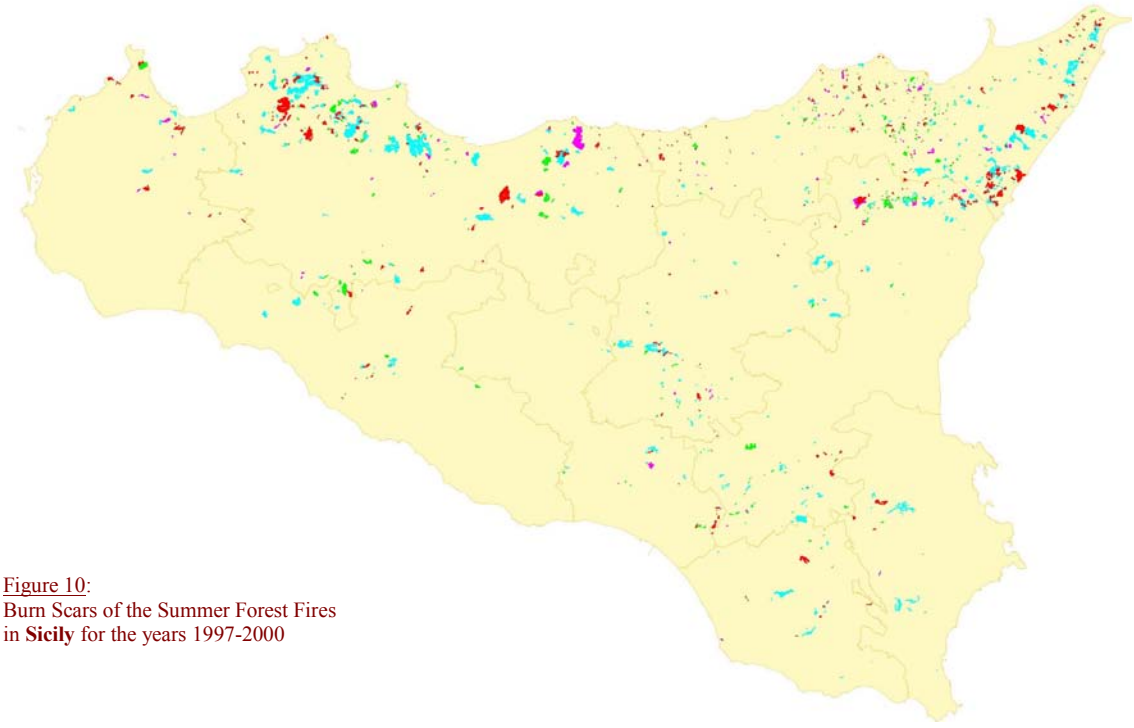

Figure 10:
Burn Scars of the Summer Forest Fires in **Sicily** for the years 1997-2000

IX. ITALSCAR EXAMPLES

Figures 11 to 13 give examples of the ITALSCAR results obtained on the Elba Island (Livorno, Tuscany).

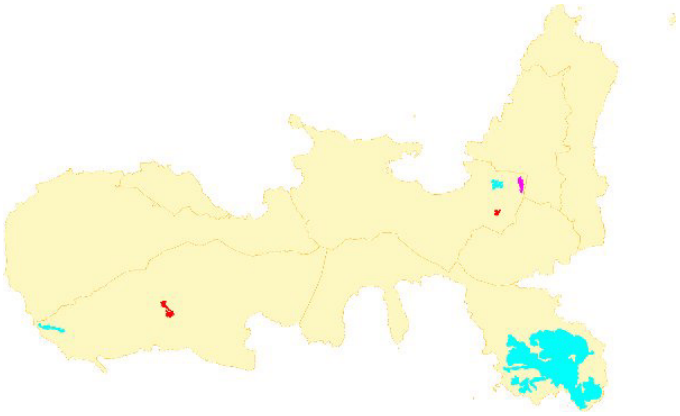

Figure 11: ITALSCAR Burn Scar Maps on the Elba Island (■ 1997, ■ 1998, ■ 1999, ■ 2000)

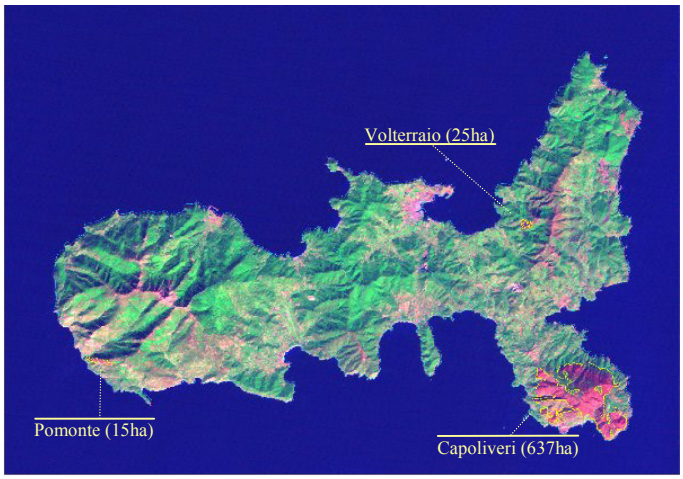

Figure 12: Burn Scars for the 1998 summer forest fires on the Elba Island, overlaid on a LANDSAT-5 Thematic Mapper (TM) false colour composite with spectral bands 7-4-1.

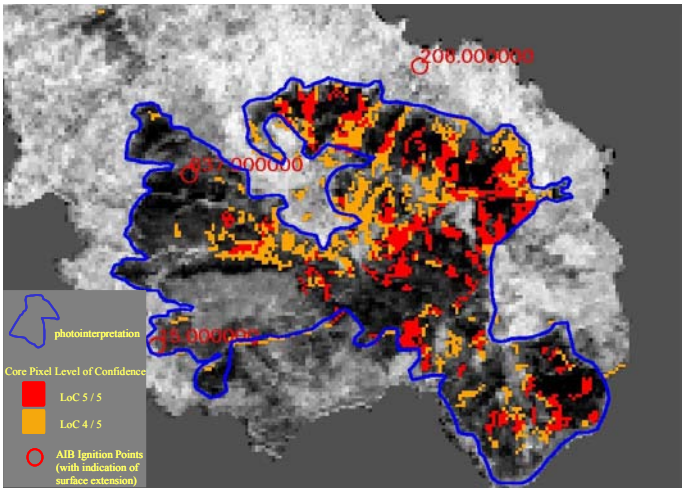

Figure 13: Core Seed Pixels of Levels of Confidence 4 and 5, and the photo-interpreted burn scars, overlaid on a background image composed of the Post Fire NDII image (NIR-SWIR) / (NIR+SWIR) Elba Island – Capoliveri fire - AIBs (637ha, 206ha, 15ha);

Figures 14 and 15 show the results of ITALSCAR in the mapping some of the most important forest fires that occurred in 2000 in the Southern Italian regions, respectively in Calabria (figure 14) and in Basilicata (figure 15).

These two examples show how different can be the approximate estimation of the burned areas provided by the Forest Guards in their AIB intervention records (figures extracted from http://www.corpoforestale.it/aib/index.htm with the courtesy of the "**Servizio AntIncendio Boschivo dell'Corpo forestale dello Stato"**) and the precise areas mapping done by ITALSCAR using satellite imagery.

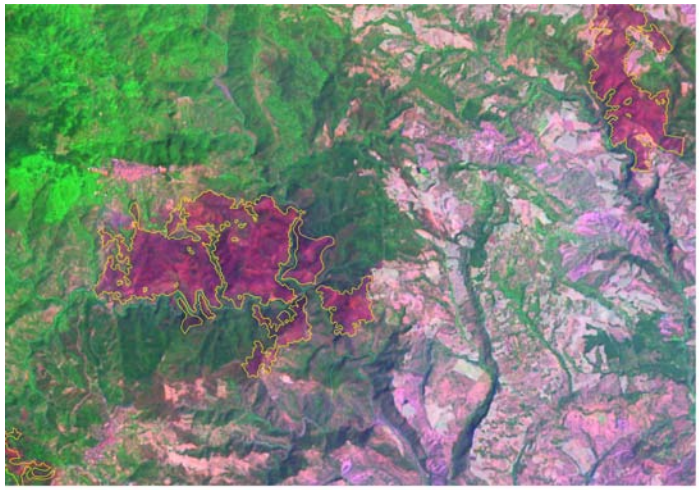

Figure 14: On the 25th August 2000, a wildfire burned 1.350 ha in Savelli (Crotone - Calabria), of which 720 ha in forested areas made of domestic pine-tress and in broad-leaved forest; The fire has been extinguished after 4 days of hard work from the provincial Forest Guards of Crotone; (*figures provided by the Italian Forest Guards*)

682 ha of burned forest were mapped by ITALSCAR and overlaid on a LANDSAT-7 Enhanced Thematic Mapper (ETM) pan-sharpened false colour composite with spectral bands 7-4-1.

Figure 15: On 22nd August 2000, the Italian Forest Guards had to intervene on a major wildfire that affected the communes of Armento and Montemurro in the province of Potenza in the Agri Valley (Potenza - Basilicata). In total 388 unit crews and 6 air tankers / helitankers worked for 5 consecutive days. Part of the Armento village had to be evacuated for safety reasons. The Forest Guards recorded a fire of 1,350 ha, out of which 600 ha in forested areas.

The burned scars were mapped by ITALSCAR using a post-fire LandSat 7 ETM Image dated 27 August 2002, which resulted in an overall area of 530 ha of burned forests on the Western side of the valley and 77 ha on the Eastern side. The burned forest mapped by ITALSCAR are overlaid on a LANDSAT-7 Enhanced Thematic Mapper (ETM) pan-sharpened false colour composite with spectral bands 7-4-1.

X. PRODUCTS VALIDATION

The ITALSCAR results have been validated on 3 Italian provinces (**Livorno** in Tuscany, **Vibo Valentia** in Calabria and **Catania** in Sicily) by comparison of the BSM products with the following independent data-sets:

- the records of the Italian Forest Guards (AIB cardset),
- the logs of the provincial Fire Brigades and;
- GPS ad-hoc field surveys conducted by the project team on a representative set of forest fires covering a wide range of vegetation, fire typologies, sizes and dates.

The ground truth data available from the national fire-related agencies revealed to be of insufficient quality (due to inaccurate geo-location and lack of contour mapping) for a reliable assessment of the quality of the ITALSCAR products.

The number of GPS surveys is to be considered as insufficient to provide a statistically meaningful quality assessment of the ITALSCAR products. Although only indicative, these validation activities resulted positive for both commission and omission errors.

The figures 16 and 17 show the comparisons of the Ad-hoc GPS surveys with the Burn scars mapped by ITALSCAR for two types of products:

(1) The **ITALSCAR Standard products** that cover only the Forest and Semi-natural areas of the Corine Land Cover Nomenclature.

(2) The **ITALSCAR Extended products** that cover the same type of Land Cover Classes as for the Standard products, extended to some of the agricultural areas.

CORINE Land Cover Classes of ITALSCAR Standard products:

311	Broad-leaved forest
312	Coniferous forest
313	Mixed forest
32x	Shrub and/or herbaceous vegetation
33x	Open spaces with little or no vegetation

Test Area	Year	# GPS surveys	# ITALSCAR mapped	Burn Scars Detection Accuracy
Vibo Valentia	2001	13	10	77 %
Catania	2000	7	6	86 %
Tuscany	2000	14	8	57 %

Figure 16: Comparison GPS surveys vs ITALSCAR standard products

CORINE Land Cover Classes of Extended products:

22x	permanent crops
243	land principally occupied by agriculture
244	agro-forestry areas
31x	forests
32x	shrubs and/or herbaceous vegetation
33x	open space with little or no vegetation

Test Area	Year	# GPS surveys	# ITALSCAR mapped	Burn Scars Detection Accuracy
Vibo Valentia	2001	22	17	77 %
Catania	2000	26	20	77 %

Figure 17: Comparison GPS surveys vs ITALSCAR extended products

XI. BSM QUALIFICATION STANDARDS

Based on the experience of the ITALSCAR project, the project team has recommended a set of guidelines on **BSM system qualification standards** that could be applied at a European level. These recommendations regard mainly standardization issues on:

- the service deployment practices;
- the product content and data format;
- the usage of reliable ancillary data (e.g. Land Cover Maps);
- the BSM validation methodologies;
- the collection of ground truth data (Forest Guards records and ad-hoc ground surveys) for qualification purpose;
- the development and acceptance of BSM production systems and related documentation.

Here follow a list of recommendations that are necessary to be well considered at the beginning of the service development and deployment in order to well respond to the stringent requirements of an **adopting Agency**, that could be any Civil Protection Authority or Environment Agency dealing with forest fires

1. The adopting agency must have well defined needs for products and services, preferably within a legal institutional framework (i.e. adopting agency with a clear mandate to do so and not only an interest);

2. Reach an agreement with the adopting agency, ideally before contract award, on the user requirements that can be realistically achieved with the current space technologies and that does not go beyond the actual needs of the adopting agency.

   For example the establishment of a minimum mapping unit of 1ha for ITALSCAR revealed to be a very challenging requirement. Fire scars in this size range are first very difficult to map with acceptable accuracy and second, although very numerous, make an insignificant contribution to the total annual burned area, due to the typically extremely skewed statistical size distribution of fire scars.

3. Get from the adopting agency clear acceptance requirements (i.e. product qualification criteria). For example precise levels of commission / omission errors (possibly as a function of the burn scar sizes) that can be accepted by the adopting agency are to be well defined a-priori since these product quality requirements will later drive the methodology adoption and the validation plan (e.g. organization of field surveys).

4. Importance to involve adequately the user organizations in the whole process. The commitment of the adopting agency to allocate resources in support to the service development is a key issue for success, in particular for (1) the user requirements definition, (2) the product validation, (3) the service quality assessment, (4) the access to ground truth data, and (5) the results dissemination in the user community;

5. The methodology must be developed, starting from solid and reliable results obtained in representative pilot research projects. Perform an exhaustive analysis of issues that can jeopardize the robustness of the methodology and avoid excessive confidence on available research results, which typically do not deal with many of the constraints and limitations that would affect a "large scale" and "operational" service development.

6. Importance to allocate appropriate time and resources when developing "large scale" and "pre-operational" services that build on the results of pilot research projects that are by definition limited in scope;

7. Existing and recognized multi-disciplinary scientific expertise in the project team is required for the development, the consolidation and the final adoption of the methodology.

8. In order to derive robust classifiers that can meet the "operational" requirements of the adopting agencies, it is important to conduct a thorough data exploration and analysis (in particular on the spectral and radiometric properties of burned areas) over a very large area, for multiple years and covering the complete diversity of land cover types present in the overall territory;

9. A pre-validation of the processing model is required before the start of the service development. The development of robust classifiers, capable of performing adequately over various dates, locations and land cover types, involving multiple High Rate satellite images from different sensors, is a very challenging task that can not be easily and always satisfactorily solved. The project schedule and budget shall therefore allow enough provision for an extensive and comprehensive consolidation and pre-acceptance of the methodology.

10. The Products are to be validated in closed collaboration with the adopting agency through appropriate ground data collection campaigns. This can include modifications to the data collection protocols already operative within the adopting agencies, e.g. modification to the records made by the Forest Guards when intervening on forest fires.

11. A proper assessment of the quality and of the accuracy of the ground truth data is needed as well as their representativeness for a statistically meaningful validation. An adequate ground truth data collection, for a project like ITALSCAR, must rely on carefully designed ground data acquisition campaigns, and not only on currently available official data (e.g. intervention records of the forest guards and fire brigades) that are typically of unknown accuracy and reliability.

12. Highly competent technical expertise allowing information system components to be built and integrated with COTS and proprietary software/hardware (reuse).

XII. CONCLUSIONS

The ITALSCAR project has reached its primary objective by proposing a methodology that has enabled a proper mapping of the burn scar maps over an extended and heterogeneous land coverage and for 4 consecutive years.

The ITALSCAR model has been conceptually conceived and calibrated for forested areas and hence requires, as a major ancillary input, accurate maps of the forested areas. The 1990 CORINE Land Cover that has been used does not have the appropriate quality to be used as a reference for the forested areas. Some experimentation has been conducted during the ITALSCAR project to extend the processing model to all natural vegetated areas and this extension has yielded positive results although some adaptation is needed.

ACKNOWLEDGMENT

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