Satellite Remote Sensing for Natural Disasters Monitoring and Early Warning

Università degli Studi di Roma "La Sapienza"

Università degli Studi di Roma CENTRO di RICERCA PROGETTO SAN MARCO "La Sapienza"

Enrico Giuseppe Cadau

enrico.cadau@psm.uniroma1.it

Abstract

Advanced data collection, relies increasingly on remote sensing satellite systems, in addition to earth-based in situ monitoring facilities. Very recently in fact satellite systems for remote sensing are required to provide images with a spatial and temporal resolution suitable to be applied for the management of disasters like earthquakes, floods, forest fires, volcanic eruptions and humanitarian crisis. High resolution (HR) satellite imagery can provide a good insight into the magnitude of a disaster and a detailed assessment of the damage but usually they are not immediately available. Low Resolution images instead are more suitable to provide a prompt but general information just after the disaster and to monitor continuously the area of interest. The synergic use of both imagery can help the decision makers in the activities related with the prevention and contrast of such crisis situations.

New Remote Sensing Orbit and Sensor Design

Remote sensing systems on board of satellites represent the best way to observe the earth without any constraint on the location of the region of interest. As a consequence of this possibility to access practically any place of the Earth satellites can be used to gather information everywhere without any restriction related to geographical and/or political reasons.

When the observation requirements are not involving temporal constraint, spatial images at the required spatial resolution (down to 0.6 m) can be easily acquired. In the recent years the interest in applying information provided by satellite systems for remote sensing in disaster management issues has been constantly increasing. In general, these applications are characterized by the fact that they need a high spatial and temporal resolution. High resolution (HR) satellite imagery can provide a good insight into the magnitude of a disaster and a detailed assessment of the damage, but this information could be of invaluable importance in the aftermath of a disaster if there are provided few hours after the event.

Presently, space based remote sensing systems result unsuitable to provide useful information when high temporal and spatial resolutions are simultaneously required. Mainly this is due to the fact that, even if many high resolution satellites are available they are not organized in a constellation and the image acquisitions, for observational reasons, are concentrated around convenient local time. Further, due to the technological limits of the transmission systems a very high resolution is usually coupled with a reduced sensor swath (typically 10 km x10 km). This means that the observation can be carried out when the area to be imaged is known. On the other side low-resolution satellite could provide, in principle, some information with the required promptness in presence of event characterized by sudden temperature increases (fires, explosions, volcanic eruption, etc.). In such a case the poor spatial resolution is compensated by the high sensitivity of the short wave infrared channels (SWIR) to high temperatures. In the framework of the activities of the Network of Excellence (NoE) **GMOSS** (Global Monitoring for Stability and Security) aiming to explore the possibility of using satellite images for security related applications, the University of Rome (Centro di Ricerca Progetto San Marco, CRPSM) is studying the suitability of a satellite based system able to monitor national borders and/or given regions of the Earth in a quasi-continuous way with an adequate spatial resolution. To meet this requirement, the so-called **Multi-Stationary (MS)** orbits have been introduced. As for the Molnya orbit case the **MS** orbits are characterized by having an orbital inclination equal to the critical inclination (63.43°). However, apart from the different orbital period (8 h instead of 12 h) for the design of the orbit a constraint on the satellite-Earth relative velocity is introduced in order to optimise the observation conditions. A constellation of few (4) satellites located on this kind of orbits allows a quasi-continuous monitoring of a selected region of the Earth.

The images, acquired quasi-continuously from a satellite located on such an orbit, are characterized by a continuously changing spatial resolution and illumination conditions. When the information required need a change detection analysis of the acquired images the variation associated with the observation condition must be considered. This paper aims to present the results of the analysis of the impact of the images spatial resolution and illumination conditions variability on change detection methods based on a time-series of these.

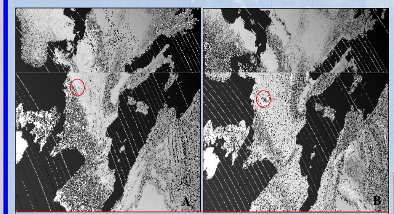


Fig. 6. Pair of images (simulated) acquired 10-minute apart to be registered (a), (b).

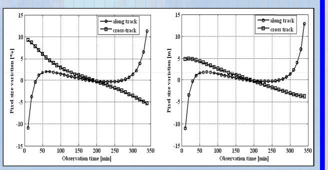
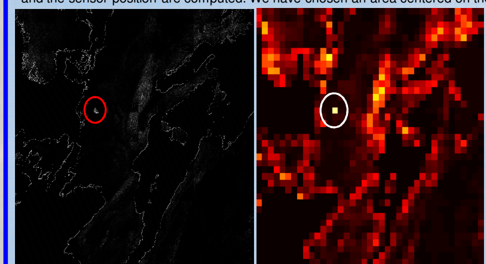


Fig. 4. Behaviour of the pixel sizes variation between two consecutive images (acquired 10 min. apart each other) during the acquisition time of about 6 hours: absolute variation (right) [m], percentage variation (left).

The problem of processing a time series of images taken from a **MS** satellite, and in general from highly eccentric orbit satellites by applying change detection techniques, in the knowledge of the authors, has never been addressed. The problems to deal with synthetically require the development of:

- an automatic technique for the co-registration of the images acquired with high temporal frequency,
- a procedure to detect changes in the scenario imaged by the sensor able to take into account the apparent changes due to the variation of the spatial resolution of the consecutive images

A series of images have been simulated with GCI-Toolkit, reproducing the ground scenario related to the sensor view on board of a hypothetic satellite flying on a MS orbit. Further, simulations of the orbital motion, carried out using the STK software, allow knowing the orbital parameters of the MS orbit, in particular the altitude of the satellite above the Earth's surface. The creation of the scenario is obtained through several steps: a satellite image of the desired area is used as input of a classification process that produces a map in which a suitable mixture of materials, with known thermo-optical characteristics, is associated to each pixel; the sensor characteristics are chosen, in particular the IFOV is set; from STK simulations the attitude of the satellite (the focal plane angle and the focal plane stare point) and the sensor position are computed. We have chosen an area centered on the Italian peninsula.



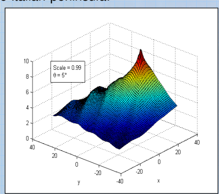


Fig. 5. Visualization of the Mutual Information

The difference image has been processed with a low-pass filter, in order to remove such points, and the resulting image is shown in Fig. 6 (d). Points with values higher than an assigned threshold are assumed to correspond to the searched changes in the scene. Future developments will include: a more accurate model of scale, which takes into account the Earth sphericity; the investigation of a new change detection technique; the test of image registration using Harris corner detector and MI for automatic extraction and tracking of ground control point.

REFERENCES

Barbara R. Hirn, Concettina Di Bartola, Giovanni Laneve, Enrico G. Cadau, Fabrizio Ferrucci, "*SEVIRI onboard Meteosat Second Generation, and the quantitative monitoring of effusive volcanoes in Europe and Africa*", **Boston**, IGARSS, 2008.

G.Laneve, E.G. Cadau, G. Santilli, "*Benchmarking of the remote sensing systems versus security applications*", Integrating GMOSS achievements in GMES, JRC, **Ispra**, 2008.

E.G. Cadau, G. Laneve, "*Improved MSG-SEVIRI Images Cloud Masking and Evaluation of its Impact on the Fire Detection Methods*", **Boston**, IGARSS, 2008.

C. Filizzola, E.G. Cadau, G. Laneve, N. Pergola, V. Tramutoli, "*Robust Satellite Techniques (RST) for early warnings in security applications: the case of Ceuta and Melilla*", JRC Scientific and Technical Report, **Bruxelles,** 2007.

G. Laneve, E.G. Cadau, G. Santilli, "*Texture Analysis on Time Series of Satellite Images with Variable Illumination Conditions and Spatial Reoslutions*", JRC Scientific and Technical Report, **Bruxelles**, 2007.

G.Laneve, G. Santilli, E.G. Cadau, "Versatility of the Mathematical Morphology to Detect any Kind of Target on High and Medium Resolution Images", JRC Scientific and Technical Report, **Bruxelles**, 2007.

G. Laneve, E. G. Cadau, "*Descrizione delle prestazioni dell'algoritmo SFIDE per la individuazione tempestiva tempestiva e il monitoraggio degli incendi boschivi da satellite geostazionario*", **Bari**, Sicurezza nei Sistemi Complessi, 2007.

G. Laneve, E. G. Cadau, "*Quality assessment of the fire hazard forecast based on a fire potential index fore the Mediterranean area by using a MSG/SEVIRI based fire detection system*", **Barcellona**, IGARSS, 2007.

G. Laneve, E. G. Cadau, D. De Rosa, "*Change detection analysis on time series of satellite images with variable illumination conditions and spatial resolution*", Fourth International Workshop on the Analysis of Multitemporal Remote Sensing Images, July 18-20, 2007 Provinciehuis Leuven, **Belgium**.

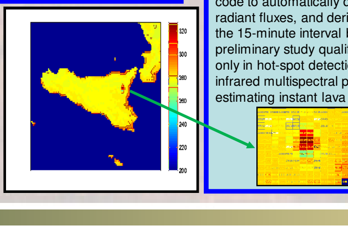
A. de la Cruz, G. Laneve, D. Cerra, M. Mielewczyk, M.J.Garcia, G. Santilli, E. G. Cadau, G. Joyanes "*On the application of night time sensors for rapid detection of areas impacted by disasters*", Symposium on Geo-information for Disaster Management, **Toronto**, Canada, May 23-25, 2007. Published to **Geomatic Solutions for Disaster Management, Springer, 2007.**

G. Laneve, E.G. Cadau, "*Performances assessment of the SFIDE algorithm devoted to early fire detection by using SEVIRI/MSG images*", 4th International Wild-land Fire Conference 13-17 May, **Seville**, 2007.

G. Laneve, E.G. Cadau, "*SEVIRI/MSG Sensor early Fire Detection performance Assessment*", 2nd GOFC/GOLD Workshop on Geostationary Fire Monitoring and Applications, 4-6 December, **Darmstadt**, 2006.

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

G. Laneve, E.G. Cadau, "*Assessment of the fire detection limit using SEVIRI/MSG sensor*", CRPSM, **Denver**, IGARSS, 2006.



Early Fire Detection

The Centro di Ricerca Progetto San Marco (CRPSM) is acquiring SEVIRI data since 2003 and has developed an innovative technique (**SFIDE,** System for Fires Detection), based on the exploitation of both the classical MIR and TIR spectral bands and the high observation frequency (15 min), to counteract the low spatial resolution characterizing such a sensor. The present paper aims to present the results obtained applying this technique and, at the same time, to confirm the applicability of the SEVIRI sensor as an instrument suitable to be employed in an operational system of early fire detection. The automatic system of early fire detection, based on the **SEVIRI/MSG** data, has been tested in the Sardinian region during the month of August 2006 and Summer 2007. The validation of the results comprises the promptness of the detections (compared with the common ground based warnings), the errors of the geo-location and the accuracy of the sizes estimate of the hot-spots. The assessment of the performances of the system has been obtained mainly comparing its results with those obtainable from higher resolution sun-synchronous sensors data (**MODIS**) and by using the Italian Forest Corps (**CFVA**) reports.

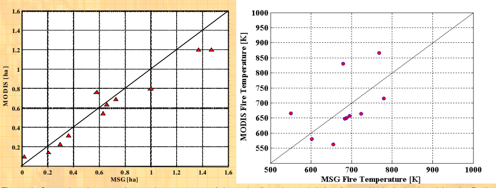


Figure 4 -Comparison between sizes and temperatures of the major fires detected during August 2006 obtained applying the Dozier relationship (Dozier 1981).

With reference to the fire sizes we can say, according to Fig. 4, that **SEVIRI**, as possibly expected, tends in general to overestimate the dimensions of a 20% or less, with respect to **MODIS**. Regarding the temperature of the fires, also this parameter results generally overestimate by **SEVIRI** of a 20%. Both fire burning temperature and instantaneous sizes are computed using the classical Dozier approach.

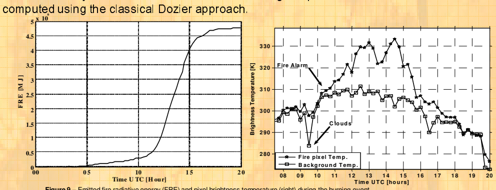


Figure 9 – Emitted fire radiative energy (FRE) and pixel brightness temperature (right) during the burning event.

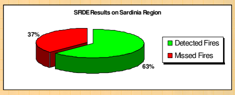


Figure A. Percentage of detected and missed fires on the Sardinia island during the August 2006.

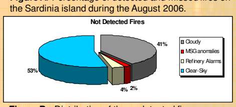


Figure B - Distribution of the undetected fires as function of the reason for missing.

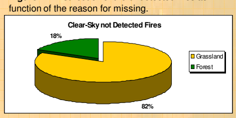


Figure C - Distribution of the undetected fires as function of the vegetation type.

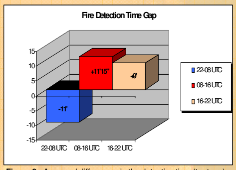
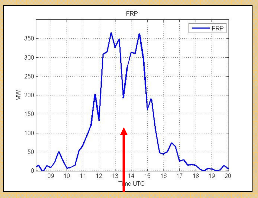


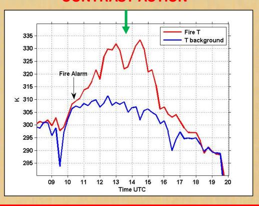
Figure 8 - Averaged differences in the detection time (t_{sat}-t_{guard}) for August 2006 fires in Sardinia.

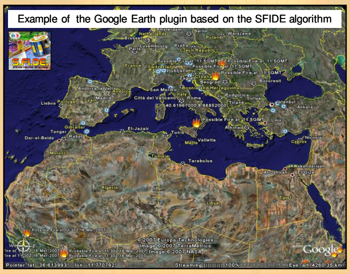
The high temporal frequency of the **SEVIRI** imagery allows following the fire evolution, providing a means to evaluate the efficacy of the fire fighting activities. Figure 9 shows the worst fire (1000 ha burned) which took place in Sardinia during the month of June 2006. From the figure (right) the behaviour of the fire can be easily monitored and the time when contrasting actions start to obtain some success can be observed (sudden brightness temperature decrease). As a consequence, we have an objective way, to follow the extinguishments process. In principle, the high image acquisition frequency can provide detailed information on the amount of biomass combusted. To obtain this result the fire radiative power (FRP) must be derived from sub-pixel fires. Figure 9 (left) shows the fire radiative energy (FRE) emitted during the big fire above recalled from which the total amount of burned biomass can be estimated. The **SFIDE** algorithm, thank to its sensitivity, allows to detect small fires characterized by FRP of the order of few MW (Fig. 10), this can improve the accuracy of the burned fuel biomass and pollutant emissions estimate. The SEVIRI 15 min. temporal resolution data used in the analysis have been directly acquired at **CRPSM** in Rome. MODIS images have been downloaded by **NASA** website. The **CFVA** provided the list of fires compiled for the Sardinia island during August 2006. In order to counteract the reduced spatial resolution (4.5 km at Italian latitude) of **SEVIRI** images, maintaining accurate fire detection capabilities, in terms of fire size and reduced false alarm, a new algorithm, called **SFIDE** (System for Fire Detection), based on the same spectral bands exploited by the classical technique (absolute or contextual threshold), has been applied. This algorithm (Laneve and Cadau 2006a) exploits the high observation frequency of the **SEVIRI** sensor, by using a comparison between the simulated 15 min pixel surface temperature variation, and the actual variation measured using **SEVIRI** data in the channel 4 (around 4 μm). In this way, if all the terms causing a surface brightness temperature variation are correctly simulated the only limitation in the minimum size of the detectable fire is related to the NEΔT associated with the detector measurement (lower than 0.2 K) in the channel 4.

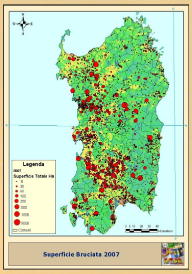
Taking into account the percentage of missed fires, the percentage of the missed fire under clear-sky conditions and the percentage of undetected forest fires it results that the **SFIDE** algorithm has missed less than the 4% of the forest fires. This result is very important since it suggests that an improvement of the sensitivity of the algorithm can be obtained, in order to allows the detection of fires characterized by a low burning temperature, by assigning the thresholds on the base of the thermal history of each pixel.



CONTRAST ACTION







Volcano Monitoring

The spectral and radiometric performance of payload SEVIRI onboard the geostationary platform MSG-2, make its data particularly well suited not only to the detection of the onset of volcanic activity, but also to the measurement of thermal radiant fluxes and eruption rates. Thorough testing was carried out on two volcanoes - Stromboli (Aeolian Islands, Southern Italy) and Piton de la Fournaise (Réunion Island, northwestern Indian Ocean) - that mostly give rise to short-lived lava flows. Aimed to comply with the outstandingly high acquisition rate, we developed an ad-hoc code to automatically detect volcanic hot-spots, measure radiant fluxes, and derive lava volume effusion rates within the 15-minute interval between two SEVIRI data streams. This preliminary study qualifies SEVIRI for volcano monitoring not only in hot-spot detection – as already done with geostationary infrared multispectral payloads GOES, e.g. – but also for estimating instant lava effusion rates at high repeat rates.

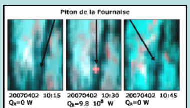


Fig. 4. Onset of the April 2nd, 2007, lava flow at Piton de la Fournaise with radiant flux determination via the MyMET procedure.

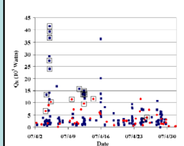


Fig. 5. Piton de la Fournaise, April 2007: radiant flux estimates by MyMET on MSG2-SEVIRI data (■) and by MyMOD on MODIS data (●) [10]. Open squares (□) mark underestimates done in scenes with one or more pixels affected by MIR or TIR radiance saturation.

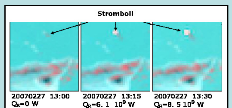


Fig. 2. Detection of February 27, 2007 eruption onset at Stromboli and radiant flux determination with the MyMET procedure.

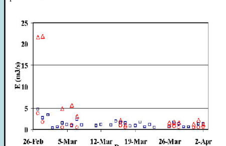


Fig. 3. Largest daily effusion rates measured with SEVIRI/MyMET (□) compared to minima (○) and maxima (Δ) of official estimates [1] done almost daily with AVHRR and MODIS.