Integration of Optical and Passive Microwave Satellite Data for Flooded Area Detection and Monitoring

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Abstract

Flooding represents a serious threat to millions of people around the world and its hazard is rising as a result of climate changes. From this perspective, flood risk management is a key focus of many governments, whose priority is to have frequently updated and accurate information about the flood state and evolution to promptly react to the disaster and to put in place effective countermeasures devoted to limit damages and human lives losses. Remote sensing technology allows for flood monitoring at different spatial and temporal resolutions with an adequate level of accuracy. In particular, for emergency response purposes, an integrated use of satellite data, acquired by both optical and passive or active microwave instruments, has to be preferred to have more complete and frequently updated information on soil conditions and to better support decision makers. In this framework, multi-year time series of MODIS (Moderate Resolution Imaging Spectroradiometer) and AMSR-E (Advanced Microwave Scanning Radiometer for Earth Observing System) data were processed and analyzed. In detail, the Robust Satellite Techniques (RST), a multi-sensor approach for satellite data analysis, has been implemented for studying the August 2002 Elbe river flood occurred in Germany, trying to assess the potential of such an integrated system for the determination of soil status and conditions (i.e. moisture variation, water presence) as well as for a timely detection and a near real time monitoring of critical soil conditions.

Keywords

Flood detection and monitoring • RST • MODIS • AMSR-E

126.1 Introduction

It is widely recognized that among the natural disasters, floods are one of the most dangerous, having a serious impact on infrastructures, environment, human lives and economy. In the context of flood risk management, decisions makers need of frequently updated and accurate information about the flood state and evolution to promptly react to the disaster and to put in place effective countermeasures devoted to limit damages and human lives losses (Martinis et al. 2009). Meteorological satellite based technologies, providing real time observing capability, may furnish reliable data and products for supporting floods monitoring actions and emergency response purposes. Such technologies (based both on optical and microwave sensors) allow to monitor the

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G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 3*,
DOI: 10.1007/978-3-319-09054-2_126, © Springer International Publishing Switzerland 2015

dynamics of hydrological events, thanks to their capacity to map surface water at a consistent level of accuracy.

Optical imagery operating in the visible and thermal regions of the wavelength spectrum offer a relatively high spatial resolution (upto 250 m) combined to a frequent acquisition (daily/sub-daily intervals, depending on the satellite system), making them theoretically ideal for mapping inundated areas (Sakamoto et al. 2007). Their main drawback, i.e. their inability in providing information when clouds are present, has favored the use of passive microwave data, available with a high temporal frequency (1–2 times daily) on a near-global scale, even if at low spatial resolution (~5–70 km). Considering the advantages and disadvantages of actual satellite systems, an effectively approach of flood management is to use the microwave and optical remote sensing imagery simultaneously (Sanyal and Lu 2004), to have more complete and frequently updated information on soil conditions.

In this paper, we assess the potentiality of such a strategy, using optical and passive microwave data acquired by two sensors onboard Aqua Earth Observing Systems (EOS) satellite. Specifically, we investigated the complementary role of Advanced Microwave Scanning Radiometer (AMSR-E) and Moderate Resolution Imaging Spectroradiometer (MODIS) data. A multi-sensor approach, based on a general change detection scheme, named Robust Satellite Techniques (RST—Tramutoli 2007), was applied to automatically identify water in/on the soil. AMSR-E data were used for a continuous and frequently updated monitoring of soil conditions aimed at an effective early warning of floods, and MODIS ones to map, with a higher detail than AMSR-E, the extent of areas involved by flood. To this aim, multi-year time series of such data were processed and analyzed for studying the Elbe rivers flood event occurred in the South of Germany in the second half of August 2002.

126.2 The Robust Satellites Techniques Approach

The RST approach (Tramutoli 2007) is a multi-temporal scheme of satellite data analysis which identifies, at pixel level, significant statistically anomalies of the investigated signal. Firstly the behavior of the signal in normal (i.e. unperturbed) conditions is defined, by collecting and processing a multi-year data-set of co-located imagery, in terms of expected value $\mu_V(x, y)$ (i.e. its monthly temporal mean) and natural variability $\sigma_V(x, y)$ (i.e. its standard deviation). Using these values a pixel is detected as anomalous, in the space-time domain, implementing the ALICE (Absolutely Llocal Index of Change of the Environment) index, so de-fined:

$$\otimes_V(x, y, t) = \frac{V(x, y, t) - \mu_V(x, y)}{\sigma_V(x, y)} \tag{126.1}$$

V(x, y, t) is defined according to the type of phenomenon to be studied and may correspond to the measurement made in a single specific spectral band or derive from the combination of several channels. Generally speaking, the ALICE index is a standardized variable, characterized by a Gaussian behavior (mean equal to zero and standard deviation equal to 1). This means that the probability of occurrence of values higher than ±2 standard deviation is less than 3 %, and it becomes lower than 0.13 for values higher than 3.

When implemented on MODIS data, the soil and water spectral behaviors in VIS and NIR bands were exploited to discriminate flooded pixels over the scene. As a previous study showed (Faruolo et al. 2013), the VIS and NIR reflectances difference, R_{NIR}–R_{VIS}, represents the signal to investigate to have a detailed map of flood affected areas, being it more sensitive to water presence than the ratio R_{NIR}/R_{VIS}. The ALICE index, implemented on daytime MODIS images at 250 m of spatial resolution, has the following formulation:

$$\otimes_{NIR-VIS}(x, y, t) = \frac{R_{NIR-VIS}(x, y, t) - \mu_{NIR-VIS}(x, y)}{\sigma_{NIR-VIS}(x, y)} \tag{126.2}$$

In correspondence of flooded areas, negative $\otimes_{NIR\text{-}VIS}(x, y, t)$ values should be observed.

When implemented on AMSR-E data, RST uses as signal to be investigated for monitoring soil moisture variations the Polarization Ratio (PR = Tbv − Tbh/Tbv + Tbh, where Tb stands for brightness temperature and the subscripts v and h indicate vertical and horizontal polarization, respectively) in order to compute a suitable Polarization Ratio Variation Index (PRVI) (Temimi et al. 2011; Lacava et al. 2012), defined as:

$$PRVI_{6,9}(x, y, t) = \frac{PR_{6,9}(x, y, t) - \mu_{PR_{6,9}}(x, y)}{\sigma_{PR_{6,9(x,y)}}} \tag{126.3}$$

where $PR_{6,9}(x, y, t)$ is the Polarization Ratio computed for the AMSR-E band at 6.9 GHz, in this specific case. The used images, at 25 km of spatial resolution, have been derived by AMSR-E Level-3 land surface product (AE_Land 3) data (Njoku 2011). High values of PRVI should be measured in correspondence of a relative and significant increase of soil wetness. Such an index, differently from the MODIS one, has been computed both in daytime (Ascending pass, 13:30 GMT) and nighttime conditions (Descending pass, 01:30 GMT).

126.3 Results and discussion

In this paper the Elbe river flood which hit the South of Germany between August 6 and 13, 2002, causing large damage and losses of human lives (Ulbrich et al 2003) was selected as test case. Following the RST prescriptions, all MODIS and AMSR-E images acquired during the months of August in the period 2002–2010 were collected and processed, in order to compute the two ALICE indices (Eqs. (126.2) and (126.3)). In particular, August 2002 PRVI values for the AMSR-E pixel centered on the most affected area along the Elbe river, located between Wittenberg and Torgau cities (red box in Fig. 126.1, pixel center located at 51°48′N, 12°53′E on the AMSR-E 25 km EASE grid), were investigated.

Figure 126.2 shows the temporal trend of PRVI, in the period August 8–31, 2002, for the AMSR-E pixel. It should be stressed that unfortunately no AMSR-E data are available in the period July 30—August 8, 2002 (Njoku 2011). The gray dashed line highlights days with higher values of such an index (>2), identifying anomalous situations (i.e. soils wetter than normal). The interruption in the line is due to the presence of heavy rainy clouds, which scattered out microwave radiation, preventing surface measurements.

Looking at the temporal pattern, it is evident how the PRVI is able to catch the evolution of the phenomenon in progress on the surface: quite "normal" PRVI values were detected up to 11 of August; then, after the heavy rains, the signal started to increase reaching values higher than 2 on August 14, when the areas started to become very wet. Such an information may be considered as a sort of early warning for the investigated area, indicating its critical status in terms of soil water content. Such a status remains almost constant at these high values till the 22 of August. Afterwards the computed signal starts to gradually decrease, indicating that soil within the pixel was coming back to almost normal conditions. It should be stressed that the detected pattern is independent from the time (Ascending or Descending pass) of the AMSR-E confirming on one side the consistency of the detected anomalous signal and on the other the robustness of the proposed approach.

Starting from such a "warning" signal, the whole MODIS dataset was analyzed by Eq. 126.2. The first almost cloud free Aqua MODIS image over the investigated area (i.e. corresponding to the investigated AMSR-E pixel, red box within Fig. 126.3) is dated August 18 and reported in Fig. 126.3a, where the presence of flooded pixel is identified at different levels of confidence of the MODIS based index (Eq. (126.2)), well in agreement with other independent information (Faruolo et al. 2013). It is important to highlight that combining also the information coming from MODIS onboard Terra satellite, the first detection of the flooded areas can be anticipated to August 16 (Faruolo et al. 2013).

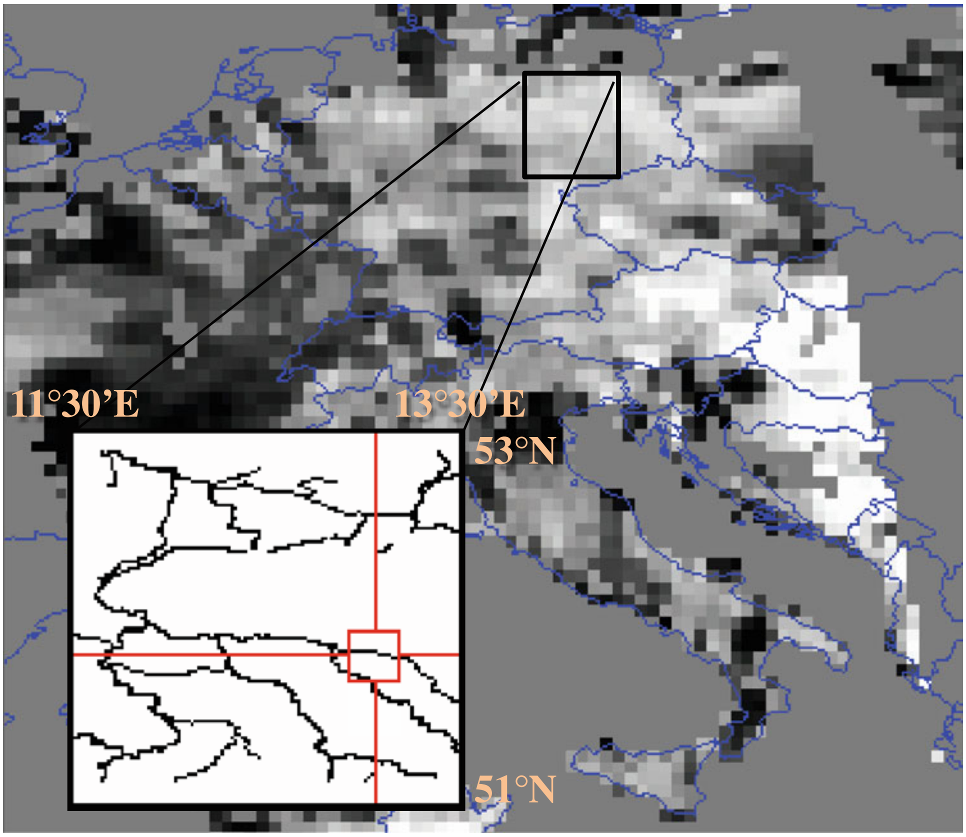

Fig. 126.1 PRVI map (*shown in grey tones*) for the AMSR-E ascending pass of August 9, 2002: the *black box* contains the German area involved by the Elbe flood. The small *red box* is the AMSR-E pixel analyzed in the study

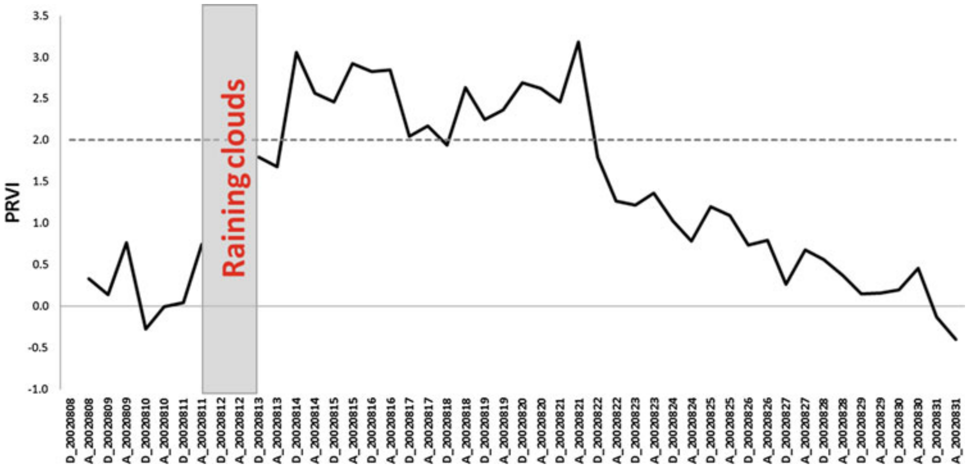

Fig. 126.2 PRVI temporal pattern from 8 to 31 August, 2002 for the AMSR-E pixel shown in Fig. 126.1 (*red box*); the gray dashed line in the graph identifies days having PRVI > 2

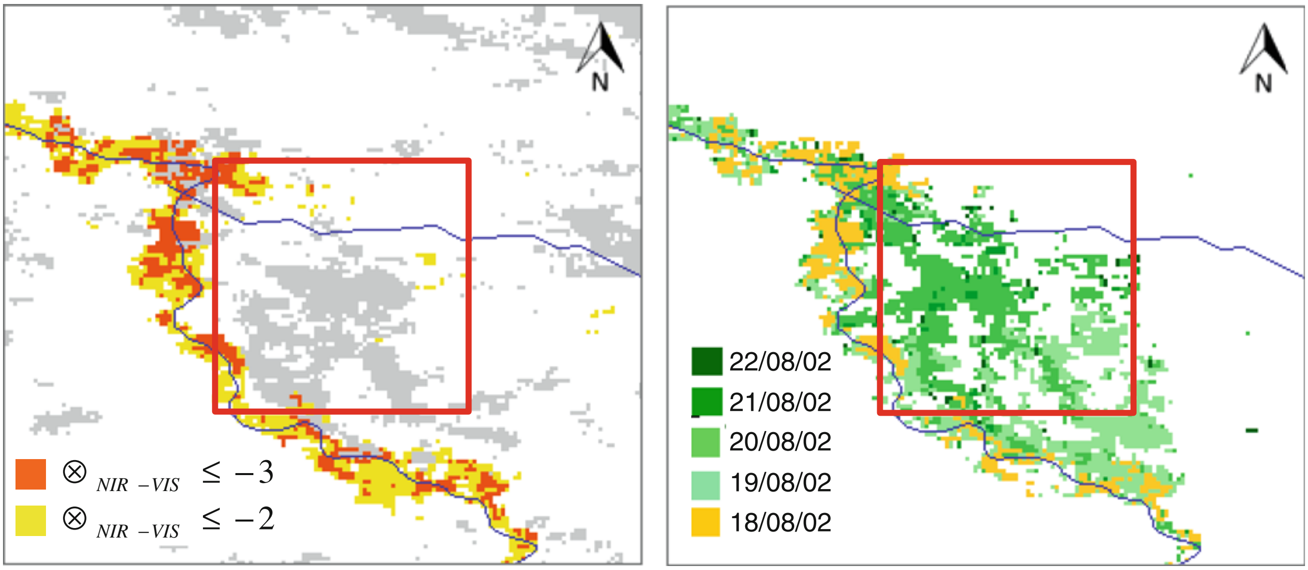

Fig. 126.3 **a** Pixels detected as flooded by implementing $\otimes_{\text{NIR-VIS}}(x, y, t)$ at different levels of confidence on the Aqua MODIS image of August 18, 2002 at 12.10 GMT. Cloudy pixels are drawn in *gray*. **b** Flood progression map obtained by implementing ALICE index ($\otimes_{\text{NIR-VIS}}(x, y, t) < -3$) on 250 m Aqua MODIS images from 18 to 22 August 2002. The *red box* represents the investigated AMSR-E pixel

Anyway, the achieved results clearly state the feasibility of the proposed approach: passive microwave data can be used to provide a first warning about the presence of soil wetter than normal, also in presence of clouds; then optical data may help in "downscaling" at local scale such an information, showing the areas mostly affected by the event. Summarizing this discussion, a total flood extent map was realized (Fig. 126.3b), combining pixels detected as flooded at the most reliable level of confidence ($\otimes_{\text{NIR-VIS}}(x,y,t) < -3$) from 18 to 22 August, 2002. As expected, water firstly started to inundate the areas close to the river banks, then it moved far from them, covering a total area of 176 km^2.

126.4 Conclusion

A multi-sensor approach for satellite data analysis, based on the Robust Satellite Techniques approach, has been tested in this work for studying the August 2002 Elbe river flood occurred in Germany. Achieved results show the capability of such a system to timely capture subsequent inundation stages. Further analyses have to be carried out over an extended set of study cases to better assess its actual reliability and efficiency.

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