FOREST DAMAGE ASSESSMENT USING SAR AND OPTICAL DATA: EVALUATING THE POTENTIAL FOR RAPID MAPPING IN MOUNTAINS

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ABSTRACT

In mountain ecosystems, forest damages are of high importance and a challenge for forest management and conservation. However, a quick assessment of these changes is difficult in complex terrain. In response to this constraint, rapid mapping using earth observation data has become an attractive solution. In particular, Synthetic Aperture Radar (SAR) offers a unique opportunity for forest management applications due to its independence of weather conditions. In this study, the potential of X-band COSMO-SkyMed Stripmap SAR images for forest change detection in mountainous environments is evaluated. A forested area in the Southern Alps (South Tyrol) is chosen which was affected by a storm event in June 2011. We mapped the forest changes using a statistical approach (Principal Component Analysis (PCA)). To evaluate the potential of radar relatively to optical data, two RapidEye images were obtained and forest changes by thresholding image differences between both years were mapped. The results show that optical data showed higher forest change accuracies than the SAR images. Using RapidEye imagery we accurately captured changes with a minimum area of 0.1 ha while the minimum detectable area was 0.5 ha with COSMO-SkyMed. The difference in results is explained by the high level of speckle noise introduced by the SAR resolution and by the high Local Incidence Angles (LIAs) within the study area (55° to 95°). The combination of these two effects introduced an increase in false alarm changes. The advantage of using SAR data is the capability of a quick assessment of changes especially in difficult weather conditions. However, the use of radar for rapid mapping of forest damages in mountains can be limited depending on the acquisition geometry. Thus, the acquisition geometry should be carefully chosen with respect to the topography to reduce layover and shadowing effects.

INTRODUCTION

In the context of forest management and conservation, forest damages present a particular threat and require rapid intervention measures (1). Besides degradation and loss of tree cover, secondary impacts such as insect infestations may limit long-term recovery of affected area (2,3).

Forest cover also plays an important role in hazard mitigation and risk reduction. In areas of steep terrain where gravitational hazards (e.g., rock-fall, landslides, debris-flow, avalanches) are predominant, the reduction of tree cover density results in an increased hazard susceptibility putting local communities at risk.

Despite its importance, monitoring and managing these changes in mountainous landscapes is challenging. The complex terrain limits fast ground-based mapping by forest authorities making rapid mapping methodologies based on earth-observation (EO) an attractive alternative. With the rise of new satellite constellations and with the increase in both spatial and temporal resolution of available data sources, a quick assessment of intra-annual changes is possible. In particular, active microwave sensors like Synthetic Aperture Radar (SAR) are especially suitable for rapid mapping as data are acquired independent of illumination and weather conditions.

Several authors have explored the development of rapid mapping methods based on SAR (4) showing the importance of SAR data mapping in the context of crisis management and hazard damage assessment (5,6) but also for forest changes (7,8). However, the strengths and limitations of radar data in comparison to optical data for rapid mapping of forest damages in mountainous environments have not been fully explored yet.

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In this study, we evaluated the potential of COSMO-SkyMed Synthetic Aperture Radar (SAR) X-band imagery for forest change detection in mountains and compared the changes with the results of a bi-temporal change detection of RapidEye images. We aimed at understanding the comparative advantages and drawbacks of both data sources for the rapid mapping of forest damages in support to forest management practices. Specifically, our research question was: How far can radar respond to the limitations of optical data for forest damage assessment in mountainous environments?

METHODS

Study Area

The region of South Tyrol, Italy covers an area of 7400 km^2 with elevations ranging from 200 m to a maximum of 3,900 m. This results in a heterogeneous and complex landscape which is reflected on the land cover. About 42% of the area is covered by forest (38% coniferous, 3% mixed and 1% broadleaved), while the valleys are largely dominated by agriculture and grasslands. In this study, a forested area in the northeast of the region was chosen because of its topographic variability (altitudes ranging from 900 m to 3,400 m with a mean slope of 25°). This area was affected by a storm event on 22 June 2011 which resulted in large forest damages (>1ha) and provides the ideal background to evaluate the performance of radar and optical data under complex topographic conditions. The study area was defined by the overlapping area between the different satellite datasets (Figure 1).

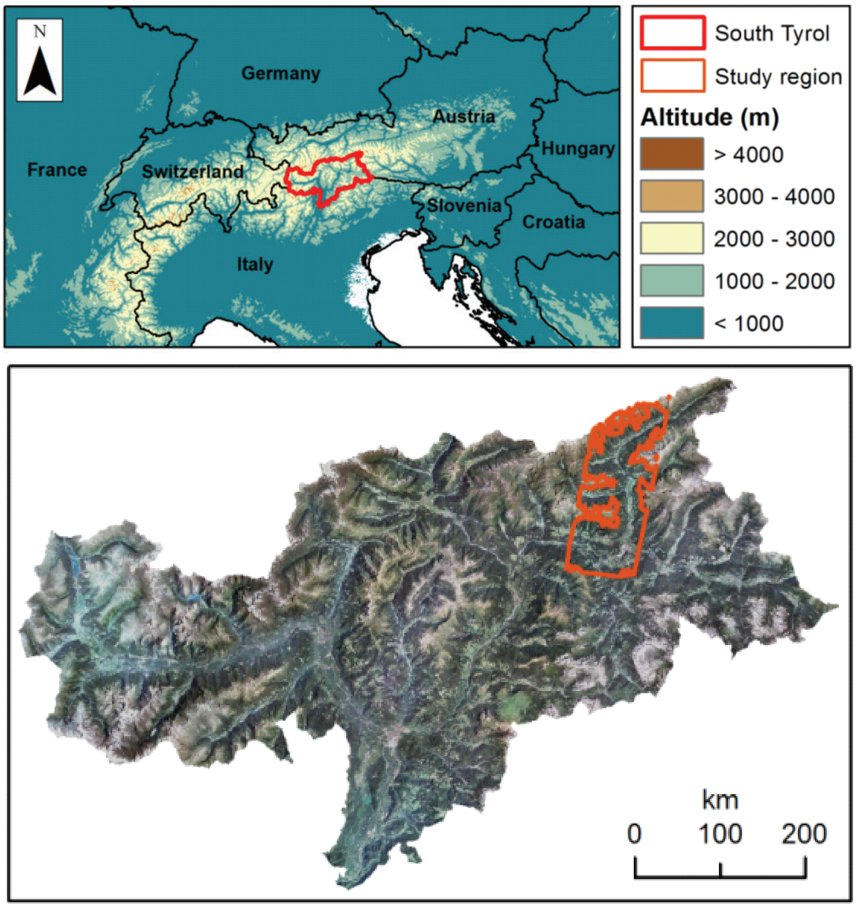

Figure 1: Location of South Tyrol, Italy within the mountain range of the Alps and our study region within South Tyrol.

DATA

In this study, we used seven HIMAGE COSMO-SkyMed X-Band acquisitions (SLC) obtained between 28 May 2011 and 31 August 2011 with a resolution of 2.16 m in range and 2.24 m in azimuth direction. The images were acquired in descending mode. Additionally, two level 1B RapidEye images (9) were obtained with a spatial resolution of 6.5 m acquired on 31 July 2010 and 29 June 2011. These images show forest damages related to the storm event with their acquisitions before and after the storm event and present a low cloud cover (11% and 9%, respectively). The reference data set was obtained through visual interpretation of an orthophoto mosaic from 2011. A total of 276 reference polygons corresponding to forest disturbances within the overlapping area of both data sets was collected. We additionally retrieved a forest mask from existing land cover information.

Optical data pre-processing

Several pre-processing steps were necessary before applying a bi-temporal change detection approach. First, we orthorectified the RapidEye images, converted DNs to top of atmosphere (TOA) reflectances and topographically corrected images using the c-correction method. The results were then radiometrically normalized using the Iterative Multivariate Alteration Detection (IMAD; (10)). Finally, we calculated the difference image between the two dates to allow suitable bands to be selected for the change detection as well as the setting of thresholds. Band 3 (Red channel) was chosen for the change detection.

Radar data pre-processing

The COSMO-SkyMed data was processed with a final 5 m ground resolution (2×2 multilooking) in order to preserve the comparability with the optical change detection. The images were then filtered using a Frost filter with a 5×5 pixel processing window. The filtered images were co-registered using the first image (28 May 2011) as a master. Finally, the images were geocoded and radiometrically calibrated using a 5 m Digital Terrain Model (DTM).

A Principal Component Analysis (PCA) was used for the change detection, over the time-series of backscattering coefficients (which are expressed in dB). Shadow and overlay effects as well as non-forested areas were masked in this process. Finally, the second principal component (PC2) was selected as being representative of the forest changes. The PC2 reported the highest number of changes when compared with ground truth as well as a lower degree of overestimation.

Change detection and comparison

In order to compare the relative performance of both data sets the changes in accuracy were evaluated with the gradual increase in Minimum Mapping Unit (MMU) within the reference polygons. A range between 0.05 ha and 1 ha was used with an interval of 0.05 ha. Simultaneously, the changes in accuracy were evaluated with different thresholds. We aimed to determine the optimal change threshold for each data set and to evaluate their performance. The changes in Producers Accuracy (PA) - ratio between the number of correctly classified pixels and the total of pixels within the reference data set - and Users Accuracy (UA) - ratio were calculated between the total of correctly classified pixels and the number of pixels classified as change. This procedure was applied with the objective of finding a compromise between the two difference measures as an indicator of the optimal MMU. A single threshold was selected for RapidEye band 3, while a double threshold was applied to COSMO-SkyMed PC2 accounting for positive (changes from forest to bare soil) and negative (changes due to increase of shadowed areas related to full removal of fallen trees) backscatter changes. In the case of COSMO-SkyMed, negative and positive values in the PC2 component were considered separately and combined after applying a neighbourhood filter. Initial results showed that considering both thresholds simultaneously resulted in a significant increase in size of false changes. Additionally, the performance of the two data sets was assessed in relation to the individual reference polygons. We evaluated the changes in PA as an indicator of the minimum patch size captured with each of the two data sets. The PA was estimated for different MMU using the optimal threshold previously determined.

RESULTS

The results suggested the selection of a threshold of 10% reflectance for RapidEye and thresholds of –3 dB and 5 dB for COSMO SkyMed with a MMU of 0.1ha and 0.5ha, repectively. We achieved comparatively higher performance of RapidEye in relation to COSMO-SkyMed (Figure 2) with significantly higher accuracy from RapidEye with PA=84% and UA=80%. For COSMO-SkyMed, the PA and UA for the optimal threshold were both below 20%. When looking at the accuracies for the individual polygons, RapidEye performed better achieving higher minimum accuracies (>50%) with a lower minimum patch size (0.05ha). However, higher accuracies were achieved with COSMO-SkyMed (around 70%) in certain conditions. These conditions are mainly related to the topography and acquisition geometry.

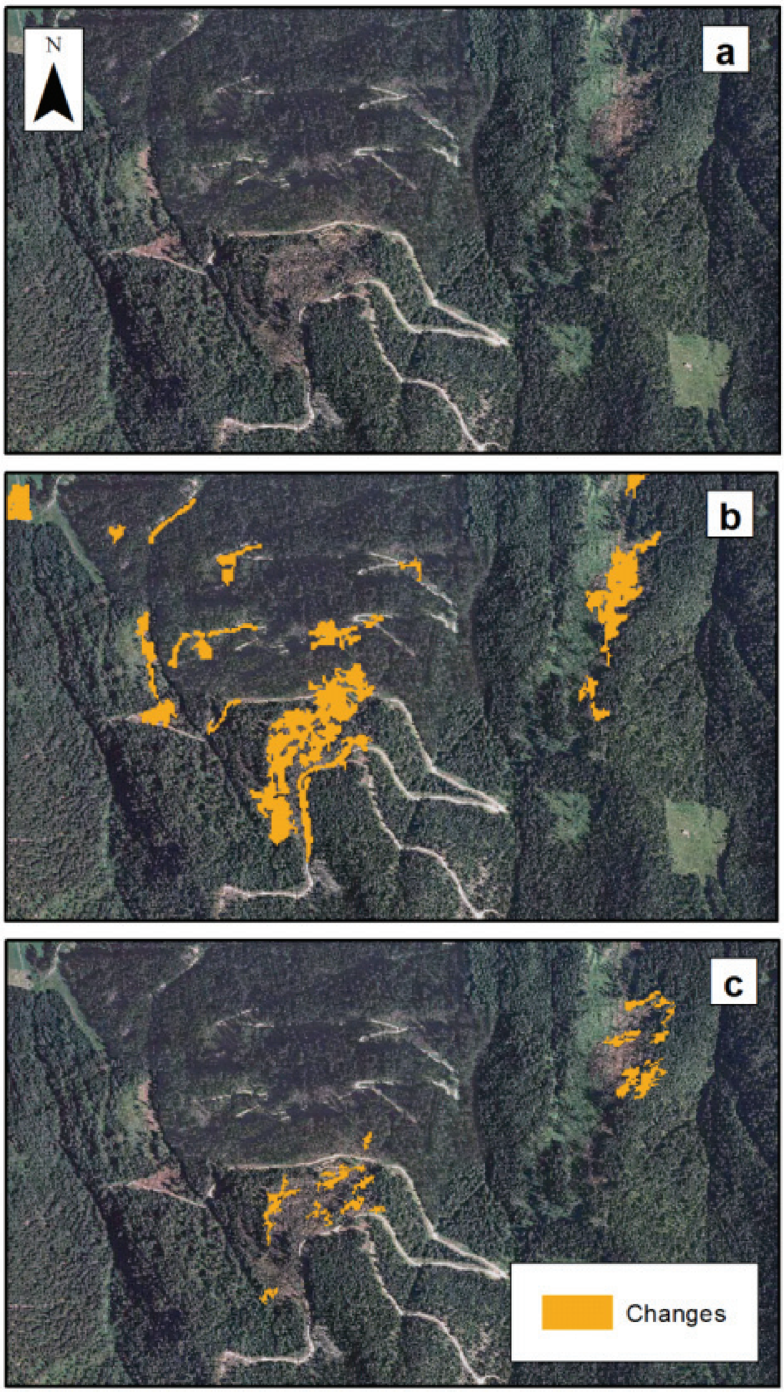

Figure 2: Orthophoto forest damage image (a) and its comparison with RapidEye (b) and COSMO-SkyMed (b) change detection results.

CONCLUSIONS

Our results show that the RapidEye optical data provides significantly higher accuracies as compared with COSMO-SkyMed X-band with a Producers accuracy (PA) and Users Accuracy (UA) above 80%, while these values remained below 20% for COSMO-SkyMed. Moreover, the radar analysis requires attention to be paid to the number of acquisitions. Preliminary tests showed that the use of a bi-temporal approach as done for RapidEye was inadequate limiting clear visualization of the changes and jeopardizing their extraction. Despite the clear differences in performance when assessing the areal extent of the reference data set, the analysis of COSMO-SkyMed showed indications of the potential use of this data set in rapid mapping of large changes. This adds on the findings of similar studies developed over less complex terrains (11,12,13).

The changes in accuracy between the two data sets can be justified by both the characteristics of the radar data set as well as the background conditions. Combining a high topographic complexity and orientation and the sensor acquisition geometry resulted in an increase in speckle noise and overlay and shadowing effects due to the very high Local Incidence Angles (55º to 95º). The selection of an appropriate acquisition geometry thus becomes crucial for the rapid mapping of forest changes. This can be achieved due to the flexibility of COSMO-SkyMed acquisition geometry. Further research is required to fully evaluate the dependencies of radar images on topography for forest change mapping.

Additionally, the presence of fallen trees within the affected areas created a particular challenge resulting in a significant underestimation of the areal extent of the disturbances. This issue is also visible in the RapidEye data analysis. The inconsistency of the accuracies for the individual disturbances reveals the influence of the fallen biomass present within the affected areas.

The higher accuracy of optical data can also be related to the analysis carried out on annual changes (changes detected between 2010 and 2011). This was necessary in order to have images less affected by shadows due to illumination conditions. This selection of optical images can be a drawback for rapid mapping. In this context, radar images can be useful for a quick assessment of change independent of cloud and sun illumination conditions, while optical imagery is essential to an accurate delineation of affected areas. As a result, the combination of radar and optical data should be explored for rapid mapping.

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