Combining InSAR and optical data to detect earthquake damages

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ABSTRACT
In this paper, we made a preliminary experimental evaluation of the capability to detect the urban changes due to an earthquake by InSAR and optical satellite based data. The test site is the area hit by the August 17th, 1999, Turkey earthquake. A multichannel/multitemporal dataset has been created including the intensity image of the pre event and the post event ERS acquisitions, the complex coherence and the intensity correlation coefficients. Using this SAR data set and the change detection provided by IRS, we performed a number of statistical tests to understand at what extent the InSAR is able to help detecting urban damages and what particular features extracted by SAR better contribute to this objective.

1 INTRODUCTION AND METHODOLOGY

The prompt detection, mapping and evaluation of urban damages due to earthquakes is a key point, particularly in remote areas or where the infrastructures are not well developed to ensure the necessary communication exchanges or where their operability has strongly decreased as a consequence of the event. The optical images presently available from space at resolution in the order of meter or better are certainly a suitable tool to perform damage assessment. However, radar remote sensing can give also a valuable contribution in this application, especially for its capability to make observations almost independently on the meteorological conditions and cloud coverage. Both remote sensing techniques are increasing their capability to provide measurements as soon as they are required, thanks to pointing flexibility of the last generation of spaceborne systems and the future availability of constellations of satellites.
Previous works used only radar data ([1] [2]) or optical images ([3]) for change detection analysis in urban areas.
The Synthetic Aperture Radar (SAR) collects maps of the backscattering coefficient and has the capability to detect urban extension and urban changes. The Interferometric SAR (InSAR) technique increases this change detection capability by exploiting another quantity measured by the radar, that is the coherence between signal echoed by the same portion of the surface as observed at different times. The urban settlements do not change their geometric and dielectric structures and therefore generally produce coherent signals if they are observed from comparable directions. Conversely, any change in the structure and thus in the scattering mechanisms producing the backscattered signal causes random variations of echo intensity and phase. In this paper, we made a preliminary experimental evaluation of the capability to detect the urban changes due to an earthquake by InSAR and optical satellite based data. The test site is the area hit by the August 17th, 1999, Turkey earthquake. In particular we focused our study on the Eastern part of the Marmara Sea, the city of Gölcük and Izmit. This seismic event have been studied by InSAR technique to assess surface changes using two pairs of tandem ERS images collected on 12-13/08/1999 and 16-17/09/1999. Two panchromatic images collected by IRS before and after the earthquake (8 August 1999 and 27 September 1999), with a spatial resolution of about 5 meters, have been also acquired for this study. A multichannel/multitemporal co-registered dataset has been created including the intensity image of the pre event and the post event ERS acquisitions (we have used a combination of the two tandem images), the InSAR complex coherence and the correlation coefficient of the intensity between the two pre event images (the tandem pair) and between the master and one post-event images. The complete remote sensed data set and the derived features are depicted in Table 1. Note that the evaluation of the information contained in the intensity with respect to the phase coherence was one of the objective of this study.

Table 1: Scheme of remotely sensed data acquisition and derived features

	Pre-seismic SAR ERS-1 12/8/99	Post-seismic SAR ERS-2 17/9/99	Post-seismic IRS 27/9/99
Pre-seismic SAR master ERS-2 13/8/99	Pre-seismic coherence/ correlation	Co-seismic coherence/correlation	
Post-seismic SAR ERS-1 16/9/99		Post-seismic coherence/ correlation	
Pre-seismic IRS 8/8/99			IRS change

In the first stage of the work, we have used the optical images as a reference map to detect the earthquake damages. A number of well identified changes have been detected from IRS data by simple image processing algorithms, confirmed by a visual inspection of the images. These detected changes have been also separated in different damage classes.
Using this SAR data set and the change detection provided by IRS we have performed a number of statistical tests to understand at what extent the InSAR is able to help detecting urban damages and what particular features extracted by SAR better contribute to this objective.
We first developed a pixel by pixel classification by dividing each change image area in test and training sets. Results of this classification are shown. It is clear how the use of both IRS and SAR data improves the accuracy.
As ground surveys in the city of Gölcük are available we used them to compare our observations with the ground truth. The comparison between pixel classification results and the ground surveys are also encouraging.

2 RESULTS

The first step of the work has consisted in selecting some damage classes based on an analysis of the two IRS optical images. Both a simple automatic technique (difference between the pre-seismic and post-seismic co-registered IRS data after having applied an histogram matching algorithm) and a visual inspection of the IRS images have been used to identify pixels belonging to five different damage classes. The visual inspection has allowed us to identify the following five classes of change: new manufacts after the earthquake, buildings with decreased dimensions, rubble, subsidence along the coastline, damaged oil tanks. A sixth class was identified corresponding to unchanged urban settlements. Figure 1 shows the damage areas in different colours superimposed to the pre-seismic IRS image collected over the region of Marmara Sea and a zoom of the Gölcük urban area.

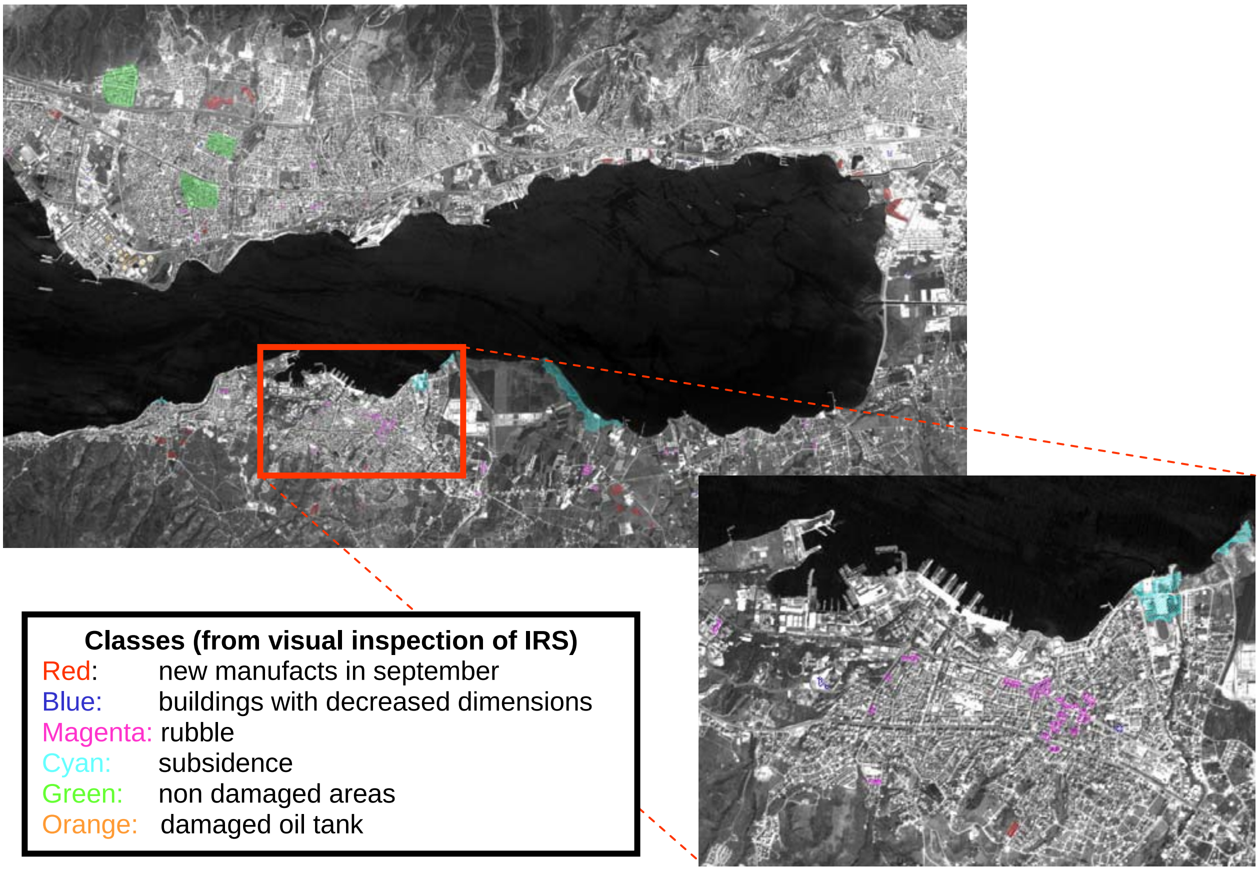

Fig. 1. Damage classes selected by visual inspection from IRS images in the area of Gölcük

The ERS 1-look complex images have been automatically co-registered by assuming as master the one of 13 August 1999. Then the SAR data set (including coherence and intensity correlation) has been co-registered with IRS by selecting a number of ground control points. An example of SAR data is depicted in Figure 2.

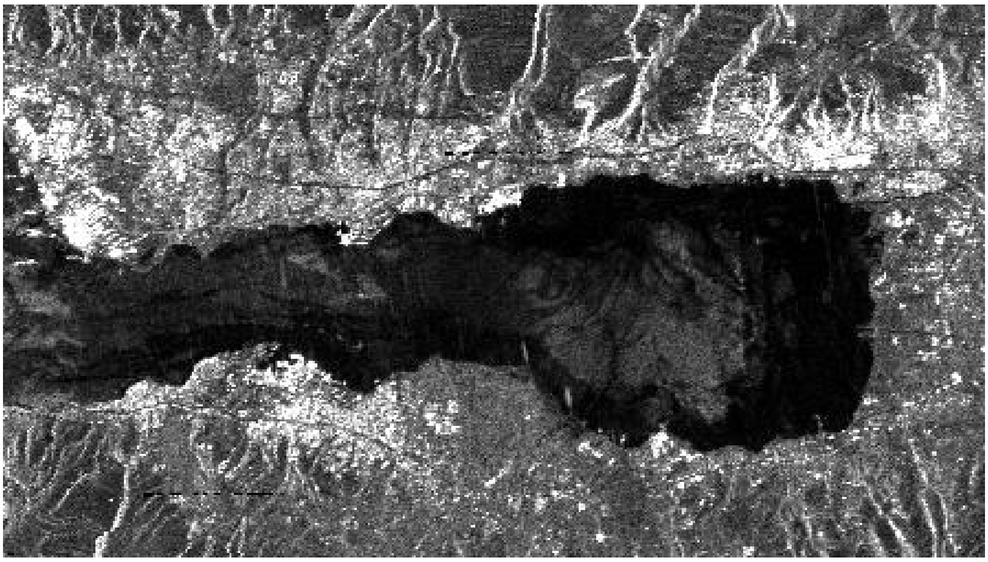
Fig. 2. ERS-2 pre-seismic SAR intensity image of the area registered on the IRS image

Figure 3 shows the preliminary analysis of the complex coherence and intensity correlation values averaged over the six selected changed areas. As expected, the damage classes have a lower value in co-seismic coherence and intensity correlation than in the pre-seismic and post-seismic cases, whilst the unchanged area has almost constant values. Note that the class “subsidence” exhibits a low post-seismic coherence due to the fact that the area has been covered by sea water after the earthquake. Besides the apparent trend of both coherence and correlation, these two parameters are very much scattered within each selected area, so that a pixel-by-pixel discrimination did not give very good results.
In order to perform a pixel-by-pixel classification, the selected regions have been divided into test and training pixels. The results of the classification obtained using a very simple maximum likelihood criterion that assumes a Gaussian distribution of the available features is shown in figure 4, where both classification accuracy (percentage of correctly classified pixels) and the well known Kappa coefficient are reported. Different combinations of features forming our multiparameter dataset are compared in order to understand which of them most contribute to the discrimination of changes. The relatively poor contribution of the SAR alone is apparent from this comparison, that could of course be slightly improved using more sophisticated SAR classification algorithms. However, the contribution of the SAR in addition to the optical data is also evident. Note that the addition of the InSAR coherence determines the best classification results, even better than the addition of all SAR features that probably suffers from the increasing dimension of a noisy feature vector.
Another analysis has been based on ground truth data that were available from a survey after the earthquake ([4] [5]). In this case the ground truth was not available at pixel level but it was aggregated within blocks of buildings. We have superimposed these information units to the multiparameter data set (see Figure 6) and we have focused our attention on the so called “collapse ratio” that indicates the percentage of completely collapsed buildings with respect to the total number of buildings within each block. The correlation of this parameter with remotely sensed features has been investigated. The more interesting result is the dependence of the change of IRS intensity and of the SAR intensity correlation on collapse ratio. The results obtained using the InSAR coherence were not encouraging so that we tried to understand what other factors could affect the InSAR coherence masking the influence of damages.
For this reason we investigated the influence of urban texture and InSAR baseline on both coherence and intensity correlation and we found a slightly but still evident correlation between InSAR coherence and a texture parameter derived from IRS that is named “dissimilarity” [6]. This is shown in Figure 7 where the pre-seismic and post-seismic cases are shown and the negative correlation indicates the decreasing of coherence in areas with smaller and denser structures (higher dissimilarity). Finally, Figure 8 shows as the coherence is also more influenced from the baseline between the two SAR acquisitions with respect to correlation of intensity. This may justify the less importance of InSAR coherence with respect to correlation when using SAR alone. On the contrary, the information contained in the InSAR coherence seems to be less correlated to the information carried by optical data, thus justifying the value of combining these two types of features.

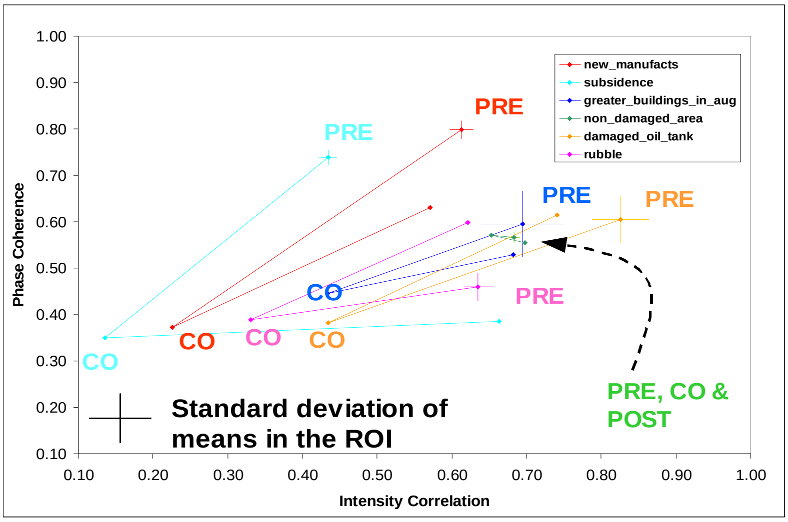

Fig. 3. Pre-, Co- and post-seismic trajectories of InSAR coherence and SAR intensity correlation

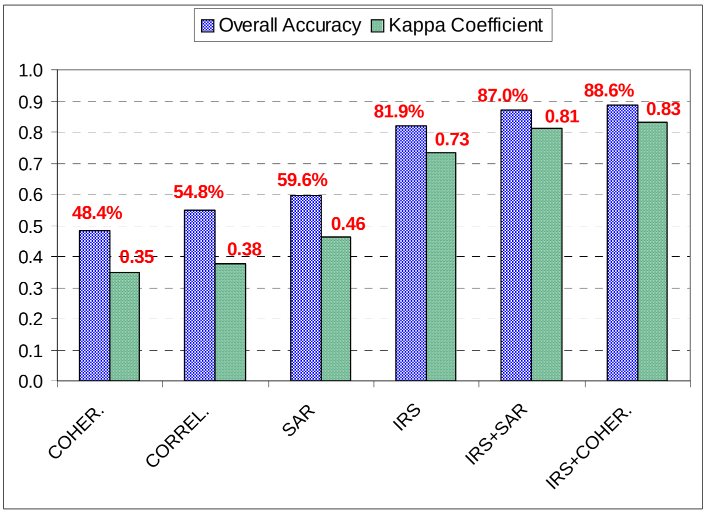

Fig. 4. Results of pixel-by-pixel classification of damaged areas (as derived from IRS) in terms of total accuracy and Kappa coefficient

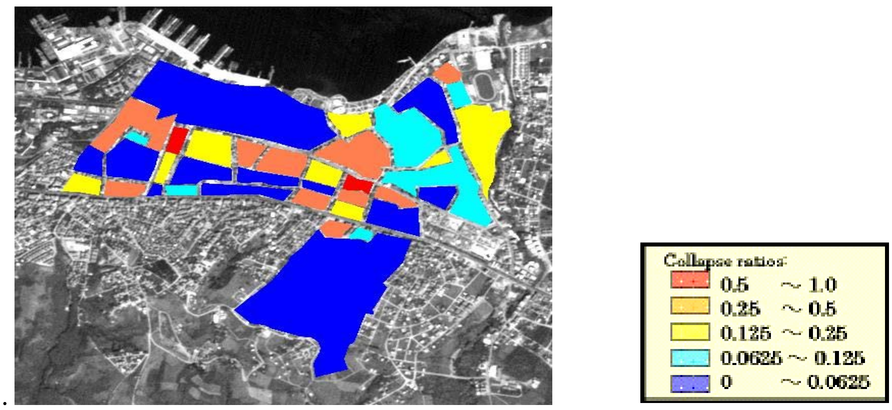

Fig. 5. Ground survey of collapse ratios superimposed to the IRS image (ground survey data have been kindly provided by Prof. Masashi Matsuoka, Earthquake Disaster Mitigation Res. Centre, Japan)

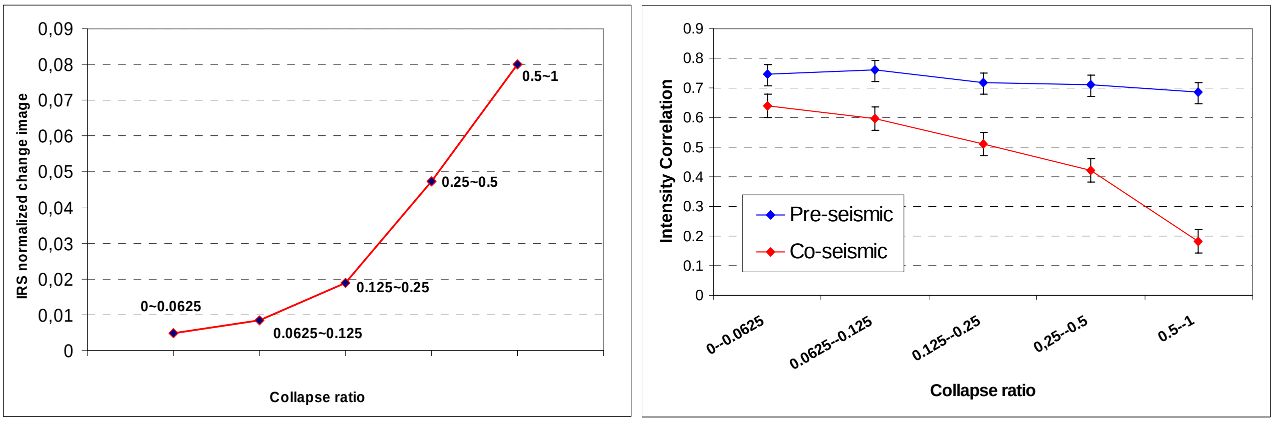

Fig. 6. Correlation between IRS change and SAR intensity correlation averaged over each surveyed area with area collapse ratio.

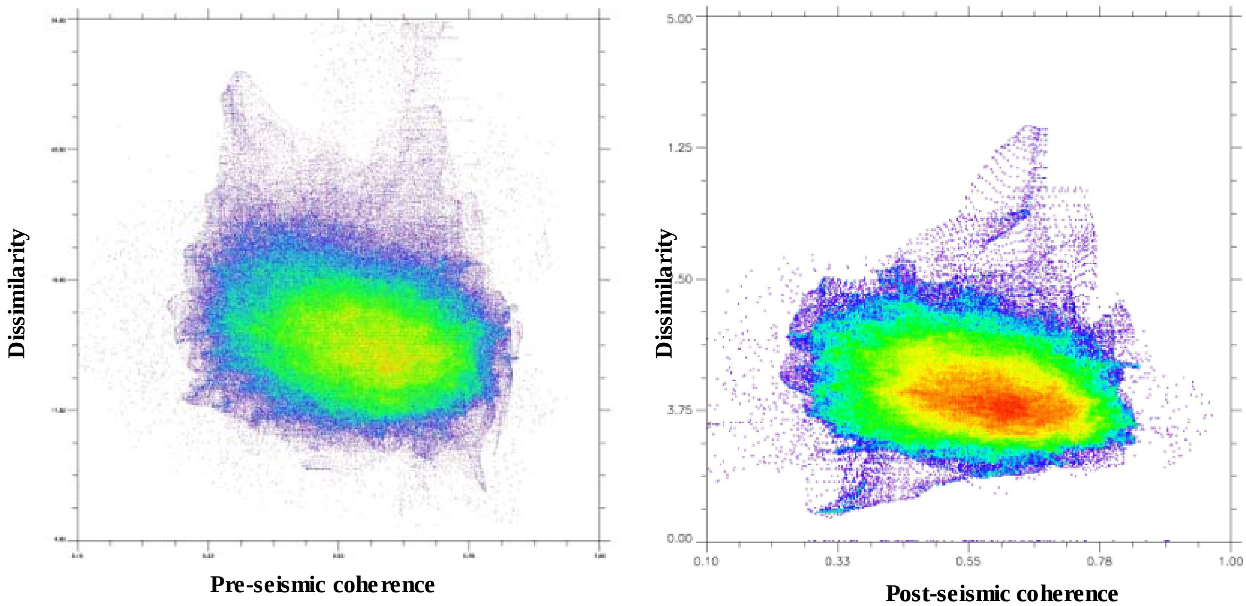

Fig. 7. Experimental dependence of InSAR coherence with IRS image texture (dissimilarity parameter)

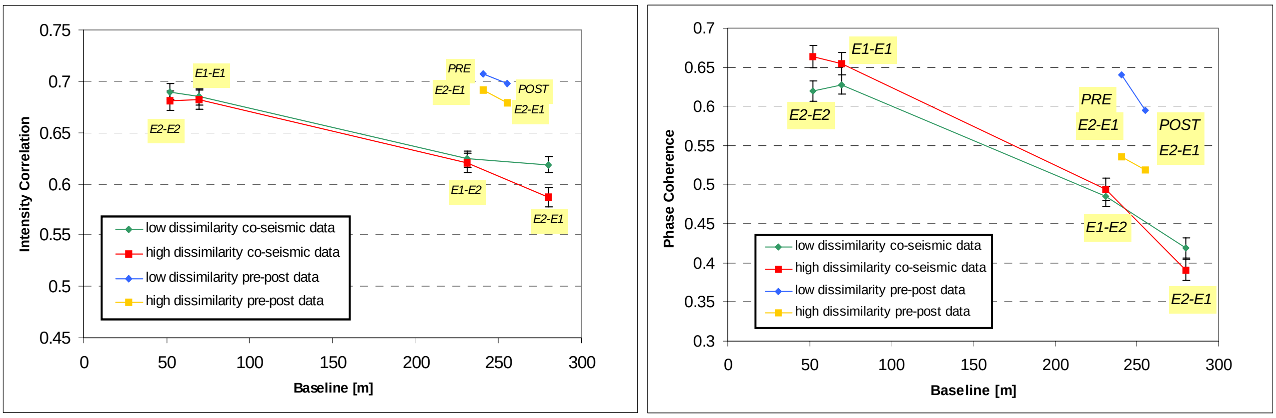

Fig. 8. Experimental dependence on SAR intensity correlation and InSAR coherence on baseline and dissimilarity. The greater sensitivity of InSAR coherence to those parameters is shown.

CONCLUSIONS

From the analysis of an InSAR data set co-registered to IRS images we have found the InSAR coherence can add information on urban damages to the optical data. SAR data alone do not provide valuable results and in particular the coherence seems to be less important than correlation of SAR intensity. The greater influence of other factors on the coherence, like urban texture and baseline, seems to explain this behaviour, even if more research should be done to verify this conclusion.

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