EARTHQUAKE DAMAGE MAPPING USING THE COHERENCE OF PERSISTENT SCATTERERS

Urs Wegmüller [(1)], Tazio Strozzi [(1)], and Charles Werner [(1)]

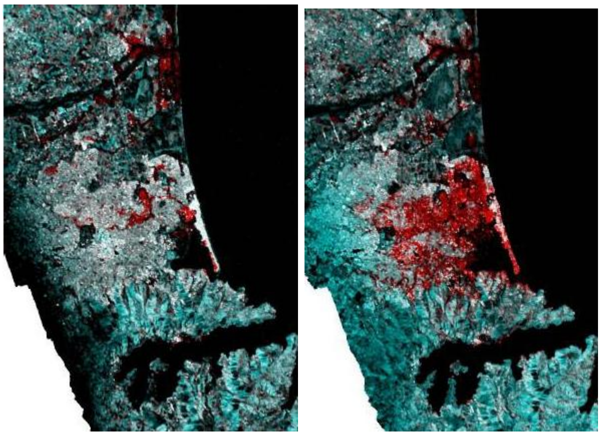
[(1)] *Gamma Remote Sensing, Worbstrasse 225, 3073 Gümligen BE, Switzerland*
tel: ++41 31 951 7005, fax: ++41 31 951 7008, e-mail: wegmuller@gamma-rs.ch

ABSTRACT

After an Earthquake earth observation methods can support the damage assessment. In this contribution we describe an earthquake damage mapping methodology that is based on the coherence of persistent scatterers using a stack of ENVISAT ASAR images. Comparing the damage map generated for Christchurch, New Zeeland, after the Darfield Earthquake on 3-Sep-2010 with liquefaction maps resulting from in-situ assessments indicates a good potential of this methodology in this case.

1. INTRODUCTION

Earth observation methods are regularly used to map damage after an earthquake. To map damage at individual building scale very high resolution optical or SAR data are used. One advantage of using very high resolution data is that damage may be determined without having a corresponding pre-seismic reference scene. High resolution SAR data (ENVISAT, PALSAR) showed in some cases good results at block scale. As an example Figure 1 shows such results for Christchurch, New Zealand, using PALSAR data. What is shown is the interferometric coherence reduction between a pre-seismic pair and a co-seismic pair. So in total 3 scenes, two before the earthquake and one after it are used.



M 7.0 on 4-Sep-2010 M 6.1 on 22-Feb-2011

Figure 1. Damage mapping over Christchurch, new Zealand, using PALSAR coherence reduction between a pre-seismic pair (shown as red channel) and a co-seismic pair (shown as green and blue channels).

The main objective of our work presented here is to assess if it is possible to also get damage information at single building scale when using high resolution SAR data. Persistent Scatterer Interferometry (PSI) provides deformation information for individual scatterers that relate in many cases to buildings. Considering a coherence measure on the persistent scatterers may therefore be a step towards achieving the stated objective.

In Section 2 the PSI based damage mapping methodology is described. Results achieved over Christchurch for the Darfield Earthquake on 3-Sep-2010 are then presented in Section 3, followed by discussion, and conclusions.

2. PSI COHERENCE REDUCTION BASED DAMAGE MAPPING METHODOLOGY

In Persistent Scatterer Interferometry (PSI) the temporal and spatial characteristics of interferometric signatures collected from temporally persistent point-like scatterers are exploited to accurately map surface deformation histories, terrain heights, and relative atmospheric path delays. The phase model used is identical to conventional differential interferometry. To use targets with point like scatter characteristics, only, has the advantage that there is far less geometric decorrelation for these targets. This permits phase interpretation even for large baselines above the critical one. Consequently, more image pairs may be included in the analysis improving the temporal sampling. Another important advantages is the potential to find scatterers in low-coherence areas permitting filling spatial gaps in the deformation maps. The point-like scatterers very often correspond to infrastructure as buildings, or other temporally rather stable targets as rocks. Due to their specific nature, targets with a point like scattering characteristics very often maintain coherence over long time periods. In an urban environment usually many persistent scatterers are present.

Before presenting the damage mapping methodology we need to consider the "coherence" in PSI. There is not a unique definition of coherence in PSI. To calculate a coherence value multiple interferogram values are necessary. Typically, the non-random phase terms are

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modeled and subtracted before calculating the coherence. In a PSI processing one coherence value regularly used is the "*temporal coherence*" that characterizes the random deviation of the phase values of a pixel from a modeled phase history. One way to calculate the temporal coherence is to consider only the phase values of a single scatterer. After subtracting terms as the topographic and atmospheric phase the coherence is calculated from the phase deviations from a (typically linear) phase model. Another way to calculate the temporal coherence is to consider the phase deviations from a spatially filtered phase. As a result the coherence does not only depend on the values of one scatterer, but also on its neighbors that are used as reference. Again a single temporal coherence value is calculated per scatterer. To characterize the coherence of a set of points in a single interferometric pair we use a "spatial coherence" that is calculated in the same way as in a 2D differential interferogram, but just considering the persistent scatterers in an area instead of all pixels. This "spatial coherence" indicates how much the residual phase values vary spatially. In areas with very high quality persistent scatterers the temporal coherence as well as the spatial coherence of each interferometric pair show values close to 1.0. Reasons for a reduced temporal coherence can either be generally reduce spatial coherence for all pairs (e.g. as a result of significant scatter fraction coming from the radar clutter) as well as a significant reduction for only a few pairs. If the coherence is too much reduced for too many pairs the scatterer is no longer considered a persistent scatterer and is therefore not included in the solution.

For the proposed damage mapping methodology we use a stack with many acquisitions before the earthquake and at least one acquisition after the earthquake. Considering the pre-seismic stack only we perform a PSI processing to determine corrected point heights, deformation histories and atmospheric phases. To include the post-seismic scene(s) we apply the point heights found and expand the pre-seismic deformation history to the post-seismic scene(s). The point differential interferogram for the co-seismic pair between the pre-seismic temporal reference and the post-seismic scene will include the co-seismic deformation phase and the atmospheric phase of the post-seismic scene. From this point differential interferogram we calculate the spatial coherence. For areas with severe damage this spatial coherence is significantly reduced. To better discriminate the seismic damage effects only we consider the coherence reduction relative to the spatial coherence of a pair before the earthquake. A high reduction in the spatial coherence (> 0.5) indicates the loss of the persistent scatterers which is a clear indication of significant damage.

3. RESULTS FOR THE DARFIELD EARTHQUAKE ON 3-SEP-2010

The described methodology was applied to a stack of ENVISAT ASAR data to get over Christchurch, New Zeeland, a damage indicator map for the Darfield Earthquake on 3-Sep-2010. A stack of 36 scenes before the earthquake and one scene after the earthquake, acquired on 17-Sep-2010 were used. To reduce noise several co-seismic pairs (each one including the only available post-seismic scene) were considered. For each selected co-seismic pair a pre-seismic pair with a similar spatial and temporal baseline was used as reference. The resulting PSI coherence change is shown in Figure 2 for a section of Christchurch. Red areas indicate a significant coherence reduction of more than 0.5 which is a strong indicator for damaged infrastructure. For comparison a map found on a New Zeeland government web-site [1] is shown in Figure 3. The red areas in the PSI coherence change map correspond well to liquefaction areas identified during in-situ surveys.

4. DISCUSSION OF POTENTIAL AND LIMITATIONS

Using a significant data stack to determine change between the last two observations appears as a tremendous effort. On the other hand PSI techniques are quite well established and using the entire stack instead of just two or three scenes adds some information. For the persistent scatterers a high coherence is confirmed over many different time intervals – consequently a strong reduction of the spatial coherence of more than 0.5 is a more clear indication that significant change occurred to the scatterer. And in-spite of the relatively coarse resolution the SAT data used (20m in ground range) the information is at single building level. But it is also clear that information is not available for every building. Another drawback concerning the spatial resolution of the PSI coherence reduction is that the estimation of a spatial coherence requires not just a single point but also its neighbors. Ideally, all the scatterers considered in such an estimation window would represent the same building. But at the ENVISAT resolution this is not the case - scatterers on neighboring building are usually also considered.

As a test we a applied the same methodology for other layers without damage from the earthquake. While few points with reduced coherence are identified for all scenes well within the data stack some areas with reduced PSI coherence are also identified for the first few scenes of the stack. Checking in Google Earth historic optical imagery over these areas indicates for some of these areas that the buildings were only built after the beginning of the time interval considered – so the scatterers were not yet present for the first scenes of the stack.

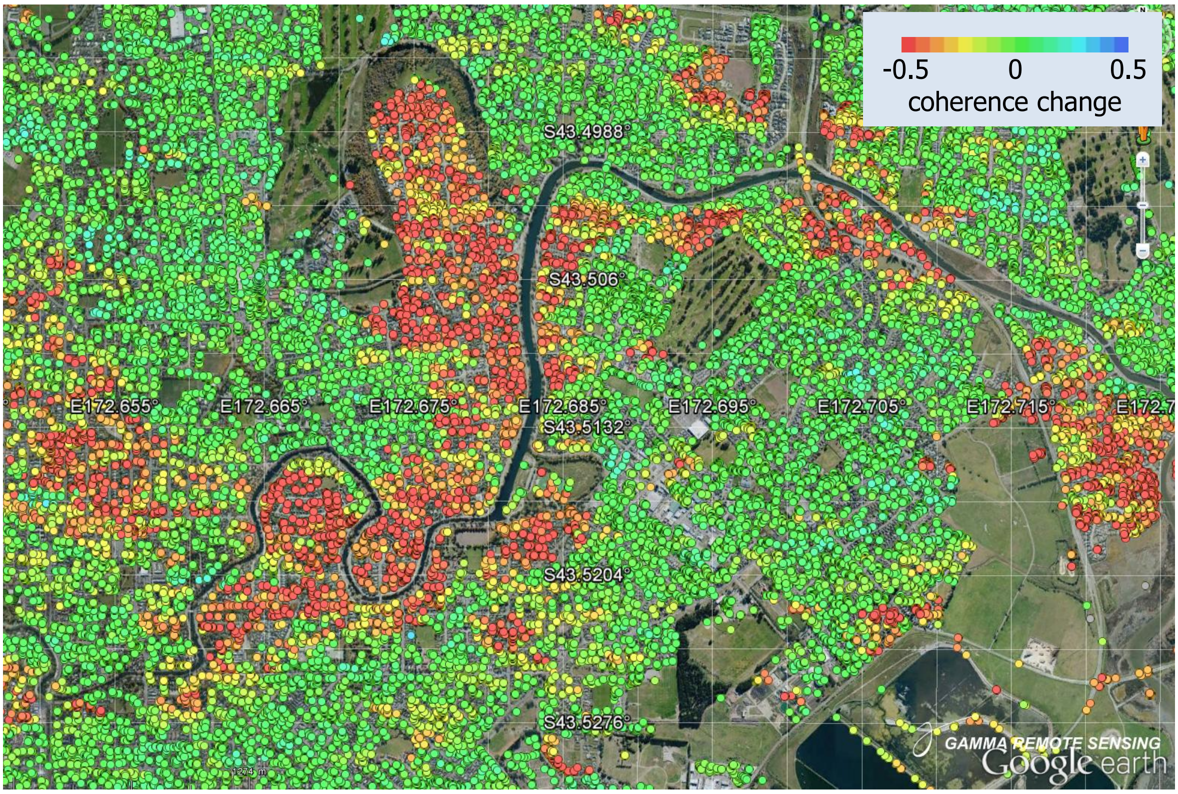

Figure 2. PSI coherence change (red indicates a strong coherence reduction) caused by the Darfield Earthquake on 3-Sep-2010 shown for a section of Christchurch, New Zealand, shown in Google Earth.

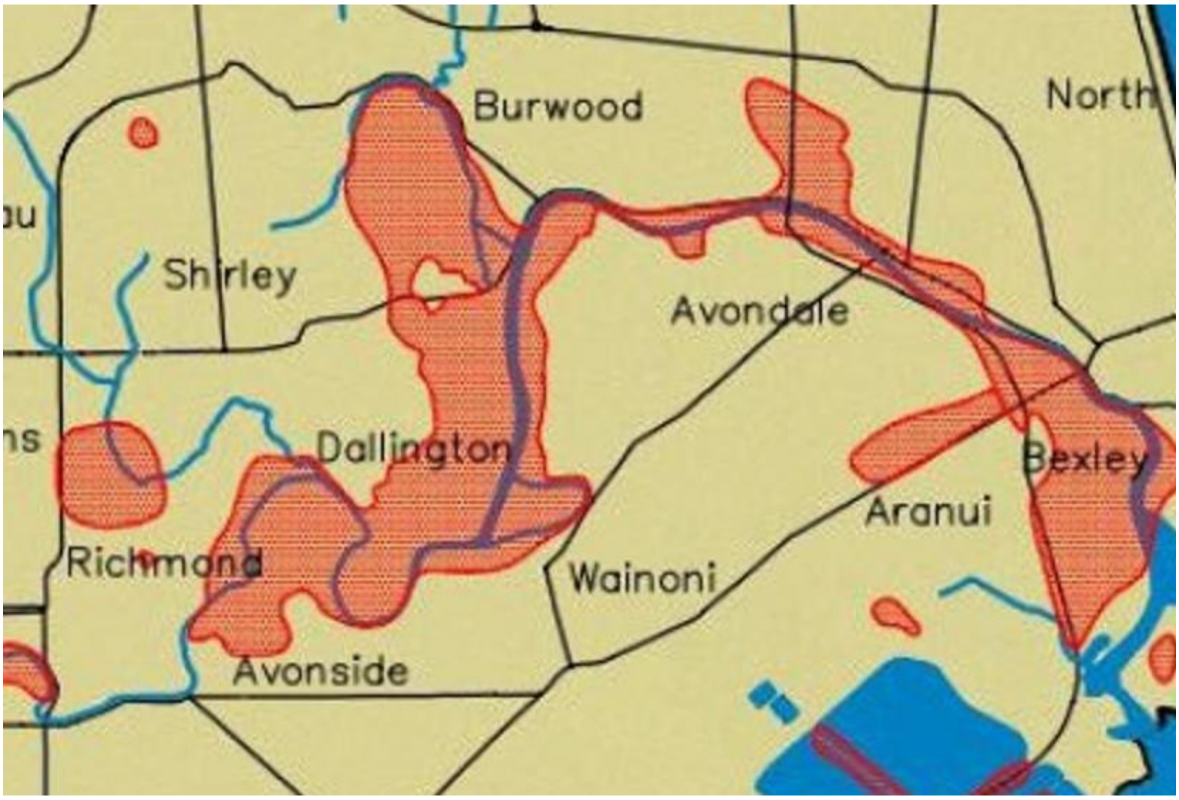

Figure 3. Red areas indicate "evidence of liquefaction visible at ground surface" as shown in the Geotechnical land damage assessment & reinstatement report (stage 1, Oct. 2010, as found on New Zeeland government web-site [1].

5. CONCLUSIONS

A methodology to map earthquake damage using high resolution ENVISAT SAR data was presented and discussed. In a first step a PSI spatial coherence is estimated. For this the same coherence estimator as used in differential interferometry, but only considering the values on persistent scatterers, is used. The difference of this spatial coherence of a co-seismic pair and a pre-seismic pair, ideally with a similar spatial baseline and time interval, is considered. A significant decrease of the PSI spatial coherence between the pre-seismic pair and the co-seismic pair is found to be a damage indicator. The methodology was applied to a data stack over Christchurch and used to get a damage indicator map for the Darfield Earthquake on 3-Sep-2010. The PSI coherence based result was compared with in-situ information available from a New Zealand Government web-site showing good correspondence. For residential areas identified in-situ as areas subject to liquefaction a significant PSI coherence reduction was observed, indicating a promising potential of the presented method and data stack in this case.

An advantage of considering persistent scatterers instead of 2D differential interferogram pixels is the higher level of the pre-seismic coherence. By definition the PSI coherence is high (otherwise the scatterers are not part of the point selection), in 2D DINSAR the coherence is not necessarily very high over a residential area because of the vegetation between the buildings. Consequently, decorrelation from damage is less obvious.

As an important limitation of the method we identified the fact that the spatial coherence estimation does not only depend on one persistent scatterer, but also on its neighbours. To significantly reduce the coherence random phase changes are required for the selected scatterer as well as for its neighbours. As a consequence it is also not really clear if the objective to get damage information at single-building scale can be reached with high resolution SAR data (e.g. ENVISAT) with this methodology. Furthermore, we can also imagine that damage may occur to a building without affecting its PSI phase, for example if the scatterer relates to a double bounce scattering on one wall of the building damage to another wall or to the roof will remain undetected.

To better understand the potential and limitation of the proposed method and possibly also to further improve it further cases should be investigated.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Geotechnical land damage assessment & reinstatement report by Tonkin & Taylor, (stage 1, Oct. 2010) at *www.eqc.govt.nz/sites/public_files/t-t-stage1.pdf* and alternatively also at *www.tonkin.co.nz/canterbury-land-information/docs/T&T-Stage%201%20Report.pdf*.