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Discussions

Interactive comment on "Calculation of coseismic displacement from Lidar data in the 2016 Kumamoto, Japan, earthquake" *by* Luis Moya et al.

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Thank you very much for your insightful review. We consider your comments in order to improve our manuscript. Details for each one are addressed below.

General comments: This manuscript presents a methodology to calculate co-seismic displacement using LIDAR data acquired after the recent earthquakes occurred in Kumamoto, Japan and the result were validated with ground motion records around. The proposed methodology represents a good alternative to monitor ground deformation using remote sensing data showing great potential to be used in disaster management and would be worthy of NHESS publication after minor revision.

COMMENT FROM REFEREE:

I would like to suggest going deeper in the literature review. For instance, one point that was not mention is the advantages and/or disadvantages of the proposed methodology compared with other methods considering several aspects such as data availability, data coverage, application for disaster management assessment

Author's response:

As recommended by the referee, we have increased the introduction, where we address his suggestions.

Author's changes in manuscript:

The extended information in the introduction was added from page 2, line 10 to page 3, line 32, as follows: " The airborne Lidar technology is an integrated system consisting of a Global Navigation Satellite System (GNSS), an Inertial Navigation System (INS) and a laser scanner, which sends pulses of laser light towards the ground and records the return time for calculating the distance between the sensor and the ground surface (Lillesand et al., 2004). Lidar has many applications in earthquake engineering, such as landslide detection (Jaboyedoff et al., 2012), and extraction of building features (Vu et al., 2003; Vu et al., 2009). Lidar data have been used in estimating ground displacement as well. Muller and Harding (2007) used the elevation of uplifted marine terraces mapped in the Lidar data to estimate the source parameter of the A.D. 900 Seattle fault earthquake. Sahakian et al. (2016) used Lidar data, in combination with other technologies such as seismic reflection, to identify a previously unmapped right-lateral strike-slip fault located in the Salton sea, California, U.S. They used the Lidar data to constrain the onshore deformation. Usually, only post-event Lidar data is available; thus, the coseismic displacement detection is limited to the identification of distortions of line features such as roads. Li et al. (2016) detected an offset of car tracks produced during the 2014 Mw 6.9 Yutian earthquake, Tibetan Plateau, by visual inspection. Chen et al. (2015) extracted two topographic profiles from Lidar data collected after the 1999 Mw 7.1 Hector Mine earthquake, California. The profiles were parallel to the fault-line and located on either side of the fault in order to estimate the slip during the earthquake. There are few cases in which Lidar data both before and after an earthquake were available. The first case was in the 2010 Mw 7.2 El Mayor-Cucapah earthquake. Oskin et al. (2012) performed a simple difference of elevation to estimate the surface rupture; however, they did not consider the horizontal displacement. Two more earthquake events: the 2008 Mw 6.9 Iwate-Miyagi earthquake and the 2011 Mw 7.1 Fukushima-Hamadori earthquake were monitored by Lidar data acquired before and after the event. Then Nissen et al. (2014) estimated the 3D displacement using the Iterative Closest Point (ICP) algorithm (Nissen et al. 2012). Their results showed a coherent displacement but with high level of noise in the horizontal component. Cross-correlation technique has been used successfully to monitor movements. Duffy and Hughes-Clarke (2005) applied cross-correlation to monitor the movements of sea–floor dunes using bathymetry data. Liu et al. (2011) extracted the shifts of vehicles between the panchromatic and multispectral QuickBird images, which were taken with a time lag of approximately 0.2 seconds, and then they estimated the vehicles' velocity. Liu and Yamazaki (2013) calculated the crustal displacement during the 2011 Mw 9.0 Tohoku earthquake by estimating the shift of undamaged buildings using the cross–correlation coefficient between the TerraSAR–X intensity images taken before and after the earthquake. Borsa and Minster (2012) evaluate the potential use of cross-correlation using Lidar data by applying a synthetic slip to the Lidar data of the southern San Andreas fault and then their result could recover the synthetic slip. Duffy et al. (2013) also used a pair of Lidar data taken before and after the 2010 Mw 7.1 Darfield, New Zealand earthquake to calculate the horizontal coseismic displacement. Measurements of the coseismic displacement in the near field is of great importance because it can be used to locate the source and to understand the rupture process. Wang et al. (2013) inverted the coseismic displacement calculated from GNSS and strong-motion stations to modulate the earthquake source of the 2011 Mw 9.0 Tohoku earthquake. Earthquake source inversion methods have become important in the last years because of its potential for forecasting tsunamis (Melgar and Bock, 2013). The

GNSS devices calculate positions and nowadays it is used for continuous monitoring of the earth crust. Strong-motion devices record acceleration or velocity, and in most of the cases, a baseline correction is required before estimating the correct displacement time history because the baseline is shifted as a result of several factors such as ground rotation and rocking movements of the instrument. The displacement time history can be calculated precisely if the six components, three translational and three rotational, are recorded (Graizer, 2010). However, the displacement time history is often estimated by a double integration of only the translational components with respect to time. Up to now the source of errors and the rotation components cannot be quantified and only empirical methods have been proposed in the past to reduce the effect of the baseline shift and retrieve a reliable displacement time history. One of the first method was proposed by Iwan et al. (1985), in which a bilinear function is used to estimate the velocity trend caused by the baseline errors. Several modifications of this approach have been proposed. Wu and Wu (2007) defined the bilinear function in an iterative process in a way that the displacement time history best fits a ramp function. Later, Wang et al. (2011) also proposed an iterative procedure; but they used a step function to constrain the displacement time history. Moya et al. (2016) used a pair of strong-motion records that were closely located and perform a simultaneous correction of both records. Although there have been a great improvement and deployment of GNSS and strong-motion networks, even the densest network, either GNSS or strong-motion, has a low spatial resolution. For instance, the nationwide GNSS network of Japan has one station in an about 20-km interval. Thus, for an earthquake of moderate magnitude, where the coseismic displacement is concentrated in a narrow area, it is difficult to depict the spatial pattern of coseismic displacement. SAR satellite images offer a better spatial resolution, but it requires a pair of images with the same viewing condition to calculate the coseismic displacement to the line-of-sight (LOS) of radar. More pairs of SAR images from different views, which are not very realistic, are required to obtain 2.5 D or 3D coseismic displacement. Another use of coseismic displacement comes up when the effects of an earthquake in the near field are estimated using remote sensing techniques. It is necessary to consider the permanent displacement if an automatic change detection is applied to extract collapsed buildings or quantify the mass movement in landslides."

Specific comments:

COMMENT FROM REFEREE:

Page 2, line 17: Since this method calculates the permanent displacement based on two different DSM scenes, it would be interesting to mention the time of acquisition of the LIDAR data.

Author's response:

In accordance with the referee's comment, we added this information.

Author's changes in manuscript:

Page 4, line 1

COMMENT FROM REFEREE:

Page 4, line 23: Please, explain why the original data was interpolated to 10 cm, and why not to 25 cm or 5 cm? Is any optimal spatial resolution considering factors such as detail of analysis, computational power?

Author's response:

As pointed out by the referee, the main reason was the computational power.

Author's changes in manuscript:

The sentence was modified and is located in page 6, line 8: "...The pixel resolution was increased from 50 cm to 10 cm by using the cubic convolution method, where a bicubic function is fitted using 4x4 pixels neighborhood and used to estimate the intermediate values. The subpixel size was decided based on the computational effort that is required to detect the peak value of the correlation coefficient...."

COMMENT FROM REFEREE:

Page 4, line 29: I understand why 201 x 201 pixel window was chosen, it however does not clearly explain why largest windows size can not be used too. Related with the previous comment, it would be interesting to see what is the relationship between the pixel size and the window size.

Author's response:

Indeed the use of larger window-size is possible, however, it will reduce the resolution of the coseismic displacement. We address this in page 5, line 28: "However, there exists a trade-off between the size of the window and resolution because the resolution of the spatial variation of the coseismic displacement decreases with the increase in the size of the window." With respect of the relationship of the pixel size and the window size. We believe that what is more important is the amount of different features that can be covered in the window size. Because it will help to detect the peak value of the correlation coefficient. For sure, the resolution of the pixel is relevant to define the features; but, we believe that a pixel size of 50 x 50 cm is enough to clearly define features such as buildings, trees, and changes in topography. This issue is stated in newly added Discussion section in Page 8.

Author's changes in manuscript:

Page 8, line 28: "...From the evaluation of the parameters used, the results were found to be highly sensitive to the window size. Basically, it is crucial that the windows have to cover several features, such as buildings, trees and different topography, in order to obtain a clear peak value in the correlation coefficient (Error! Reference source not found.c). This issue was our main concern in agricultural fields because large areas have uniform elevation. In this study, a constant window size was used; however, if the land use information is available, different window sizes can be applied. For instance, in urban areas the window size can be smaller than that for agricultural lands..."

COMMENT FROM REFEREE:

Page 6, line 26: Considering that a 201 x 201 pixel window is used to calculate the co-seismic deformation, please explain what is the selection criterion of the value from the DSM result that is compared with the displacement time history. On other words, is the value at the location of the seismic station used in this comparison?

Author's response:

Yes, the coseismic displacement from Lidar data used in the comparison comes from the window that contains the strong-motion station.

Author's changes in manuscript:

We modified the sentence to clarify this question. We appreciate the referee for this suggestion. Page 8, line 3: "…The coseismic displacement calculated from the Lidar data at the same location of the strong-motion station, shown as a black thick line…"

COMMENT FROM REFEREE:

Page 7, line 5: Although, the Figure 13 does show good agreement of the co-seismic displacement between the result using LIDAR data and the ground motion records, a quantitatively validation would be more convincing. For instance, the result of this methodology can be correlated with the result obtained from DInSAR analysis of PALSAR-2 data conducted by the Geospatial Information Authority of Japan (http://www.gsi.go.jp/BOUSAI/H27-kumamoto-earthquake-index.html).

Author's response:

The comparison of our results from the Lidar data with the coseismic displacements from strong-motion records is quantitative. Besides, we consider that the comparison with the displacement measured at the surface rupture points in the field surveys is conclusive considering that this is tangible information. We showed the comparison with the figures for better understanding. With all due respect we believe that a com-

parison of our results with SAR data will not contribute so much to our manuscript. As stated in Introduction, DInSAR results are to the line-of-sight (LOS), not the 3D displacement.

Author's changes in manuscript:

No changes.

Minor changes

COMMENT FROM REFEREE:

Page 1, line 29: Change "…Japan Aerospace…" to "… The Japan Aerospace…"

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located at page 1, line 29.

COMMENT FROM REFEREE:

Page 1, line 30: Change "…sensor PALSAR-2…" to "…PALSAR-2 sensor…"

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located at page 1, line 30.

COMMENT FROM REFEREE:

Page 2, line 4: Change "…the authors of this paper…" to "…we…"

Author's response:

With all due respect to the referee, we prefer to keep the original version.

Author's changes in manuscript:

No changes.

COMMENT FROM REFEREE:

Page 2, line 4: Change "...calculated the spatial coherence values (International Charter, 2016), which could highlight the extensive landslides and severe damages to buildings 5 along the Futagawa fault line. ..." to "...calculated the coherence image that shows the extensive landslides and severe damages to buildings 5 along the Futagawa fault line (International Charter, 2016). ..."

Author's response:

With all due respect to the referee, we prefer to keep the original version.

Author's changes in manuscript:

No changes.

COMMENT FROM REFEREE:

Page 2, line 6; Change "...earthquake, the government agencies..." to "...earthquake, government agencies..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 2, line 7.

COMMENT FROM REFEREE:

Page 2, line 7; Change "...As well as..." to "...such as..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 2, line 8.

Comment from referee:

Page 2, line 8: Delete "...were also conducted..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 2, line 9.

COMMENT FROM REFEREE:

Page 2, line 17: Change "...one just after..." to "...one soon after..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 1.

COMMENT FROM REFEREE:

Page 2, line 18: Change "...is available..." to "...were used..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 2.

COMMENT FROM REFEREE:

Page 2, line 22: Change "...a day after..." to "...one day after..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 7.

COMMENT FROM REFEREE:

Page 2, line 24: Change "...Furthermore, because of an unexpected..." to "...Due to the..."

Author's response:

With all due respect to the referee, we prefer to keep the original version.

Author's changes in manuscript:

No changes.

COMMENT FROM REFEREE:

Page 2, line 25: Change "...acquire the Lidar data..." to "...acquire Lidar data..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 10.

COMMENT FROM REFEREE:

Page 2, line 28: Change "... For the sake of brevity,..." to "...Here,..."

Author's response:

With all due respect to the referee, we prefer to keep the original version.

Author's changes in manuscript:

No changes.

COMMENT FROM REFEREE:

Page 2, line 31: Change "...most parts of the town of Mashiki and a few parts of the town of Kashima, the town of Mifune,..." to "...most parts of the Mashiki town and a few parts of Kashima town, Mifune town..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 16.

COMMENT FROM REFEREE:

Page 3, line 15: Change "...more clear evidence..." to "...more clearly evidence..."

Author's response:

Considering the referee's comment, we have change the sentence to "...a clearer evidence..."

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 4, line 32.

COMMENT FROM REFEREE:

Page 3, line 15: Change "...an overlap..." to "...color composite image..."

Author's response:

The referee is right to point out that the technical word is color composite image. However, since NHESS gathers readers from different disciplines, we prefer to show the definition rather than the technical term..

Author's changes in manuscript:

No changes.

COMMENT FROM REFEREE:

Page 5, line 7: Change "...occurred because of the mainshock..." to "...occurred as a result of the mainshock..."

Author's response:

In accordance with the referee's comment, we have change the sentence.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 6, line 25.

COMMENT FROM REFEREE:

Page 13, line 2: Please add north direction at Figure 4

Author's response:

In accordance with the referee's comment, we have modified the Figure 4.

Author's changes in manuscript:

The change is located in the new version of the manuscript at page 16, line 1.

Please also note the supplement to this comment:

http://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2016-315/nhess-2016-315-AC2-supplement.pdf

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Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-315, 2016.