[Authors' Response for nhess-2016-285]

Editor Decision: Reconsider after major revisions (further review by Editor and Referees) (26 Nov 2016) by Prof. Dr. Paolo Tarolli / Comments to the Author:

Dear Authors, your paper has been revised by two reviewers. They raised several critical issues that need to be fixed before the publication. You provided a detailed feedback during the NHESS open discussion. I think you should have a chance to propose a revised version of your work. My recommendation is to accept this paper after major changes.

In submitting your revised version, please provide a detailed list of the changes made to the text, and a detailed list of your responses to the reviewers' comments.

Please note that this editorial decision does not guarantee that your paper will be accepted for final publication in NHESS. A decision will be made when the revised version will be available, and will be evaluated with the help of the same, or further reviewers.

Best regards / Paolo Tarolli

The authors appreciate continuous handling of this manuscript on NHESS. The manuscript was revised as follows. Revised parts are colored in red in a new manuscript and their pages and lines are denoted in a bold font in this document.

Reply comments (AC1) for the interactive comments on "Multiple remote sensing assessment of the catastrophic collapse in Langtang Valley induced by the 2015 Gorkha Earthquake" by Hiroto Nagai et al.

The authors thank the anonymous referee #1 for his/her valuable comments. We improved the manuscript according to his/her comments as following:

General comments

This paper demonstrated an assessment of the sediments caused by a catastrophic avalanche, using Remote Sensing data, such as, ALOS-2, WorldView-3, ALOS World 3D, etc. The topic of this manuscript is quite interesting, because L-band (PALSAR-2) could penetrate the cloud and vegetation. In fact, catastrophic collapse (earthquake, debris flow, landslide, etc.) always seem to be associated with rain and vegetation. So, PALSAR-2 have a great potential to immediately indicate a catastrophic collapse and contribute to decision-making for such hazards in the monsoon season. However, this manuscript need more information to illustrate its conclusions. Below, I comment on the few things which I think can be improved.

We improved our manuscript especially to clarify what was already known for this hazard, what remote-sensing techniques which we used can identify the mountain hazard, and what we can mention from the technique for this specific hazard.

Specific comments

(1) "Introduction", in this section, introduced too many information about study site (move it to the 2.1 section), but lack the background and innovation to this research, it can't attract the reader's interest immediately.

We moved "The Langtang Valley is one of…**[previous: P02L05-L09]**" to the end of the section 2.1. **[new: P02L30]**. In terms of describing our motivation, we already know that was a catastrophic avalanche event including debris and glacier ice which completely destroyed a mountain village (Kargel et al., 2015; Fujita et al., 2016; Lacroix, 2016). Here we aim to emphasize detail information (further than saying "avalanche") and what aspect can be identified using remote sensing techniques for such a catastrophic avalanche event. We added here;

> **[new: P02L07]** *"Damage detection through SAR technique has been applied for urban damaged areas (e.g., Kobayashi et al, 2011; Yonezawa and Takeuchi, 2001; Tamura and El-Gharbawi, 2015; Watanabe et al., 2016), but almost no case for a large-scale mountain hazard was studied. We apply SAR damage detection for the avalanche case. In addition, a detailed interpretation of the damaged area by means*

of high-resolution optical satellite imagery coupled with sediment volume estimation would provide detailed features of this avalanche. In this study…"

(2) "2.1 study site", I think you'd better add a location map of study site to help to understand where is it.

We added a location map with satellite coverage as **Fig. 1**.

(3) "2.2 Synthetic aperture radar imagery", just defined normalized coherence decrease (NCD), didn't explain what is Coherence calculation and how to calculate it, in addition, you can't leave out the process and method to noises filter, it's too brief in this part.

<Coherence calculation and its normalization >

We added further information on the paragraph from **P03L12** "Not only…":

Not only the amplitude imagery but also the phase information emitted and received by the synthetic aperture radar (SAR) contributes to the situational awareness. We performed coherence calculation using interferometric phase information of SAR, which was explained by Plank (2014) in detail. Coherence can be calculated from two SAR images observing an identical place twice from the same orbit and incidence angle, thereby achieving similar phase and intensity information of the receiving microwave, which is calculated for a pair of SAR images by

$$\gamma = \frac{E\langle c_1 c_2^* \rangle}{\sqrt{E\langle c_1 c_1^* \rangle E\langle c_2 c_2^* \rangle}} \qquad (1)$$

where c_1 and c_2 are the corresponding complex-valued pixels of the two images, c^* is the complex conjugate of c, and E indicates the expected value. The detailed mathematical procedure is described in Touzi et al. (1999) and López-Martínez and Pottier (2007). A significant change in surface feature between two observations results in lower coherence (in other words, lower similarity). Other noisy influences, including vegetation growth, can be reduced by calculating normalized differences with a coherence calculated from two pre-hazard images. The normalized coherence decrease (NCD) is calculated as

$$\gamma_{diff} = \frac{\gamma_{pre} - \gamma_{\mathrm{int}}}{\gamma_{pre} + \gamma_{\mathrm{int}}} \qquad (2)$$

where γ_{pre} is the coherence value between two images before the earthquake (October 4, 2014 and February 21, 2015), and γ_{int} is the coherence value between the two images over the earthquake (February 21 and May 2, 2015). These data were acquired from a same orbit with a spatial resolution of 10 m. When γ_{diff} is calculated *for images over a hazard, higher-valued pixels of γ_{diff} indicate the reduction of the similarity, which has high potential of hazard-induced deformation or destruction. Several previous studies applied this method using L-band SAR for damage detection in urban areas (e.g., Kobayashi et al., 2011; Yonezawa and Takeuchi, 2001; Tamura and El-Gharbawi, 2015; Watanabe et al., 2016), but no such study applied this method for mountain hazard. Throughout this study, we aim to emphasize the possibility of normalized conference difference by using L-band SAR for damage detection in mountain regions.*

<Noise filtering>

We added further information and a figure **(Fig. 2)** on the paragraph from **P04L03**;

Numerous noises are removed by focal statistics. In the NCD raw image, all pixel values are overwritten by the mean values within 15-pixel circles around each pixel (Fig. 2). This filter emphasizes the concentration of high values, whereas the homogeneously scattered high values are de-emphasized. The detailed steps are as follows:

1. *The radius of a window circle is set as 15 pixels.*
2. *A mean value of the pixels in a circle is calculated.*
3. *The mean value is placed in the center pixel of the circle.*
4. *Moving the circle, every pixel on the output image is filled with the mean values in the same way.*

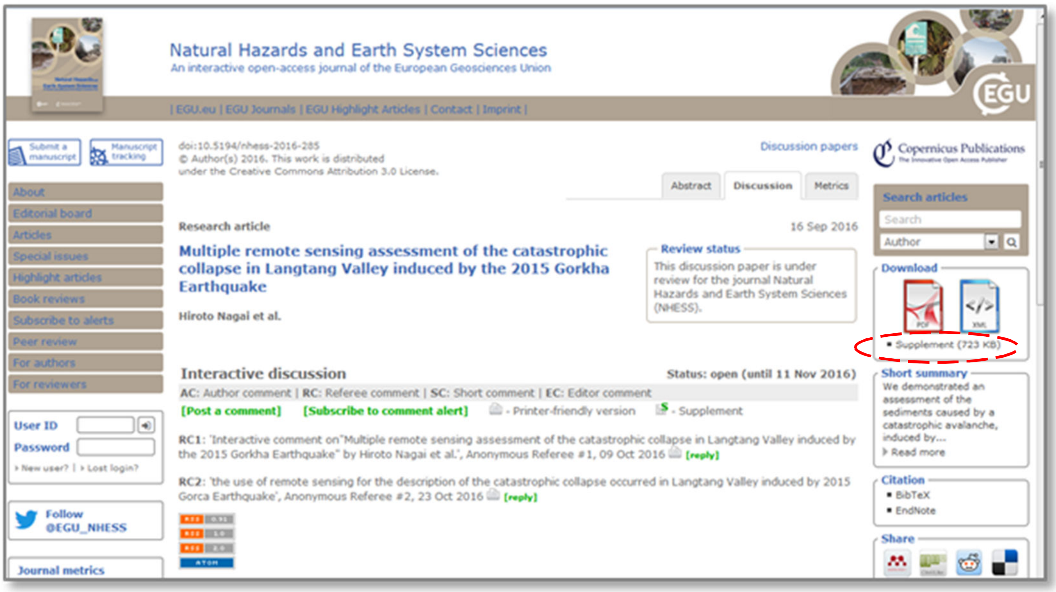
(4)" 2.4 Post-event optical imagery and DSM", the post-event DSM is very important to calculate the sediments volume, this paper just said "was produced by NTT DATA as its commercial service", obviously it's not enough, And "relative calibration/validation of this DSM and the AW3D DSM was performed and summarized in a supplementary material", I didn't find the supplementary material.

We understand. After that sentence we added further information as;

[P04L29] *The DSM is generated by stereo photogrammetric method using two WV-3 images acquired on May 8, 2015 using stereo-area-collect mode (26.2 km swath, 112 km path). Two images that are (1) forward looking with cross-track tilting to the west hand (i.e., average off-nadir angle: 27º, average target azimuth: 245º /scene id: 104001000BA62E00) and (2) backward looking with cross-track tilting to the west hand (i.e., average off-nadir angle: 27º, average target azimuth: 319º /scene id: 104001000B3B2300) were acquired. Spatial resolution after cross-track tilt was 0.38 m, coarsened from 0.31 m because of tilting. DSM generation flow (i.e., stereo matching,* *RPC ortho-rectification, pixel resampling, and DSM data output) was performed by NTT DATA with their original software, where the geo-referencing process was supported by WV-3 accurate orbit information without any in-situ ground control point and a resampled pixel spacing of 2 m. Officially announced specification shows a vertical accuracy of 4 m and a horizontal accuracy of 5 m as root mean square errors. In two sites that are neighboring the sediment surface, relative calibration/validation of this DSM and the AW3D DSM was performed and summarized in a supplementary material, in which a standard deviation error of 1.5 m between WV-3 and AW3D DSM is reported. A pan-sharpened image (high-resolution and composite-color image) generated from one scene of the pair was orthorectified by an author with 178 tie points onto the PRISM image taken on October 12, 2008.*

Acknowledgement contains new mention for cooperation by NTT DATA **[P10L16]**.

The supplementary material is provided from the right column here (circled in red below).



(5) Is it possible to do field survey to verify the results?

Fujita et al. (2016) performed an in-situ survey. They estimated the total volume of the avalanche sediment as 6.81×10^6 m^3, which is 109% of what we estimated. We added their information to the discussion chapter;

[P09L21] *Furthermore, Fujita et al. (2016) performed an in-situ survey from which they estimated the total volume of the avalanche sediment as 6.81×10^6 m^3, which is 109% of what we estimated. Thus, a comparison with the satellite-based studies by*

Kargel et al. (2015) and Lacroix (2016) indicates that our estimated sediment volume is within the most equivalent order to that from the in-situ measurement by Fujita et al. (2016).

(6) Improve the quality of the figures

We have higher resolution figures in the revised version.

Reply comments (AC2) for the interactive comments on "Multiple remote sensing assessment of the catastrophic collapse in Langtang Valley induced by the 2015 Gorkha Earthquake" by Hiroto Nagai et al.

The authors thank the anonymous referee #2 for his/her valuable comments. We improved the manuscript according to his/her comments as following:

In this manuscript, the authors describe the use of different remote sensing approaches for the identification of the effects of the 2015 Gorka Earthquake. In my opinion, the topic is very interesting and suitable for this journal, but the manuscript could be considered ready for the publication only after major revisions. In the following some suggestions for the authors:

We improved our manuscript especially to clarify what was already known for this hazard, what remote-sensing techniques which we used can identify the mountain hazard, and what we can mention from the technique for this specific hazard.

Page 1 line 30: in the abstract the authors describe an avalanche and they introduce that the paper will be focused on it. After, in the introduction, they introduce the presence of avalanche, but also landslides and other gravitational processes. For the reader is not very easy to understand which what happened in this area and then to follow the authors in the description of their work. I suggest to rewrite the introduction and to describe better the effects of the earthquake. Starting from the avalanche it is important to define if it is an ice avalanche from glaciers or rock avalanche or another more complex phenomenon. A good definition of the effects of the earthquake is fundamental to give to lectors the possibility to evaluate the effectiveness of the approach proposed by the authors.

We are sorry for this complicated expression. Now most of the material is considered as an avalanche including numerous boulders (debris) and possibly involving glacier ice along the path. To review this proceeding, further information and a figure **(Fig. 5)** was attached at the beginning of section 4.2. as;

> **[P08L27]** *At an early time, Kargel et al. (2015) defined this event as a landslide, but they also mentioned "co-seismic snow and ice avalanches and rockfalls" with an image of lower surface temperature observed by Landsat-8 thermal infrared sensor. Lacroix (2016) defined it as a debris avalanche composed mostly of ice and discussed its triggers around the mountain ridge above two glaciers. Fujita et al. (2016) confirmed sediment boulders on the surface, including melting ice (Fig. 7) and rapid surface lowering after the quake, through an in-situ survey, thereby suggesting that contained ice and snow were melting under the debris. Fujita et al. (2016) concluded*

that extremely heavy snowfall before the quake increased its volume, a finding that was coupled with weather station data. Therefore, we think this event should be defined as "a catastrophic avalanche event including debris and glacier ice" in our introduction. Our finding from the interpretation of a high-resolution WV-3 image suggests several layers of the sediment. Multiple segments of the collapsed sediment classified with a WV-3 image imply different sediment sources that have fallen continuously in a short period of time, generating sediment layers (Fig. 5). We could…

Also a new sentence was added to the abstract as;

[P01L19] *Our findings suggest that the avalanche event did not supply a homogeneous snow-and-ice material with debris but supplied multiple kinds of sediments from sequential collapse in a short period.*

Page 2 from line 7: The introduction describe what the authors want to describe in the manuscript, I'm not sure that the authors really satisfy this objectives. For this reason, I strongly suggest the authors to check the text and control that they describe all this topics.

We moved "The Langtang Valley is one of…**[previous: P02L05-L09]**" to the end of the section 2.1. **[new: P02L30]**. In terms of describing our motivation, we already know that was a catastrophic avalanche event including debris and glacier ice which completely destroyed a mountain village (Kargel et al., 2015; Fujita et al., 2016; Lacroix, 2016). Here we aim to emphasize detail information (further than saying "avalanche") and what aspect can be identified using remote sensing techniques for such a catastrophic avalanche event. We added here;

[new: P02L07] *"Damage detection through SAR technique has been applied for urban damaged areas (e.g., Kobayashi et al, 2011; Yonezawa and Takeuchi, 2001; Tamura and El-Gharbawi, 2015; Watanabe et al., 2016), but almost no case for a large-scale mountain hazard was studied. We apply SAR damage detection for the avalanche case. In addition, a detailed interpretation of the damaged area by means of high-resolution optical satellite imagery coupled with sediment volume estimation would provide detailed features of this avalanche. In this study…"*

Page 2 chapter 2.1: the description of the study area is very short and poor. I suggest that the authors consider the possibility to improve both the geological and geomorphological aspect of the study area.

We added geological and geomorphological information as;

[P02L24] *The Lantang valley consists of the Gosainkund gneiss zone (various gneisses and granitic migmatite) and the Langtang Himal migmatite zone (medium-grained garnet-mica-gneiss of granitic composition and coarse-grained augen-gneiss) (Arita et al. 1973; Shiraiwa and Watanabe 1991). Six successive glacial stages were recognized from an in-situ dating survey on moraine compositions (Shiraiwa and Watanabe 1991; Shiraiwa, 1994). Relatively extensive glaciation in the Langtang Stage (3650–3000 yr BP) is suggested in the late Quaternary. Permafrost is not highly expected in this valley because of the large amount of winter snow, which prevents deep freezing in winter (Shiraiwa, 1994).*

Page 4 chapter 3: this is the most important part of the paper, but it is also very hard to understand. Since it was not presented in the introduction a good description of what occurred in this area, now it is very critical for readers to understand what the authors have found. I suggest to rewrite this part of the article and to start the description from the evidence of the gravitational phenomena that caused the disaster and then to describe the effect in the lower part of the slope. One of the main limitation of this paper is that authors concentrate their description on the technical description of satellite images and results, but they did not pay too much attention to the description of the occurred events. I know that a correct reconstruction of the sequence of events is very hard, but I also think that if you want to present a methodology that use multiple remote sensing systems to describe the catastrophic collapse in Langtang Valley, at the end is mandatory have a description of the collapse and the sequence of events reconstructed by authors.

An avalanche including numerous boulders (debris) and possibly involving glacier ice occurred. Overview of this event has already been summarized in the introduction chapter from **[P02L01]**. In addition, already known findings are reviewed at **[P08L27]** as noted above. The results chapter is constructed by what we additionally found from satellite observations highlighting technical topics, and instead we renamed chapter 4.2. as "Details of the avalanche event" to integrate what was already known and what we found, aiming new insight.

Additional references (for AC1 and AC2):

Fujita, K., Inoue, H., Izumi, T., Yamaguchi, S., Sadakane, A., Sunako, S., Nishimura, K., Immerzeel, W. W., Shea, J. M., Kayashta, R. B., Sawagaki, T., Breashears, D. F., Yagi, H., and Sakai, A.: Anomalous winter snow amplified earthquake induced disaster of the 2015 Langtang avalanche in Nepal, Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-317, in review, 2016.

López-Martínez, C., & Pottier, E. (2007). Coherence estimation in synthetic aperture radar data based on speckle noise modeling. Applied optics, 46(4), 544-558.

Plank, S. (2014). Rapid damage assessment by means of multi-temporal SAR—A comprehensive review and outlook to Sentinel-1. Remote Sensing, 6(6), 4870-4906.

Touzi, R., Lopes, A., Bruniquel, J., & Vachon, P. W. (1999). Coherence estimation for SAR imagery. IEEE Transactions on Geoscience and Remote Sensing, 37(1), 135-149.

Shiraiwa, T., & Watanabe, T. (1991). Late Quaternary glacial fluctuations in the Langtang valley, Nepal Himalaya, reconstructed by relative dating methods. Arctic and Alpine Research, 404-416.

Shiraiwa, T. (1994). Glacial fluctuations and cryogenic environments in the Langtang Valley, Nepal Himalaya. Contributions from the Institute of Low Temperature Science. Series A, 38, 1-98.

Watanabe, M., Thapa, R. B., Ohsumi, T., Fujiwara, H., Yonezawa, C., Tomii, N., & Suzuki, S. (2016). Detection of damaged urban areas using interferometric SAR coherence change with PALSAR-2. Earth, Planets and Space, 68(1), 131.