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 will improve 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 will improve our manuscript especially to clarify what is already known for this hazard, what remote-sensing techniques which we used can identify for 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 remove "The Langtang Valley is one of…in the future. [P02L05-L09]". 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 would like to emphasize what was happened there (further information than saying "avalanche") and what aspect can be identified using remote sensing techniques for such a catastrophic avalanche event. We will add here;

"Damage detection by remote-sensing SAR technique has been applied for urban damaged area (e.g. Kobayashi et al, 2011; Yonezawa and Takeuchi, 2001; Tamura and El-Gharbawi, 2015; Watanabe et al., 2016), but almost no case for huge-scaled mountain hazard was done. Then we apply the SAR technique of damage detection for the avalanche case. In addition, detail interpretation of the damaged area by means of

high-resolution optical satellite imagery coupled with sediment volume estimation would suggest detail feature 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 add a location map with satellite coverages before 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 would like to add further information on the paragraph from P03L03 "Not only…":

- 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 same orbit and an incidence angle.
- Coherence means similarity in terms of phase and intensity information of receiving microwave which is calculated for a pair of SAR images by

$$\gamma = \frac{E\langle c_1 c_2^* \rangle}{\sqrt{E\langle c_1 c_1^* \rangle E\langle c_2 c_2^* \rangle}}$$

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. Detail mathematical procedure is described in Touzi et al. (1999) and López-Martínez and Pottier (2007).

- Great change of surface feature between two observations results in lower coherence (lower similarity, in other words).
- Other noisy influences including vegetation growth can be reduced by calculating normalized differences with a coherence calculated from pre-hazard two images. The normalized coherence decrease is calculated as;

$$\gamma_{diff} = \frac{\gamma_{pre} - \gamma_{int}}{\gamma_{pre} + \gamma_{int}}$$

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 those over the earthquake (February 21 and May 2, 2015).

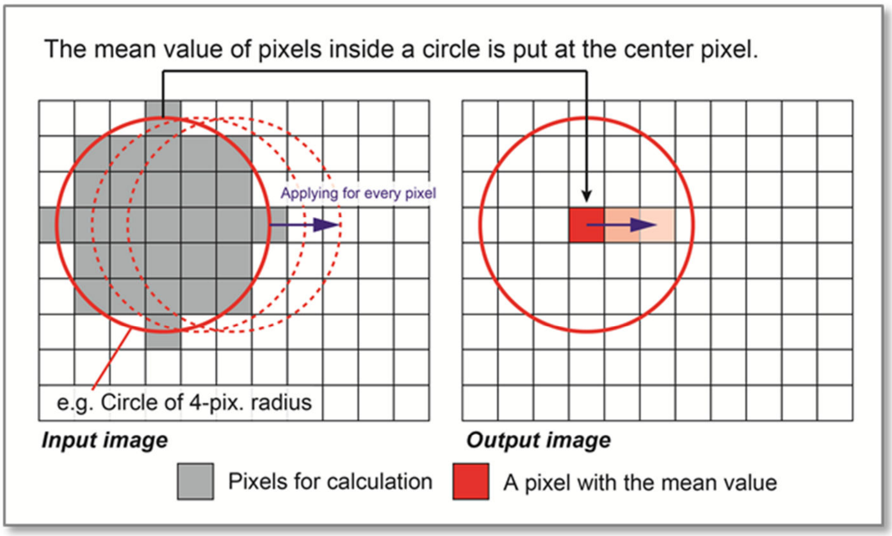
- When γ_{int} is calculated for images over a hazard, higher-valued pixels of γ_{diff} indicates the reduction of the similarity which have high potential of hazard-induced deformation or destruction.

- Several previous studies have applied this method using L-band SAR for damage detection in urban area (e.g. Kobayashi et al, 2011; Yonezawa and Takeuchi, 2001; Tamura and El-Gharbawi, 2015; Watanabe et al., 2016), but we could not find such a study applied for mountain hazard.
- Throughout this study, we aim to emphasize possibility of normalized conference difference using L-band SAR for damage detection in the mountain regions.

<Noise filtering>

We would like to add further information and a figure on the paragraph from P03L15 “Secondly, numerous…”;

1. Radius of a window circle is set as 15 pixel.
2. A mean value of the pixels in a circle is calculated.
3. The mean value is put at 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.



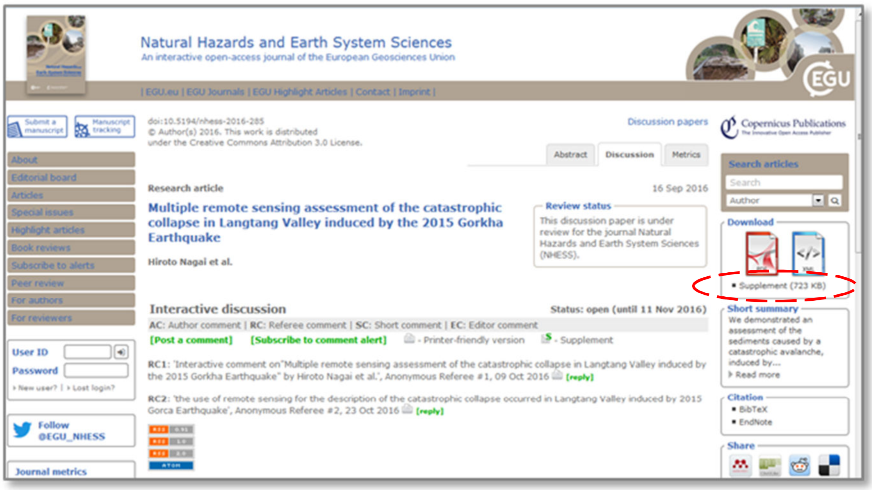
(4)” 2.4 Post-event optical imagery and DSM”, the post-event DSM is very important to calculate the sediments volume, this paper just said “was produced by NTT DATA as its commercial service”, obviously it’s not enough, And “relative calibration/validation of this DSM and the AW3D DSM was performed and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

We understand. After that sentence we would like to add information of;

- The DSM is generated by stereo photogrammetric method using two WV-3 images acquired on the same date (May 8, 2015).

- Stereo area collect mode (26.2 km swath, 112 km path) was selected.
- Two images of (1) forward looking with cross-track tilting to the west hand (i.e. average off nadir angle: 27 deg., average target azimuth: 245 deg. / scene id: 104001000BA62E00) and (2) backward looking with cross-track tilting to the west hand (i.e. average off nadir angle: 27 deg., average target azimuth: 319 deg. / scene id: 104001000B3B2300) were acquired.
- Spatial resolution after cross-track tilt was 0.38 m, coarsened from 0.31 m due to tilting.
- DSM generation flow (i.e. Stereo matching, RPC ortho-rectification, pixel resampling, and DSM data output) was operated by NTT DATA with their original software, where geo-referencing process was supported by WV-3 accurate orbit information without any in-situ ground control point and resampled pixel spacing is 2 m.
- Officially announced specification shows a vertical accuracy of 4 m and a horizontal accuracy of 5 m as root mean square errors.
- Our calibration with AW3D DSM in the study region shows a standard deviation error of 1.5 m (described in the supplement material).

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 will add their information to the discussion chapter.

(6) Improve the quality of the figures

We will put higher resolution figures in the revised version.

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.

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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.

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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.