Reply for review comments

We sincerely thank you for the efforts you have made to improve our submission to *Natural Hazards and Earth System Sciences*. We have responded to all review comments in the following paragraphs. The blue-highlighted sentences are the review comments; sentences in black represent our responses to these review comments.

This study is an analysis is an attempt to characterize better the source zones of debris-flow in relationship with the storage slope angle and precipitations. The data were acquired in a catchment, which includes a large landslide. The monitoring was performed using TLS, video cameras, rainfall gauges and pressure sensor. In addition, field works were performed. The paper tries link saturation of the sediment, the volume of the initiation zones, the type of flow and slope angles. In conclusion, the flow characteristics be explained by the interplay of rainfall patterns saturating or not large or small volume of sediment. The slope gradient can be linked with the above conditions by the Takashi formulas. It shows that the fully saturated debris-flows create low gradient profile with breaks, while the partially saturated ones create constant steeper gradient.

Thank you for summarizing our paper.

General comments

The paper presents interesting results, but sometimes it is rather difficult to follow. It was difficult for me to write a summary, maybe the findings are not enough underlined and strengthened. In my opinion the authors have to read there paper carefully again simultaneously with a colleague that is not involved in the paper in order to clarifies make the text easier to read.

We will asked our colleague, who is not involved in this paper, to read our paper. In addition, we will improve "abstract", "introduction", and "summary and conclusion" to emphasize findings in our paper.

The abstract is as well no very informative.

The other reviewer also requested to revise abstract. We think statements on the findings were ambiguous. Therefore, we will revise the abstract to emphasize findings in our study.

The figures about the site are often too small and too dark.

We will changed lightness and contrast of the figures. In addition, we will extend the figures. The revised figure is shown in pg. 3 in this reply.

Information about rainfall are lacking such as IDF or other information. In addition, the relationship of the debris flows with the landslide is not really described.

We will added a figure showing initiation condition of the debris flow in the Ohya landslide. Please see details below written as replies for specific comments (pg. 6-8 in this reply). Although the initiation condition of the debris flow is basic information of the debris flow study, the target of our study is not the initiation condition, but the interaction between flow characteristics and accumulation condition of sediment storage. Therefore, we may not deeply discuss the initiation condition in the text.

In my opinion if the author clarify the text and make more easy to read this will be valuable paper about debris-flow behaviours.

Thank you for your comments improving our paper.

Specific comments

P2 line 1: “debris” instead of “decries”

We would like to remove the sentence based on the comment by the other reviewer.

P2 line 4: “Hungr” instead of “Hunger”

We should revise the misspelling.

P4 line 14: this must be explained.

When we apply Eq. (5) to the debris flow, porosity n can be expressed as $1 - C$ using solid fraction C. The n in the moving sediment mass becomes larger than the n of storage when sediment particles start to disperse by collision with other particles (Hungr, 2005; Takahashi, 2014). We will add these explanations to the sentence. In addition, we would like to explain how we applied Eq. (5) to the debris flow by presenting the following equation, which explains relationship between the solid concentration in the steady-state flow (called equilibrium concentration) and the slope gradient is obtained (Takahashi, 1991; Egashira et al., 2001, Takahashi, 2014).

$$C = \frac{\gamma_w \tan\alpha}{(\gamma_s - \gamma_w)(\tan\phi - \tan\alpha)},$$

P4 lines 18-19: more explanations about dispersion

We would like to change the expressing for the better understanding by readers as follows: “By substituting the porosity of the storage into n, Eq. (5) expresses the slope gradient needed for the entrainment of a fully saturated sediment mass, of which solid fraction is same as that of storage (hereafter referred to as α_2).

Fig 1 caption: remind the letters meanings.

We will add explanation of the variables in the figure as follows:
"The h, h_w, and z_1 in the figure indicate heights at surface of the sediment mass, water table, and bottom of the sediment mass, respectively."

P6 line 10-14: to introduce this subject reference to Theule paper in NHESS can be introduced in the introductive section.

We think citation of Theule et al., 2012 is appropriate in "Introduction", rather than "study site". Thus, we would like to add the citation in the "Introduction".

Figure 2: limit of the landslide are missing or unclear.

We will changed lightness of the Figure 2 (please see below). We think boundary of the landslide is clear now. Lower end of the landslide is not obvious because more than three hundred years has been passed since initial failure of the landslide.

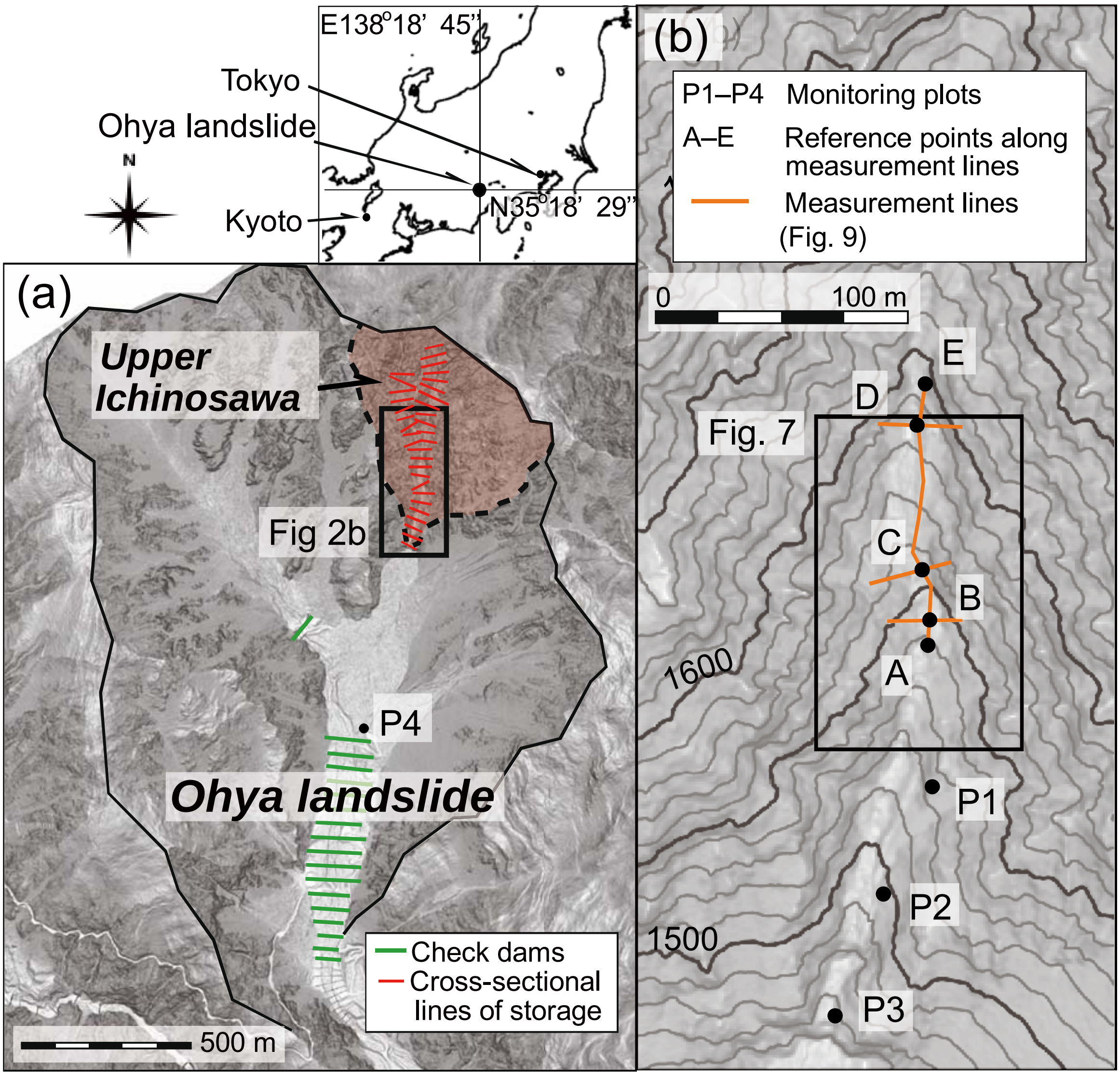


Figure 2

Page 7 line 13- p8: line 4: more explanations are needed to explain how these parameters are evaluated.

We will add detailed explanation on the analysis methods as follows.

"We identified timing of such debris flows based on changes in the topography observed by periodical photography with an interval of appropriately one week. Surface velocity of debris flows at 1 second intervals were obtained from time required for boulders on the flow surface to pass through fixed channel sections (2.0–5.0 m length) on the video images. The surface velocity provided by the video image analysis does not represent the flow depth averaged velocity. The mean velocity was estimated from surface velocity multiplied by 0.6, based on the velocity profile throughout the flows on movable beds obtained from a physically based model by Takahashi (1977, 2014). Flow depth of debris flows at 1 second intervals were also obtained from the video image analysis by reading level of the flow surface. Analysis points of the flow depth were set within the channel sections where changes in the channel bed topography attributed to occurrence of debris flows were minimum."

P8: this page is not well structured difficult to follow. For instance the ultrasonic sensor are used to measure the surface height are explained at the end but already introduced at the beginning of the page.

Flow depth obtained from video image analyses was used to calculate flow discharge. The flow depth obtained by the ultrasonic sensor was used to identify occurrence of debris flow as the backup of video cameras. We would like to added explanations to clarify aim of each observation method.

P8: line 23: where are installed the pressure sensor.

The water pressure sensor were installed at P3. We will clarify the location of installation site.

P9 lines 9-10: this accuracy was checked or it is it the manufacturer data?

This is data in the specifications. We will clarified source of the accuracy. The overall uncertainties of the point clouds, including scanning, registration, and georeferencing by GNSS, were considered in the order of centimeters to a decimeter. As noted at the end of this section, the accuracy of the measurement is explained in Hayakawa et al. (2016).

P10 line 4: only two target were used ???? not 3 minimum?

Unknowns needed for definition of a coordinate system to point clouds are x, y, z coordinates of the sensor, direction of x and y axes for rectangular coordinate system (two variables), depression angle of z axis (total six unknowns). Because the laser scanner was correctly leveled with its internal tilt sensor (giving an angle accuracy of 6''), the z axis is defined. Therefore, number pf unknowns in our study is four (coordinates of the sensor (x, y, z) and yaw angle (horizontal direction)). The z coordinate of the sensor is readily obtained from that of one of the targets. The xy coordinates and yaw angle can be solved from the target xy coordinates by the 2-dimensional distance resection. We measured x, y, z coordinates at two targets (total six parameters). Therefore, number of parameters obtained by our measurement is sufficient to obtain values of unknowns.

In text, we will added an explanation that the scanner was correctly leveled with its internal tilt sensor.

P10 first lines are repeated.

We will revise the repeated sentence as follows:

“The two point clouds measured from different scan positions were registered using at least five reference targets placed between the two scan positions with accuracies of 0.5–6 mm.”

Table 1: please add the point spacing of the cloud points.

We have added the point spacing in the Table 1 as follows. In addition, we will noted the point spacing in the text.

Table 1: Date of TLS survey

Year	Date of survey	Number of debris flow after previous scanning	Date of last debirs flow event*1	Aveage point spacing of the cloud points (m)
2011	November 11	-	October 14	0.075
2012	May 14	0	-	0.077
	August 23	2	June 22	0.056
	November 21	3	September 30	0.038
2013	May 10	0	-	0.078
	August 16	0	-	0.040
	November 19	2	September 15	0.057
2014	May 16	0	-	0.094
	August 17	1	August 10	0.066
	November 28	2	October 5	0.085
2015	May 15	0	-	0.094
	August 23	4	August 17	0.083
	December 4	1	September 9	0.130

*1 Date of the last debris flow event are not listed when debris flow had not occurred in the year , because the topography was possibly affected by the winter sediment supply rather than the last debris flow in the previous year.

P10 line 10: original density of points is needed here

As requested by the reviewer, we will noted the point density in the text. The point density ranged from 59.5 to 689.9 pts m^{-2} (average 249.6 pts m^{-2}).

P10 lines 21-23: unclear please clarify.

To clarify meaning of the sentence, we would like to revise the explanation on the mapping of

geomorphic units as follows:
"The extent of typical geomorphic units in the TLS survey area, including three rock slopes, three talus slopes, and a channel around the monitoring plot P1, was mapped by field surveys (Fig. 4). Distribution of the slope gradient with in these geomorphic units were calculated from TLS DEMs with various grid sizes. The mapping was conducted at the same time as each TLS survey because the area changed over time due to the sediment supply from outcrops and transportation of sediment by debris flows."

P11 line 5: how the photographs are used to define volumes?
The other reviewer also requested to clarify the method. We would like to add detailed explanation on the calculation method as follows:
"Photographs from site P4 cover the entire study site, whereas those from P1 focus on channel deposits at the bottom of the incised main channel, which is shaded in photographs from P4. By comparing these photographs with catchment topography and ortho photographs, which are obtained by airborne laser scanning (ALS) in seven periods (2005, 2006, 2009, 2010, 2011, 2012, and 2013), the area covered by storage (i.e., channel deposits and talus slopes) in each photograph periods was mapped on GIS. The bedrock topography in the upper Ichinosawa catchment was estimated from terrains by ALS in the periods when sediment storage was almost absent (i.e., in 2011 and 2012). Thirty-three cross-sectional areas of the storage with spacing of 25 m along the channels (24 cross-sections along the main channel and 9 cross-sections along a tributary) were calculated from the bedrock topography estimated from terrains by ALS and the location of both ends of the storage along the cross-sections on the GIS storage map (Fig. 2a) under the assumption that surface topography of the storage was an inclined line connecting both ends of the storage. Total volume of the storage was calculated by sum of the cross-sectional area multiplied by the spacing of cross-sections (25 m)."

Section 4.3: a map is probably needed to illustrate this paragraph.
In Figure 2, we will added cross-sectional lines used for estimation of the volume of storage. Please see revised Figure 2 shown above (pg. 3 in this reply). Cross-sectional lines are indicated as red lines.

P11: lines 15-19: papers form Hungr can be cited.
As suggested by the reviewer, we would like to cite Hungr et al. (2009) in the explanation of the errors in our analysis.

Section 5.1: why to not present IDF to characterize rainfall and debris flow initiation or some other information about rainfall.
As the reviewer pointed out, analysis on the rainfall threshold for occurrence of debris flow is essential for the debris flow studies. Thus, we would like to add a new figure showing rainfall

threshold for initiation of debris flow (please see following figure).

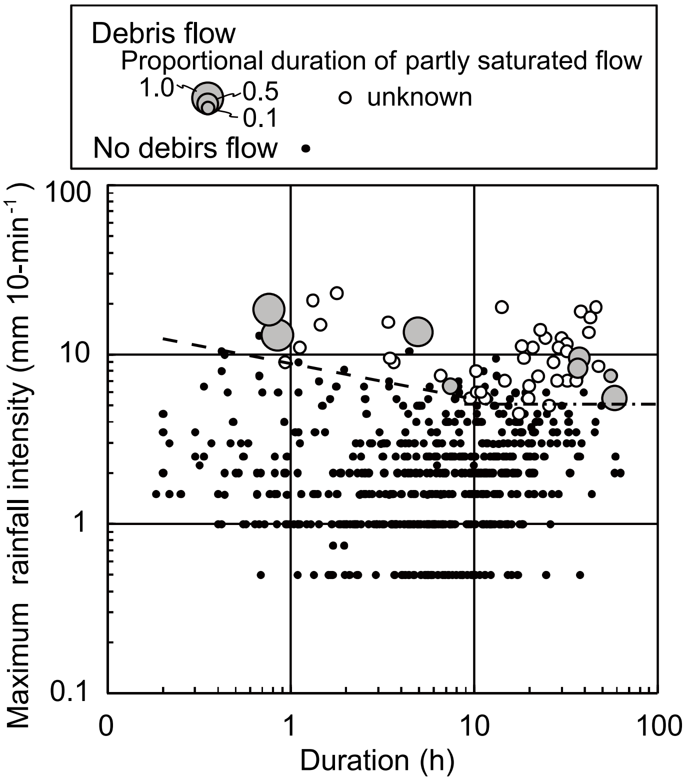
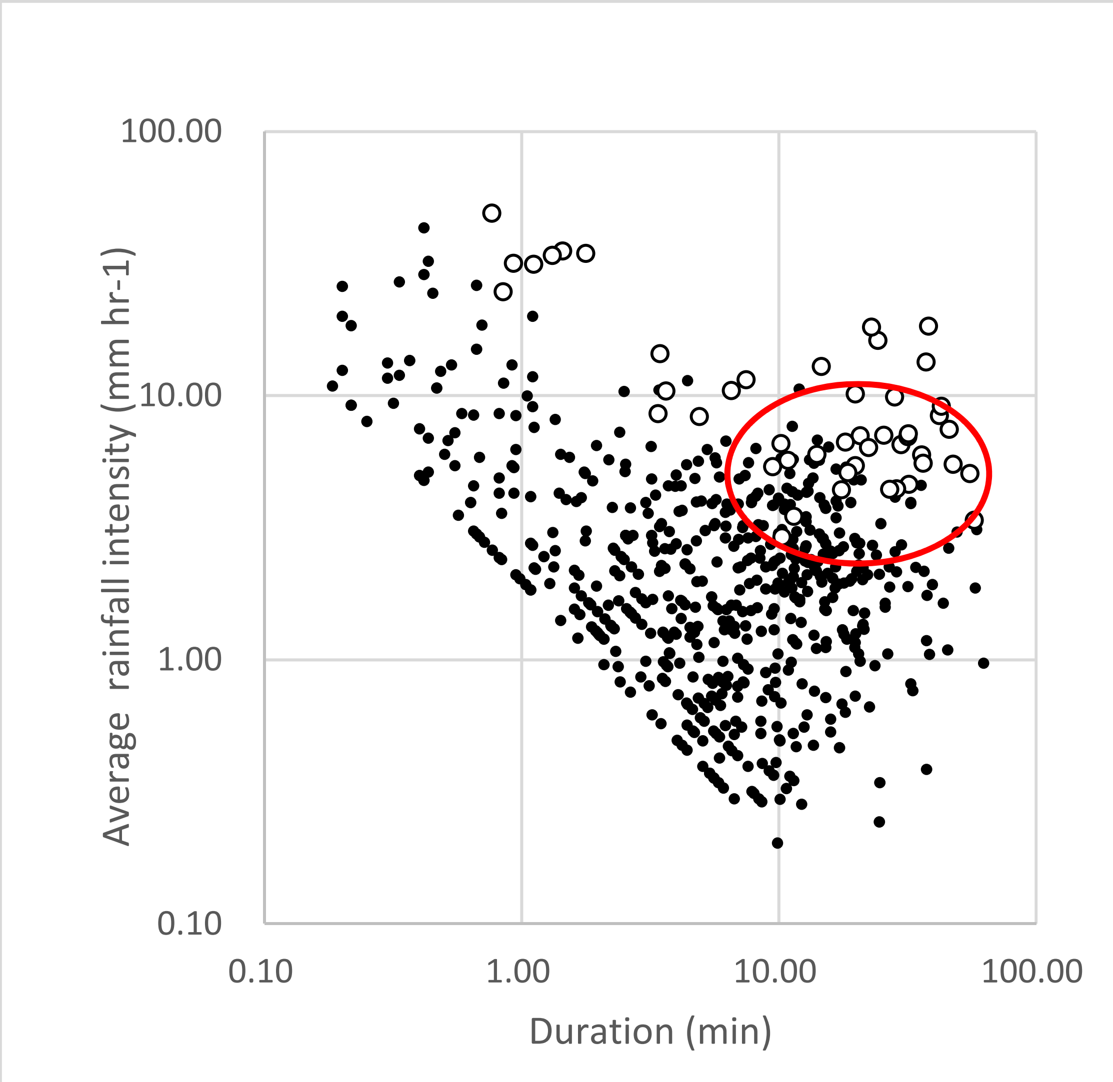


Figure: Comparison between rainfall duration and maximum 10-min rainfall intensity of rainfall events with total rainfall depth >2.0 mm and rainfall duration >10 min in the period from April 1998 to September 2015. Rainfall events with and without debris flows were potted using different markers. Size of the plot for debris flow events expresses proportional duration of partly saturated flow in overall debris flow surges. The rainfall intensity was calculated from rainfall data with a logging interval of 1 min. Rainfall events without 1-min interval data were not plotted. Dashed line, which can be expressed as Intensity = 8.86 $(\text{Duration})^{-0.21}$, indicates lower limit of the rainfall condition needed for occurrence of debris flows when rainfall duration < 10 hr. Dash-dot line indicates the maximum rainfall intensity equals to 5 mm per 10-min, which is the rainfall threshold for occurrence of debris flow when the rainfall duration ≥10 hr.

We have also compared rainfall duration and average rainfall intensity during rainfall event (the total rainfall depth the divided by rainfall duration, please see below). Because initiation condition of debris flow in the Ohya landslide is highly affected by the short time rainfall intensity (10-min intensity), difference in the distribution of debris flow plots and non-debris flow plots were not clear in the IDF using average rainfall intensity (see the area surrounded by the red circle in the figure).



P 12: lines 13-16: what do you mean?

Based on suggestion by the other reviewer, we have revised the sentence as follows:

"The duration of each flow phase varied between the events. For example in the event of 5 August 2008, 88% of debris flow surges (percentage respect to the total event duration) was composed of partly saturated flow, while in the event of 30 August 2004 (Fig. 6), 90% in time of the phenomenon was composed of fully saturated flow."

Table 2 caption: remind TLC meaning.

We will explanation of TLC (time-lapse camera) in the Table 2 caption. We will also added meaning of TLC in Figure 3 caption.

P14 lines 5-8: it is inconsistent.

We think the first half of the sentence in the previous version of the manuscript (location of the geomorphic units) was not needed. Therefore, we would like to remove the sentence as

follows:
“Mapping of the three geomorphic units (rock slopes, talus slopes, and the channel) in the TLS survey area showed that the size of each unit changed with time due to sediment supply and transport processes.”

P14 line 14: because of the boulders?
As the reviewer comments, the slope gradient decreases with increasing in the grid size because of the boulders. We will added statements relevant to the boulders as follows.
“As reported by previous studies (Loye et al., 2009), the average slope gradient of each geomorphic unit becomes gentler with an increase in the grid size, because small scale asperities of terrains (e.g., boulders) are smoothed when the grid size is larger (Fig. 9a).”

P14 lines 15-24: this is well known, you can find in NHESS paper about that (for instance Loye et al.)
We would like to added citation of Loye et al. (2009) in the section. As the reviewer points out, the relationship between the slope gradient and the grid size is widely known, and is not novel. However, this part is basis of the discussion about the interaction between channel topography and debris flow type. Therefore, we would like to leave the section.

Figure 8b: are sure that the integrals of the histograms have identical surfaces? If not why explain!
Integrals of the histograms for each geomorphic unit are identical (=1). Therefore, histograms with different grid size (and different geomorphic units) are comparable. Because step of slope-gradient categories was 2 degree, integral of some histograms looks smaller than others. Thus, in the figure caption, we will explain that integrals of the frequency for each geomorphic unit in Fig. 8b, which are categorized with 2 degree step, are all 1.

P16: instead of using deformation, it is better to use change of the bed topography or something similar. . .
We agree that “changes of the channel bed topography” is easier for readers to image. Therefore, we will replace “channel bed deformation” to “changes in the channel bed topography” or other similar words. In some sentences, “changes in the channel bed topography” makes the sentence too long. Since “channel (or river) bed deformation” is also widely used in scientific papers, we would like to leave “channel bed deformation” in some sentences.

P16 line 17: how do you know that it is partially saturated?
We visually identified temporal changes in the flow type during debris flow events from

video images based on the existence of interstitial water on the flow surface. Video images just provide information at the flow surface. Therefore, we do not know thickness of the partly saturated layer. Nevertheless, based on the video image analysis, we can tell if the flow surface is saturated or unsaturated. We think the classification of the flow types was not easy for readers to image. Therefore, we will add video images of the two flow types as a new figure.

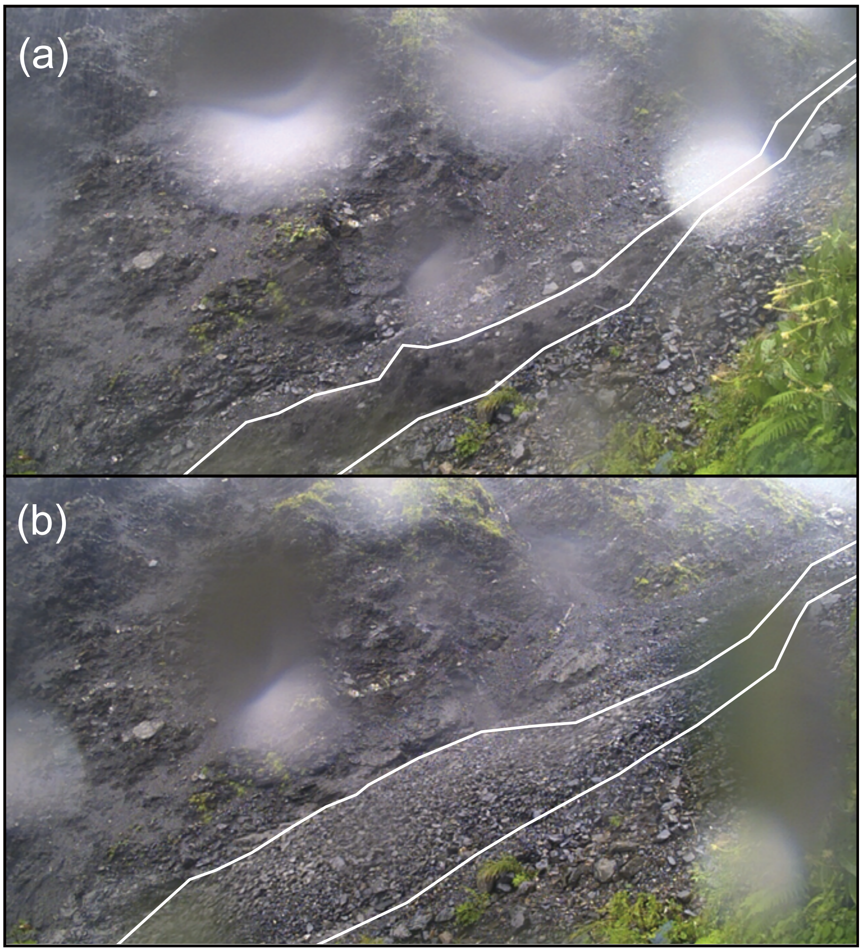


Figure: Images of fully and partly saturated debris flows captured by a time-lapse camera (TLC) at plot P2 in Fig. 2. (a) Fully saturated debris flow captured 9 September 2015, 8:41 (LT). (b) Partly saturated debris flow captured at 9 September 2015, 7:43 (LT). Cobbles and boulders covers flow surface of the partly saturated debris flow (Imaizumi et al., 2016b).

Figure 10 and page 21 line 20: clarify the meaning of length ratio

We will improve title of y-axis and caption of Figure 10. We also improved explanation on the length ratio at pg. 21, line 20 as follows:

"… the sum of the length ratio of the channel sections in the theoretical range of fully and partly saturated debris flows (between α1 and α2) in the active channel bed deformation zones was almost 1.0."

P 20 line 13-15: I do not understand

We would like to improve the sentence as: "our observations in the debris flow initiation zone of the upper Ichinosawa showed that overall debris flow surges were sometimes mainly composed of partly saturated flow".

P21 lines 14-19: what does mean exactly the percentage: gradient or proportion of something?

We will add a statement that the percentage is based on the slope gradient histogram.

Page 22 line 5-8: fine sediment were not discussed before, why?

We would like to delete the sentence based on the comment by the other reviewer. We think changes in the grain size distribution of channel deposits would be one factor affecting temporal changes in the standard deviation of the channel gradient, especially in the analyses with small grid size. However, we do not have quantitative data explaining temporal changes in the grain size distribution. In addition, as pointed out by the other reviewer, changes in the grain size of the channel deposits attributed to selective transport by the debris flow need deep discussion because that is not commonly recognized by the researchers. We think such additional discussion obscure target of this paper.

P 22 line 10: Meunier instead of Meunie

We will revise the citation.