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Interactive comment on "First Sentinel-1 detections of avalanche debris" *by* E. Malnes et al.

Anonymous Referee #2

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General Comments:

The authors visually inspected radar backscatter images from Sentinel-1 to detect manually the debris of avalanches. A large number of avalanches have been detected.

The possibility of avalanche detection from space is a very interesting topic and only very few publications exist which target this topic. However, the paper shows a significant lack of quantitative analysis and the used method of color-composition of radar scenes is not clearly described. The theory to explain the increased backscatter signal returned from avalanche debris is quite vague and speculative.

In the current status, the paper would be an interesting contribution in the form of a journal letter. However, I would recommend the paper for publication in "The Cryosphere" after a major revision which addresses the following specific points:

- provide a short review of the state-of-the art of avalanche detection from ground-

based and space-borne sensors.

- give a concise review of theoretical understanding which explains the increased backscatter signal, and distinguish between wet and dry snow as both have a very different microwave penetration depth.

- show numbers or even a graph how much the backscatter signal increases for the detected avalanches.

- please comment, if there is any advantage in using polarimetric (VV, VH or HH, HV) radar acquisitions compared to single-pol acquisitions, especially with respect to the scattering theory in the snow pack of avalanche debris.

- please describe your method more clearly, as it is not clear which polarizations you used to compose your RGB-composition images.

- Please state, why you need geocoding and if you composed geocoded images or if you composed the images in radar coordinates and geocoded them later on. Is there an advantage in geocoding for the detection of avalanches or do you use it only to be able to get the precise position where the avalanche occurred?

- provide some statistics about the size of detected avalanches.

- replace as many speculative formulations as possible like "we assume, we believe", "relatively straightforward" with more scientific and quantitative formulations.

- please improve the readability of the figures, the are very small and details are hardly visible.

—– Below follows a list of specific and technical comments which refer to specific locations in the text of the printer-friendly version, defined by page (p) and line number l using format p-l, neglecting the first two digits (19) of the page numbers 1943 - 1963.

44-10: I would remove "for the first time" It is not clear if you did it the first time, or it is shown for the first time or if it is shown for the first time using S1A-acquisitons.

TCD
9, C1139–C1147, 2015

44-14: "first proof-of-concept": remove "first".

44-26: "Traditionally, ... problem." This sentence is not clear. rephrase.

45-6..11: discuss or at least mention the following (or others) references to embed your paper in the scientific contest.

- Bühler, Y., et al. "Automated detection and mapping of avalanche deposits using airborne optical remote sensing data." Cold Regions Science and Technology 57.2 (2009): 99-106.

- Martinez-Vazquez, Alberto, and Joaquim Fortuny-Guasch. "A GB-SAR processor for snow avalanche identification." Geoscience and Remote Sensing, IEEE Transactions on 46.11 (2008): 3948-3956.

- Frauenfelder, Regula, et al. "DUE avalRS: Remote-Sensing Derived Avalanche Inventory Data for Decision Support and Hind-Cast after Avalanche Events." Proceedings of ESA Living Planet Symposium. 2010.

45-14: "we show for the first time" -> see comment 44-10.

introduction: could you mention, that you detect wet-snow slab avalanches?

45-20: "we use both avalanche" -> we use both words, avalanche and avalanche debris

45-23: The paper "Eckerstorfer and Malnes (2014)" is not yet available online. I can only find the paper from the "Proceedings of the Inter-15 national Snow Science Workshop. 2014." which does not contain a quantitative model. Please shortly summarize the cited quantitative model or provide another reference or theory.

45-26: "increased snow volume, liquid water content, ... leads to increased backscatter." (whole sentence) Please be more precise, e.g. liquid water content is also known to have significantly less backscattering. see e.g.

- D. Small "Flattening Gamma: Radiometric Terrain Correction for SAR Imagery",

TCD
9, C1139–C1147, 2015

TGRS vol 49, no.8 (2011), page 3091.

- T. Schellenberger et al., "Wet Snow Cover Mapping Algorithm Based on Multitemporal COSMO-SkyMed X-Band SAR Images", JSTARS vol.5 no. 3 (2012).

45-28: air-snow surface interface -> air-snow interface

45-27: They further assume .. Who is They? Ulaby or Eckerstorfer?

46-01: "air-snow interface ... is the dominant snow parameter" Can you proof this? Either by theory, reference or measurement? I think, it depends strongly on the case of wet or dry snow. For wet snow, the rough surface will be the dominant scattering component, but for dry snow it might be volume scattering. A polarimetric analysis might help to understand which is the case for your kind of snow surface.

46-10: "The magnitude of an avalanche cycle" Could you define both, magnitude and what an avalanche cycle is?

46-12: "inconsistent availability" -> I think you mean "limited" or "sparse" availability.

46-19: What is "varsom.no, 2015" ? An URL? Which date/report from which time do you refer to?

46-24: 6° -> 6°C.

Meteorology: Could you provide a graph which shows the meteorological conditions during the time of your radar acquisitions (temperature, snow depth, wind, precipitation)? Maybe, also the avalanche risk level?

47-09: Did you order them short term or were the acquisitions planned in advance? I don't think, you acquired them. Rephrase.

47-11: "The reference image" Which reference image did you use? From which satellite / date?

47-13: (regObs.no, 2015) see comment 46-19.

TCD
9, C1139–C1147, 2015

47-15: "Similar to the image with avalanche activity (frozen ...) The snow is dry.." You mentioned warm temperatures (6°C) and wet snow. This contradicts your need for dry snow. How do you deal with that?

47-26:), however enriched RGB ... -> . However, RGB ...

48-1..10: Why did you add the intensity of different color-channels? Would you not profit more, from a difference or ratio of backscatter intensities? Bright features which are not avalanches would cancel out.

Which polarizations did you use in your composed images? VV, VH or both? Why?

You mention a contrast of 2-3 dB (49-12). This should be easily detectable in difference images.

Could you provide a more comprehensible / reproducible description of your analysis method?

48-16: How many avalanches did you detect in photographs or counted manually?

48-22: How do the results from January 8 compare to the results form Jan 6?

48-25: see comment 46-19.

49-03: These avalanches -> The detected avalanches

49-? : There is no reference to Fig. 2a. Please refer to it, where it is needed in the text or remove the figure. (dangling bound).

Fig 1: The fonts and avalanche features in this image are very small and are hardly readable. I suggest to use this image as an overview and zoom into areas of interest to show the features which you discuss.

Fig 1, caption: "reference ... visualized in green, .. 6. January .. in red and blue.. " I think you mixed the colors here. 48-1..5 claims the opposite.

49-6..11: Could you quantify the area fraction which was affected by layover and

TCD
9, C1139–C1147, 2015

shadow where you could not detect avalanches? I think, this are only very few percent.

49-12: 2-3 dB (Eckerstorfer and Malnes 2014): Which contrast did you observe for the avalanches you detected? Or do you refer to the same avalanches in the cited paper?

49-19: 80 m x 80 m: How does this compare to the typical size of avalanches observed on your area of interest? Could you provide a number how many percent of the total occurring avalanches you could theoretically detect? Maybe, which resolution is required to detect which percentage of the total number of small / mid-size / large avalanches?

49-24: increased snow depth and surface roughness -> I believe, the increased contrast originates from the high snow density, but not from snow depth. For wet snow, I expect a very limited penetration depth at C-Band.

- William I. Linlor, "Permittivity and attenuation of wet snow between 4 and 12 GHz", Journal of Applied Physics 1980 vol. 51 no. 5.

- Hallikainen, M. and Ulaby, F. and Abdelrazik, M., "Dielectric properties of snow in the 3 to 37 GHz range", IEEE Transactions on Antennas and Propagation vol.34 no.11 (1986)]

50-03: light gray -> did you not use any color-composition here? Why?

50-07: minor areas with radar shadow -> How large is the percentage compared to to the S1A acquisitions? (see comment 49-6..11).

50-08 "is to date the reference" -> is the reference which you used.

50-14..19: this lines are almost redundant with section 2.4. I would move or merge the lines 50-14..19 with section 2.4.

50-29-27: Please describe the measurements done in section 2.4. Here, in section 3.3 please discuss only results how the validation data matches the satellite observations.

TCD

9, C1139–C1147, 2015

50-18..19: Figure 4 is not discussed. See comment 49-? .

Figure 4, caption line 3: "New Year was dry and cold." You mentioned warm weather until Jan 2nd. How does this match? How much precipitation fell in January?

Figure 4: The green numbers are hardly visible. The white fonts are too small. (but better visible).

50-24: "agree very well" How well? please quantify.

51-07: "The clear contrast" -> How strong is the contrast? please quantify.

51-08..09: "relatively straight forward" compare 49-11: for an expert observer, relatively straight forwards.

51-15: "increased snow depth, SWE and most importantly increased surface roughness." I believe, your have inclusions of air in very compact snow. The inclusions or snow-pieces are on length-scale of the wavelength of the C-Band and do therefore significantly increase the backscatter signal. Do you have data or a reference about the snow density of avalanche debris? How large is the dielectric contrast? For dry or wet snow, depending on what you had at the time of acquisitions?

50-14..20 quite speculative. Can you distinguish between volume and surface scattering? The HH and VH polarizations might help to find this out. The explanation for the increased contrast needs to be in section 1.1. In the discussion, discuss your results with respect to the theory.

50-18..20: "The total backscatter ..." This sentence needs to be in your theory-section 1.1.

51-21: "change detection algorithm" -> not clear. Do you use an automated detection algorithm, an supervised algorithm or pure manual detection based on visual inspection? Please state this clearly.

51-24: "stark" ? is this Norwegian? I think you mean strong.

TCD
9, C1139–C1147, 2015

52-02: make -> makes.

52-02..05: "Misinterpreting features .." Using your change detection method, you should be able to exclude such features. 52-05: "as well as under detection" not clear. rephrase.

52-06: We believe -> could you quantify a false-alarm-rate?

52-11: "This allows for detection of small avalanches.." Which size of avalanches is most important to detect?

52-12: "significant avalanche" -> what is a "significant" avalanche?

52-12..13: "..avalanches ... close to a road are .. clearly detectable in the S1A image." Sounds like only avalanches close to a road are detectable using S1A images. Rephrase.

53-06..07: "In each forecasting region ... other data." Do you need this sentence here?

53-21..22: ", and increasingly climate change related studies " Rephrase to emphasize the importance of avalanche record in climate change studies. (this is not clear in the current formulation)

53-25: problem of data storage -> Should not be a problem, if you store the results but not the raw data.

53-28: "such algorithm could use the backscatter contrast" -> How does your suggestion relate to your observations? Instead of writing "could use" write "we suggest to use"

54-20..21: "We are confident .. " Please check grammar.

Figure 2: Please provide a higher resolution and zoom into detected avalanches. I do not see any green tongue-shaped features nor green points.

Figure 3: Please enlarge figure or zoom into relevant areas.

TCD
9, C1139–C1147, 2015

Interactive comment on The Cryosphere Discuss., 9, 1943, 2015.