Comment on essd-2021-432
Kristine Larson

(1) I think this is an excellent paper describing a new snow depth dataset. My comments below - tagged by page number/line - are meant to improve the readability and value of the paper.

Thanks for all the insightful comments from Prof. Larson to improve the quality of the manuscript. We have revised the contents/figures and given point-by-point responses. Please see below for detailed information. Comments are shown in black, the authors' responses are shown in blue, and the revisions in the manuscript are shown in red. A revised manuscript will be uploaded during the subsequent "final response" stage according to the journal's review rules.

In addition, we have updated the data set during this round to reconsider several issues. The updates are described below. The results show that the quality of the data set has been improved. We have also revised the figures and the corresponding texts in the manuscript to match the updated data set. Some of the updates will be shown in the following responses, and the remaining will be shown in the revised manuscript during the subsequent "final response" stage.

- Added a new quality flag, i.e., the Signal Strength Indicator (SSI), to do the quality control (SSI >=2).
- Changed the strategy to deal with the non-repeating GLONASS tracks, i.e., used twelve azimuths separated by 30° as a basis to derive the snow-free surface reflector heights.
- Used a more accurate way to consider the penetration depth of the GNSS signal through bare soil, i.e., the penetration depths of each site for GPS L1/L2, GLONASS B1/B2, and BDS B1/B2/B3 were separately calculated using the prepared soil components and VSM parameters.
- Used the maximum snow depths during 2010-2020 as constraints to remove possible outliers of the raw GNSS snow values per track.

The updated GSnow-CHINA v1.0 data set has been uploaded at https://doi.org/10.11888/Cryos.tpdc.271839.

(2) Some of my comments are directed to the figure captions. I think the goal should be to allow people to read/look at the figures without reading the paper. So this means they haev to explicitly say how many sites are in the figures and so on.

We apologize for the incomplete figure captions. We have revised these captions following the corresponding comments. Please see below for detailed information on each revised figure.

(3) My main technical comment is that the authors describe whether they set an azimuth mask for each site. I do like that they are investigating new ways to evaluate the QC for their sites, but we really need to know a little bit more about how they did that (peak ratios e.g.). I agree that setting the bare soil values is complicate - using NDVI is a good way to get a handle on whether the vegetation is dead and thus a better proxy for bare soil.

Thanks for giving us these valuable technical comments.

We did not use azimuth masks. For each site, we used the "h_0 plot" to define rules to evaluate the site quality. Here, h_0 is the reference reflector height over non-snow days. The "h_0 plot" is made by the sorted h_0 values colored by azimuth. One example of the "h_0 plot" for site "bttl" is shown as below. If one specific h_0 value is within the "flat" segment on the curve, this h_0 is treated as a valid value, regardless of which azimuth is. Please also see similar responses to the following comments # 15 & 25.

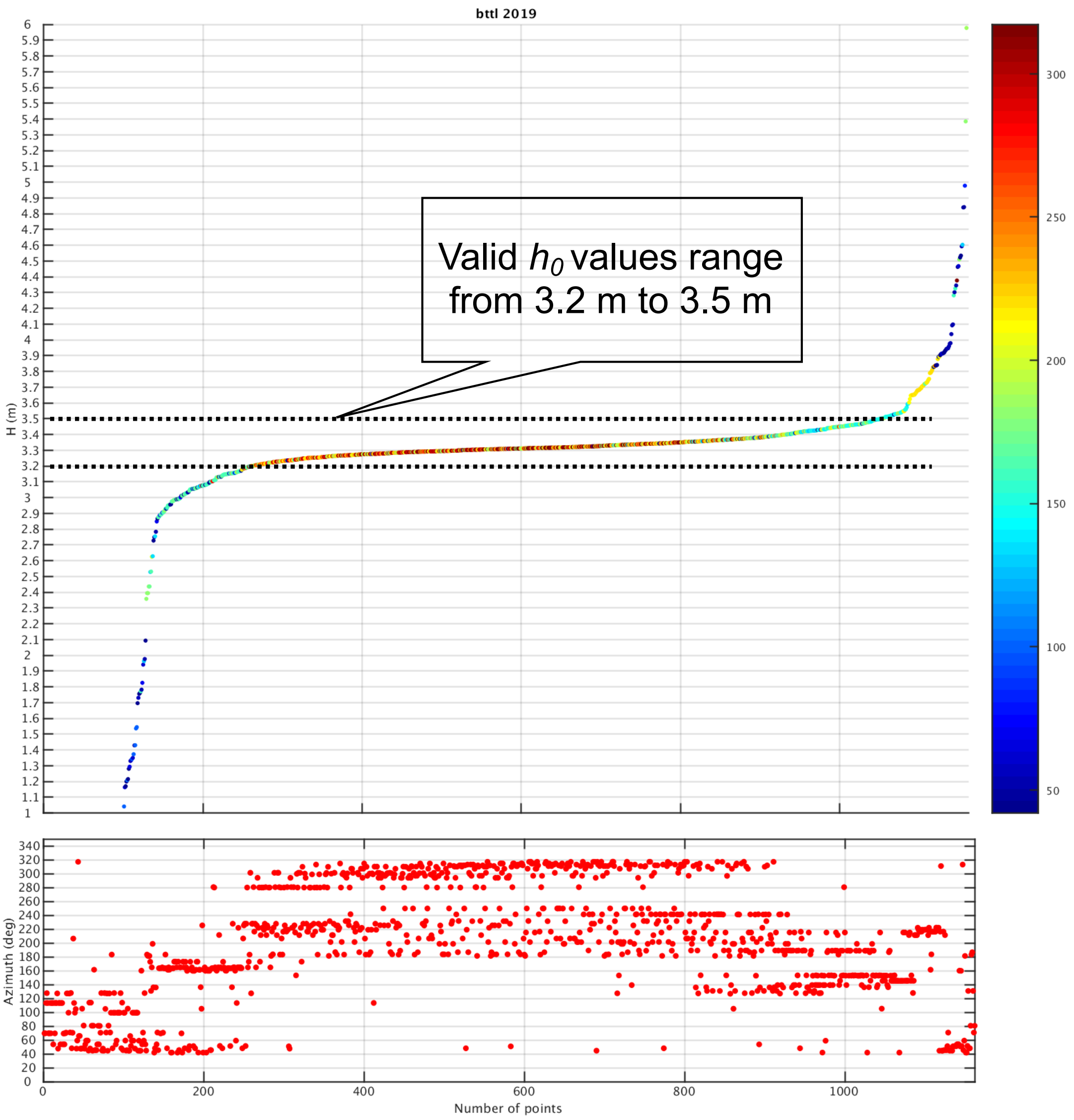

Figure caption: Example of the "h_0 plot" used to define rules to evaluate the quality of each GNSS site. Site name: bttl. Year: 2019

We have added one sentence to describe the "peak ratios" in "Section 3.1 Snow depth retrieval model" around the lines before Eq. (2): "In this study, the Peak-to-Noise Ratio (PNR) of the LSP is set to be greater than 5 to filter out the quality-controlled satellite tracks."

We have reconsidered the penetration depth of the GNSS signal through bare soil more accurately. We have updated the data set and revised the texts to give detailed descriptions. Please see below:

The penetration depth of the GNSS signal through bare soil (h_p) directly influences the determination of the reflector height of the snow-free surface. The h_p is dependent on the soil permittivity and the GNSS wavelength. The soil permittivity is related to soil moisture and soil components. Figure 8 (a) shows the relationship between penetration depth of GPS L1 band and soil moisture/soil components calculated using parameters provided in (Hallikainen et al., 1985). The penetration depth is deeper than 10 cm when soil is very dry (i.e., volumetric soil moisture (VSM) < 0.1 $cm^3.cm^{-3}$). The penetration depth is around or shallower than 5 cm under normal soil moisture conditions. In this study, the soil components data for each site, i.e., the percentages of sand and clay, are approximatively derived from the China Soil Science Database (http://vdb3.soil.csdb.cn/) by the soil attributes of the specific city and province that the site is located in. The average VSM of each site is calculated as the multiple-year mean value of the SMAP VSM. The penetration depths of each site for GPS L1/L2, GLONASS B1/B2, and BDS B1/B2/B3 are subsequently calculated using the prepared soil components and VSM parameters. Figure 8 (b) shows the number of GNSS sites categorized by the soil penetration depths (h_p). The majority has a shallow penetration depth of 4~8 cm, with only a few having 10 cm or deeper. The h_0 is modified as $(h_0 - h_p) + C$ for the final production of the snow depth data set. C is an empirical constant set as 3 cm in this study to represent the offset of the complicated land surface conditions.

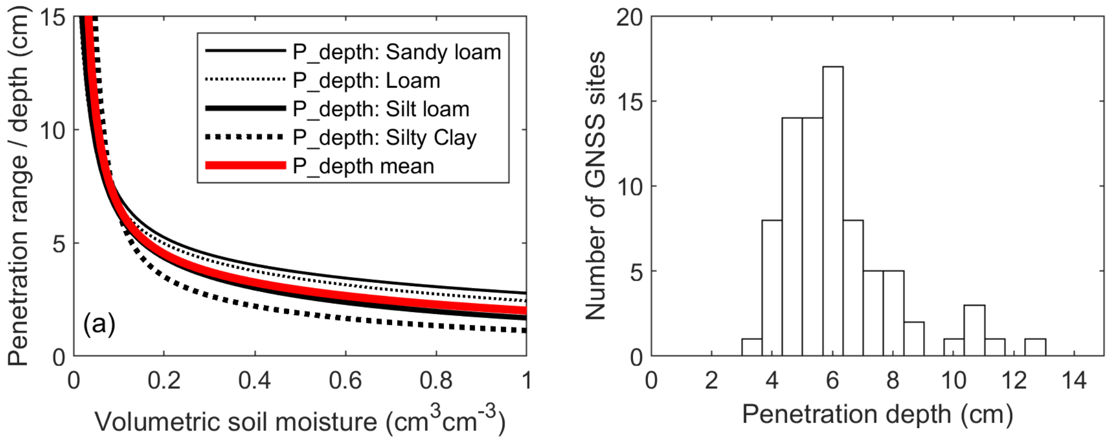

Figure 8. (a) The penetration depth of GNSS signals over the soil layer, taking GPS L1 band (wavelength = 19 cm) as an example. The red line indicates the mean penetration depth for various soil types; (b) Statistics of the number of GNSS sites categorized by the soil penetration depths (also taking GPS L1 band as an example).

(4) I would also ask the authors to add a few more sentences about how they dealt with the non-repeating ground tracks for Glonass satellites.

In the previous version, since there are only four GLONASS sites in the data set, we used the same strategy as that of GPS to deal with the non-repeating ground tracks. However, it reduced the valid observations. In the revised version, we have changed to use a specific strategy to reproduce the GLONASS data, using twelve azimuths separated by 30° as a basis to derive the snow-free surface reflector heights.

We have updated the data set. We have also added a paragraph in Section 3.2 to describe how we dealt with the non-repeating ground tracks for GLONASS satellites. Please see below:

For each site, ~ ten days of data with no snow on the ground are used to calculate the raw snow-free surface reflector height (h_0). According to the data availability, days of the year (DOYs) 110~119 or DOYs 274~283 are generally selected since these days have no snow according to historical in-situ data. Specifically, for GLONASS, to deal with the non-repeating tracks, one-month snow-free data (DOY 105~135) are used to calculate the raw h_0. The reflector height for each GNSS satellite, quadrant, and GNSS frequency band is calculated using the Lomb-Scargle spectrum, and it is just the initial height being used for the quality evaluation of the GNSS sites. Due to the complex natural environment for various sites, it is not clear whether one site is suitable for snow depth retrieval. The following section will define a rigorous rule to evaluate the quality of all the GNSS sites. For those high- and medium-quality sites determined in the following section which are suitable for snow depth retrieval, the finalized snow-free surface reflector height will be determined as the mean value of heights of the ten days.

It is worth mentioning that GPS ground tracks have sidereal repeatability and reappear at the same azimuth. In contrast, GLONASS satellite and BDS MEO satellite have non-repeating ground tracks. GLONASS orbits repeat every eight sidereal days, with the ground track shifted by 45° in longitude per day (Tabibi et al., 2017b). BDS MEO satellites repeat approximately every seven sidereal days (Ye et al., 2015). In this study, there are only 4 GLONASS sites (i.e., bfqe, bttl, hltl, and hlhl) and 1 BDS site (e.g., qxdw). The strategy for processing GLONASS data is slightly different from that of GPS, i.e., the snow-free surface reflector heights are given in twelve azimuths separated by 30° for all available GLONASS satellite tracks and frequency bands. While for BDS satellite, due to the relatively low number of available satellites, the reflector height is given by quadrant only without distinguishing tracks and frequency bands to preserve as many observations as possible. Previous research developed a multistep clustering algorithm to handle the non-repeating ground tracks of GLONASS (Tabibi et al., 2017a). We are also developing a new algorithm in an upcoming study considering terrain effects, which will be particularly effective for non-repeating tracks.

References:

Tabibi, S., Nievinski, F., and Van Dam, T.: Statistical Comparison and Combination of GPS, GLONASS, and Multi-GNSS Multipath Reflectometry Applied to Snow Depth Retrieval, 10.1109/TGRS.2017.2679899, 2017b.

Ye, S., Chen, D., Liu, Y., Jiang, P., Tang, W., and Xia, P.: Carrier phase multipath mitigation for BeiDou navigation satellite system, GPS Solutions, 19, 545-557, 10.1007/s10291-014-0409-1, 2015.

(5) I do echo the comment of the previous reviewer. For this dataset to be truly useful, it needs to be easily found. For soil moisture, I could point to the International Soil Moisture Netwrok. Even though my soil mositure project has ended, the ISMN has provided a way for researchers to use our soil moisture data without contacting me directly. I do not know the best place for snow data, particularly for the international community.

We have put the data set on the TPDC website along with this paper which is freely available to the international community (see https://doi.org/10.11888/Cryos.tpdc.271839). We are also considering putting the extended data (e.g., every five years) in the future to some data-sharing websites or making an FTP or website to maintain and share the future data versions.

First page

(6) A new snow depth data set over northern China by developing a comprehensive framework using the complex GNSS station network

I would suggest a slightly different title. We don't use complex in quite this way. Yes, the dataset is complicated - but really the issue is that the sites were not located in an ideal way for snow sensing. Maybe:

"A new snow depth data set over northern China derived using GNSS interferometric reflectometry from a continuously operating GNSS network."

This is a suggestion - not any kind of required change.

Thank you for your suggestion. We took your advice and use this title "A new snow depth data set over northern China derived using GNSS interferometric reflectometry from a continuously operating network".

(7) page 3, line 67 I think you should explicitly say in the US (the reader should not need to go to the website to find out that SCAN and SNOTEL are only in the western US).

We have added "In-situ measurements from ground networks such as SCAN and SNOTEL in the United States"

(8) page 4, line 92 For **typical** GNSS sites the spatial footprint is ~1000 m^2. (rather than saying recognized).

We have corrected "For typical GNSS sites the spatial footprint is ~1000 m^2, which is a scale between point-scale and satellite-scale"

(9) page 4 last couple sentences my copy has the commas in 9,000,000 and 4,200,000 as ‘ rather than ,

We have corrected "China's annual mean snow extent is greater than 9,000,000 km^2, with a stable snow-covered area of ~ 4,200,000 km^2."

page 6, line 138

(10) and the stations have turned into a certain amount since 2012.

better to say " and the station build phase was completed in 2012. " ???

We have rephrased. "China started to construct ground GNSS stations in 2009, and the station build phase was initially completed in 2012 with some regions later in 2015."

page 7

(11) I think it is sufficient to say you used the broadest ephemeris. They should be the same everywhere and it should not matter where you got them from.

We have simplified this sentence "The broadcast ephemeris was used to calculate each GNSS satellite's position."

(12) page 7, last line. the RINEX files may truly only have 10 degree data - but was that imposed when the file was made or when the GPS station was set up? It is pretty unusual to set that at the RINEX creation stage (not saying it wasn't done, just asking to be clear).

We have checked with the CMA data administrator and rewritten this sentence. For CMA and CEA sites, the minimum elevation angle of the GNSS satellite was set to be 10° when the sites were built.

Page 8

(13) Shouldn't there be references for these data, SMAP, NDVI data etc?

The references have been added. As below:

O'Neill, P. E., Chan, S., Njoku, E. G., Jackson, T., Bindlish, R., and Chaubell, J.: SMAP L3 Radiometer Global Daily 36 km EASE-Grid Soil Moisture (Version 6), NASA National Snow and Ice Data Center Distributed Active Archive Center [dataset], https://doi.org/10.5067/EVYDQ32FNWTH, 2019.

Didan, K.: MODIS/Terra Vegetation Indices 16-Day L3 Global 1km SIN Grid (V061), NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC) [dataset], https://doi.org/10.5067/MODIS/MOD13A2.061, 2021.

(14) Add a reference for Lomb Scargle Periodogram

The reference has been added. As below:

Lomb, N. R.: Least-squares frequency analysis of unequally spaced data, Astrophysics and Space Science, 39, 447-462, 10.1007/BF00648343, 1976.

(15) As part of your quality control, I think you have set a mask for each site, but you don't really say it. Why not make it clear? You should not bother calculating reflector heights if they are not useful for snow sensing.

We did not use azimuth masks. The main form of the defined rule is the "h_0 plot". An example of the "h_0 plot" was shown in Comment # (3) mentioned above, and also is shown at the bottom of each subfigure in Figure 6 (copied below). The "h_0 plot" shows sorted h_0 values colored by azimuth. If one specific h_0 value is within the "flat" segment on the curve, this h_0 is treated as a valid value, regardless of which azimuth is.

In addition, we have written the last two paragraphs of "Section 3.3 Quality evaluation of the GNSS sites" to make the definition of the rule clearer. Please see detailed revisions in the following Comment # (22).

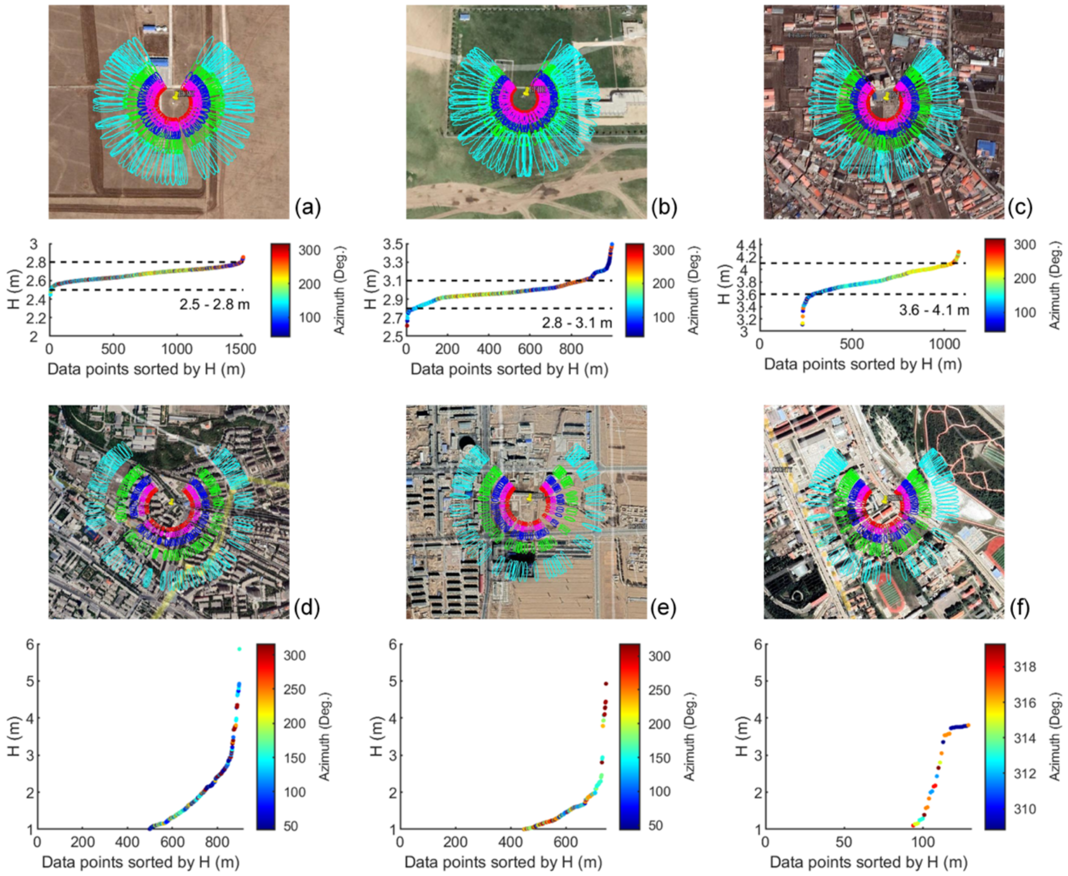

Figure 6. Examples show the high/medium-quality sites and the low-quality sites. High/medium-quality sites: (a) bumz, 2017; (b) bfhr, 2019; (c) bgfc, 2019; Low-quality sites: (d) uqwl, 2019; (e) qhdl, 2020; (f) qhbm, 2018. The top image in each subfigure shows the footprint of the observation for elevation angles of 10°, 15°, 20°, 25°, and 30°, respectively. The bottom image in each subfigure shows the distribution of the reflector heights for non-snow surfaces calculated from 10-days of observations using the SNR model. The background of this figure is from Google Earth (https://earth.google.com/web/) © Google Earth 2021.

page 9

(16) mean Peak-to-Noise Rate (PNR). I think you mean peak to noise ratio, not rate

We have corrected “In this study, the Peak-to-Noise Ratio (PNR) of the LSP is set be greater than 5 to filter out the quality-controlled satellite tracks.”

page 11

(17) line 219 are analyzed in Table 1, You really mean to say that they are listed - not analyzed

We have corrected “The main formulas and applicability of the five models mentioned above to the data of GNSS sites in this study are listed in Table 1”

(18) Even though, the SNR model has been verified to have higher accuracy than the L4 and F2C models (Liu et al., 2021).

remove “Even though”

We have removed “Even though”. “The SNR, L4, and F2C models are suitable for all sites because the observables used as inputs for these models are available in the GNSS raw data.

~~Even through~~, ~~t~~The SNR model has been verified to have higher accuracy than the L4 and F2C models (Liu et al., 2021)."

(19) It is worth mentioning that, for GPS and GLONASS satellite, the reflector height is given per satellite, quadrant, and frequency band, while for BDS satellite, the reflector height is given by quadrant only because the BDS MEO satellite changes its trajectory day by day.

GLONASS does not have a daily repeatable ground track. What do you do to account for this?

We have reproduced the GLONASS data using a new strategy described in Comment # (4). We have revised these sentences and added a paragraph in the same place in this Section 3.2 to describe the method that we dealt with the non-repeating ground tracks for GLONASS satellites. Detailed revisions have been shown in Comment # (4). To save the reviewer's time, we will not repeat here.

Figure 13

(20) The caption of Figure 4 should be expanded to describe the subplots, especially the ones with data in them. I know what is in the figures, but most people would not.

I also suggest using grid lines in the plots.

We have expanded the caption of Figure 4, and we have also added grid lines in the plots. Please see below:

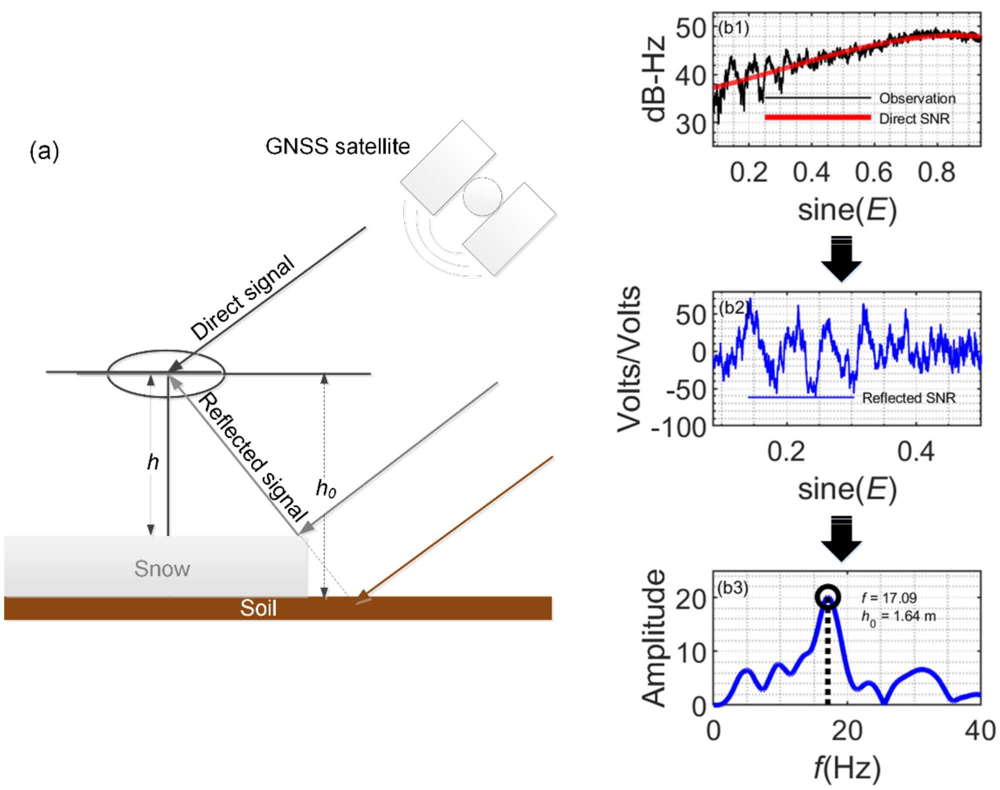

Figure 4. Geometry and principle of the SNR model. (a) The geometry of the direct and reflected signal over the snow surface; (b1) Example of the recorded GNSS SNR data and the removal of the direct signal with a second-order polynomial; (b2) Residual of (b1) below elevation angle (E) of 30°, converted from dB to linear units (for simplicity, Volts); (b3) Lomb-

Scargle analysis of (b2) to find out the dominant frequency of the transformation and the resulting reflector height.

page 14

(21) The majority of the CEA antennas are settled down on a standard rooftop, with the GNSS receivers being put in the accompanying small house. It explains why most of the CEA sites are not suitable for snow depth retrieval.

I suggest you say "set upon a rooftop." Settled is used for something that starts at one height and slowly changes, like snow settling.

We have revised this sentence. "The majority of the CEA antennas are set upon a rooftop, with the GNSS receivers being put in the accompanying small house. It explains why most of the CEA sites are not suitable for snow depth retrieval."

page 16

(22) Figure 6 shows the rule being applied to six individual sites with various surroundings,

You say this before you define the rule. I think you really need to define the rule first.

We have written the last two paragraphs of "Section 3.3 Quality evaluation of the GNSS sites" to clarify this issue. Plese see below:

A rigorous rule is defined to evaluate the quality of all the GNSS sites. For each site, the 10-day reflector heights of non-snow surface (i.e., h_0) are calculated, sorted, and colored by azimuths to make a "h_0 plot". Examples of the "h_0 plot" are shown at the bottom of each subfigure in Figure 6. The "h_0 plot" is visually checked carefully and determines whether it is suitable for the retrieval of snow depth. Suppose one site shows relatively long and stable h_0 values during the entire observation period. In that case, i.e., the "h_0 plot" has a relatively "flat" segment on the curve, which indicates that this site is qualified to determine the initial range of the non-snow surface reflector height. Afterward, a range of h_0 is given manually to narrow the good h_0 values. The difference of the minimum and maximum value of the range is set to be no more than 0.5 m. The finalized non-snow surface reflector height for each satellite, each quadrant, and each GNSS frequency are respectively determined as the mean value of the good heights of the ten days. In contrast, if one site has no "flat" segment on the "h_0 plot", this site is determined as a low-quality site and will not be used for snow depth retrieval. It should be noted that during this processing step, it can only eliminate those sites with poor data quality for snow depth retrieval rather than distinguishing high- and medium-sites. There are no apparent differences for the high- and medium-quality sites regarding the natural environment. Instead, the medium-quality site is defined using two simple rules, i.e., one is the site has good-quality data, but there is no snow for almost all the years. The other is the site's lack of data for most of the years.

Figure 6 shows the defined rule applied to six individual sites with various surroundings, i.e., bumz, bfhr, bgfc, uqwl, qhdl, and qhbm. The top panel of each subfigure shows the environmental conditions around the station on Google Map, with different colors indicating the footprints for elevation angles of 10°, 15°, 20°, 25°, and 30°, respectively. The bottom panel of each subfigure shows the sorted 10-day reflector heights of non-snow surface (i.e., h_0). The plots clearly show the differences in the heights for different sites. The first two sites, i.e., bumz and bfhr, show relatively long and stable h_0 values for all the GNSS satellites, quadrants, and frequency bands during the entire observation period. It indicates that these sites are flat enough for all the orientations and are ideal for determining the initial range of the non-snow surface reflector height, i.e., 2.5 ~ 2.8 m for bumz and 2.8 ~ 3.1 m for bfhr. Unlike these two sites, the bgfc site has relatively stable h_0 values only in specific orientation whose natural condition is open and flat; This phenomenon can be verified from the photo of the site in Figure 5. This site is also good enough to determine the initial range of the non-snow surface reflector height, i.e., 3.6 ~ 4.1 m for bgfc. On the contrary, the three sites at the bottom of Figure 6, i.e., uqwl, qhdl, and qhbm, show continuously changed h_0 values because of the poorly defined peaks for most Lomb-Scargle periodograms. It indicates that it is unreliable to determine a true h_0 due to complex environmental conditions.

Figure 6

(23) How do we know that these are good retrievals? Maybe some of the periodograms have poorly defined peaks?

We agree with this reviewer. We have added one sentence to explain this issue. As below:

On the contrary, the three sites at the bottom of Figure 6, i.e., uqwl, qhdl, and qhbm, show continuously changed h_0 values because of the poorly defined peaks for most Lomb-Scargle periodograms. It indicates that it is unreliable to determine a true h_0 due to complex environmental conditions.

page 16

(24) the three sites at the bottom of Figure 6, i.e., uqwl, qhdl, and qhbm, show continuously changed hX values. It indicates that it is unreliable to determine a true hX by the Lomb-Scargle spectrum due to complex environmental 280 conditions.

I know what you are trying to say here, but I think it is simply a matter that you are computing reflector heights at sites where you should not bother. The sites are surrounded by too much clutter.

We agree with this reviewer that these sites are not suitable for snow depth retrieval. However, initially, we did not know the environmental condition of each site because the CMA who provided the raw GPS data did not give us photos or other supportive information. The only information we had was the Google map; This is why we defined the rule mentioned above (see Comment # (22)) to pick out these "bad" sites.

(25) When you are using your rules to find good sites, do you prepare and save azimuth masks? It is not clear to me that you do.

To save your time, the response to this comment has been shown in Comment # (15).

page 18

(26) 0 ~ 12 am or 12 ~ 24 pm within one specific day.

You should say 0-12 UTC and 12-24 UTC.

We have corrected. "For most sites with only GPS observations, we try to produce 12-hour snow depth if there are no less than five valid observations from 0 ~ 12 UTC or 12 ~ 24 UTC within one specific day."

(27) Figure 7 is this for one site? Which one?

Yes, this is for one site named “bfqe”. We have added the site name in the figure caption. We have also updated the values in this figure using the revised data set. As below:

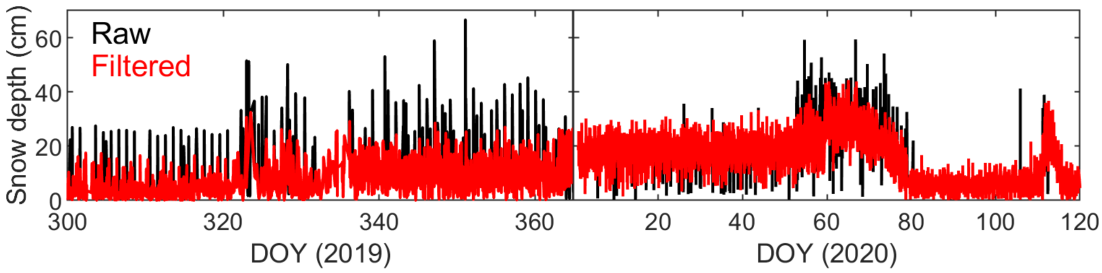

Figure 7. Examples showing the moving-average filtering of the snow depth results over one snow season. The site presented in this figure is “bfqe” which is a CMA site. DOY: day of year.

(28) Figure 9 add the number of sites this represents in the caption. My recollection is that you don’t have that many that observe both GPS and Glonass.

We have added the number of sites in the caption. There are only 4 sites that observe both GPS and GLONASS. We have also updated the values in this figure using the revised data set. As below:

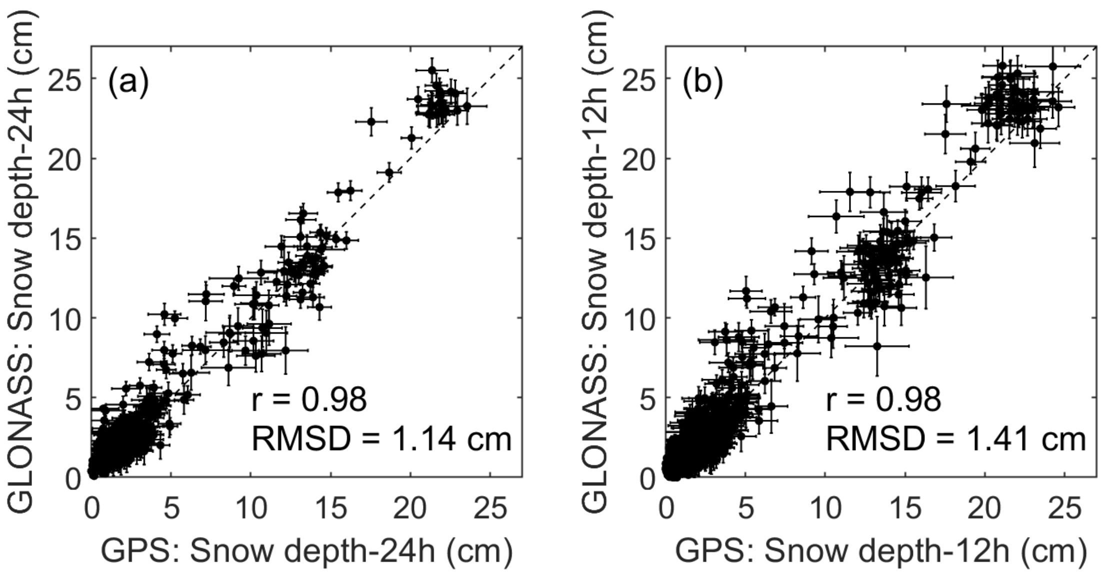

Figure 9. Correlations of 24 h/12 h snow depths from GPS and GLONASS observations. (a) 24 h; (b) 12 h. The error bar of each point is the standard error (STE) of the snow depths for all the observation records. Four available sites, i.e., “hltl”, “hlhl”, “bfqe”, and “bttl”, during the GPS/GLONASS overlapped periods (i.e., the year 2014 and 2015) are used to plot this figure. For each point in the figure, the number of valid observations is more than ten, and the STE of snow depths is less than 2 cm.

(29) Figure 10- Couldn’t part of the difference between L1 and L2 be due to the phase centers not being in the same place? Did you assume the phase centers were the same? How many sites are shown in these figures?

We did not consider the L1/L2 difference of the antenna phase centers. We agree with the reviewer that the raw reflector heights of L1 and L2 have bias. For snow depth in this study, we calculated the L1 and L2 snow depth separately, i.e., using h0_L1-h_L1 and h0_L2-h_L2. Here h0 and h are the reference snow-free height and the daily height. Because we subtracted the bare soil value, the L1/L2 bias no longer exists (or is very small). We have added discussions on this issue in the revised manuscript. Please see below:

Figure 10 (a) (b) shows correlations between the snow depths between GPS L1 and L2 and between GLONASS L1 and L2, respectively, using data from the same four GPS/GLONASS compatible sites as in Figure 9. The results from different frequency bands show good consistency with each other, with the correlation coefficient r = 0.94 / RMSD = 2.66 cm for GPS and r = 0.98 / RMSD = 1.70 cm for GLONASS. It should be noted that a small part of the difference between L1 and L2 is due to the antenna phase centers not being in the same place. The initial bias occurs on the raw L1 and L2 reflector heights. However, the final bias becomes negligible because, during snow depth calculation, the reflector height value of bare soil is subtracted. The BDS results still are not used for comparison due to the limited number of observations.

We have added site numbers used to make these figures. We have also updated the values in this figure using the revised data set. As below:

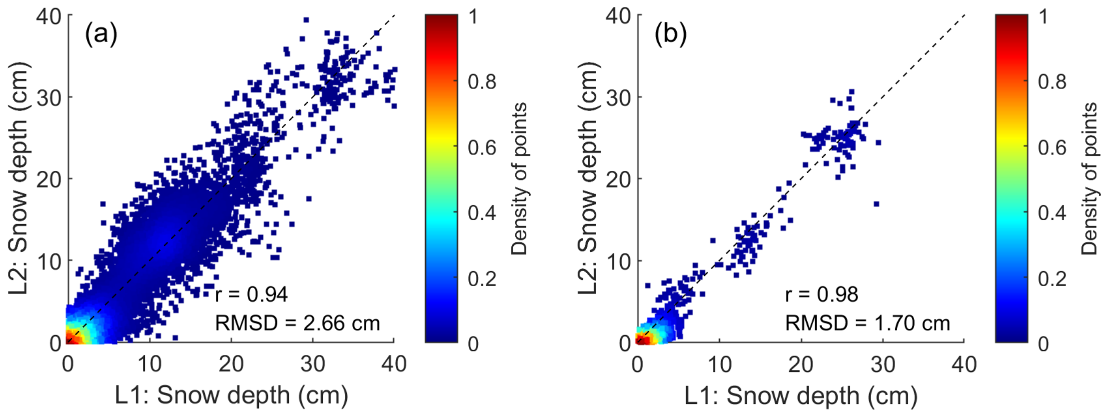

Figure 10. Correlations of snow depth from different GNSS frequencies. (a) GPS L1 vs. GPS L2; (b) GLONASS L1 vs. GLONASS L2. The color bar represents the density of points. Fifty-one high-quality GPS sites of CMA and four GPS/GLONASS compatible sites are respectively used to plot (a) and (b) of this figure. For each point in the figure, the number of valid observations is more than five, and the STE of snow depths is less than 5 cm.

(30) Figure 11 add the 1 to 1 (diagonal) line as you had in Figure 10.

How many sites are represented in each figure? This information should be in the caption or in the figure.

We have added the 1 to 1 line. We have revised the caption to include the number of sites. We have also updated the values in this figure using the revised data set. As below:

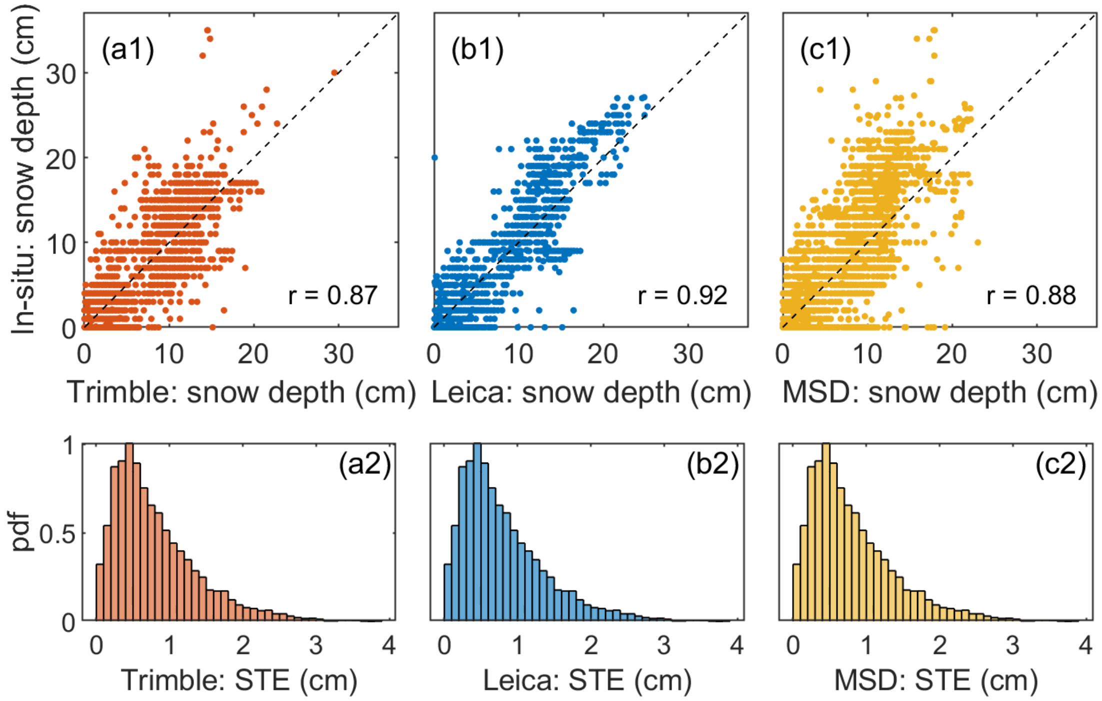

Figure 11. Comparisons of the GNSS-derived snow depth and the in-situ measurements from different types of GNSS receivers: (a1) Trimble; (b1) Leica; (c1) Minshida (MSD), and the histogram of the standard error (STE) of snow depths for different types of GNSS receivers: (a2) Trimble; (b2) Leica; (c2) Minshida (MSD). The number of sites representing Trimble, Leica, and MSD is 20, 5, and 24. To prevent other possible effects besides the receiver type, each data point used to plot this figure are more than ten valid observations, and for (a1), (b1), and (c1), the STE of snow depths is less than 1 cm.

page 23

(31) In addition, the peak of the PMW snow trend for each snow season moves to the right,

Say instead that the peak is later in the season rather than moves to the right

We have corrected. “In addition, the peak of the PMW snow trend for each snow season is later in the season, which is due to the change of snow grain size (Dai et al., 2012).”

(32) Figure 12 Explicitly say in the caption how many sites are shown.

We have added the number of sites in the caption. We have also updated the values in this figure using the revised data set. As below:

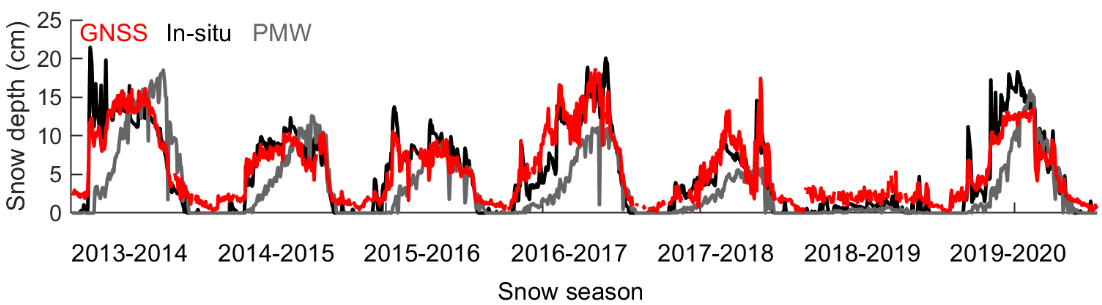

Figure 12. Comparisons of daily snow depth derived from GNSS, in-situ, and PMW. The data used in this figure is from 17 GNSS sites with the most extended temporal coverage (i.e., from 2013 to 2020), and the daily mean snow depth of the three data sets is calculated and shown in the figure.

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(33) This result indicates that the laser measurements in operational meteorological observations are not always reliable.

Could say "this result is a reminder that operational laser measurements of snow depth are not always reliable.

We have corrected. "This data point is an outlier because the historical weather reports showed no significant snowfall events before or after these dates. This result is a reminder that operational laser measurements of snow depth are not always reliable."

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(34) First, the minimum elevation angle of GNSS satellites should be set to 5° ~ 15° to preserve the multipath effect as much as possible because only data with low elevation angles can show the surface reflection.

I don't understand this sentences. If you had said "set to 5 degrees" I would agree because you said you are setting a minimum, which should be a single number. I do not know why you mention 15. Despite the fact that these organizations unfortunately used an elevation mask of 10 degrees, your paper demonstrates that stations with an elevation minimum of 10 degrees can be used (though not optimal).

We apologize for the unclear expression. We tried to say that, under normal circumstances, the minimum elevation angle of 5°, 10°, and 15° should be all fine. However, we did not test other combinations, like 15°-35°, 15°-30°, etc. We have revised this sentence as below:

"First, the minimum elevation angle of GNSS satellites should be set to a single number like 5° or 10° to preserve the multipath effect as much as possible because only data with low elevation angles can show the surface reflection."

(35) Third, the cycle slip of GNSS observation can severely reduce the data quantity available for snow depth retrieval.

I don't understand why a cycle slip would by itself reduce the data quantity for SNR?

We apologize for misunderstanding the meaning of cycle slip. We have replaced this sentence using the following to clarify this issue:

Third, the GNSS tracks may miss data in some epochs during the ascending or descending sequences, although they satisfy the condition of minimum to maximum elevation angles. These data are removed in this study to ensure the accurate acquisition of the reflector heights.

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(36) Also, the snow depth results on snowy days could, to some extent, affect the accuracy.

What do you mean here? I don't disagree with you - but if you say it, you have to explain why you say it.

We are sorry for the unclear description. We wrote this because we read this point from the conclusions of the following paper. However, we misunderstood the real intention of the authors. For simplicity, we have deleted this sentence.

Reference:

Ethan D. Gutmann, Kristine M. Larson, Mark W. Williams, Felipe G. Nievinski, and Valery Zavorotny. Snow measurement by GPS interferometric reflectometry: an evaluation at Niwot Ridge, Colorado. Hydrol. Process. 26, 2951–2961 (2012).

CONCLUSIONS

Snow depth variations associated with accumulation and ablation were measured using GPS-IR over an entire winter season in an environmentally and topographically challenging site, then validated against terrestrial and airborne laser mapping as well as manual snow surveys. We have shown that GPS-IR can accurately measure snow depth in a cold, dry alpine environment within 9 to 13 cm. When one considers the differences between the locations of the GPS measurement and the verification measurement, the GPS may actually be more accurate than that. Snow depth can be measured in both accumulation and melt periods, despite variations in snow density and water content. However, snow depth increases during snowfall events may be overestimated (5–10 cm bias). A model that incorporates variability in snowpack density as well as more complex topography and spatial heterogeneity in snow depth and roughness may improve on the current results.