Answer to Reviewer 1 ESSD-2021-160

We thank Reviewer 1 for their comments. We provide here our responses to those comments and describe how we addressed them in the revised manuscript. The original reviewer comments are in normal black font while our answers appear in blue font.

General comments

This manuscript describes a pan-Canadian data set on snowpack water equivalent (SWE), along with snow depth and snow density for observations for which snow depth has been reported in addition to SWE. The data set is an updated version of the Canadian Historical Snow Survey Data (CHSSD) archive, which has been used in a number of research studies since its publication in 2019. The current version corrects a number of issues in the earlier version, incorporates additional data sets, and applies a consistent quality control protocol. The steps involved in the updating are all clearly described and logical.

Based on the usage of the earlier version by the international community, I anticipate that this updated version will be an important resource for a range of studies related to atmospheric and climate science, cryospheric science, hydrology and ecology. I have a few suggestions for some additional information and technical corrections, as outlined below.

Specific comments

The introduction seems to me a bit long, and I wonder if all of the information is necessary in the context of introducing the data set. I would suggest that the authors consider ways to shorten it. For example, perhaps some of the information on measurement approaches in the first two paragraphs could be summarized in a table. That table could also be referred to later in the manuscript in relation to the metadata.

We thank Reviewer 1 for this comment. During the revision process, we consider the possibility of shortening the introduction. However, based on several comments from Charles Fierz (Reviewer 2) asking to add information regarding manual SWE measurements, we decided to keep in the introduction the two sections that describes the measurement approaches and the measurement networks used by different countries. We believe these two sections provide useful general information for the readers interested in snow dataset.

To help set the motivation for producing the current data set, it may be useful to add a couple of sentences to the introduction about the use of the earlier CHSSD by the international community. For example, a Web of Science search on the article by Brown et al. (2019, Atmos. Ocean) showed that it has already been cited eight times.

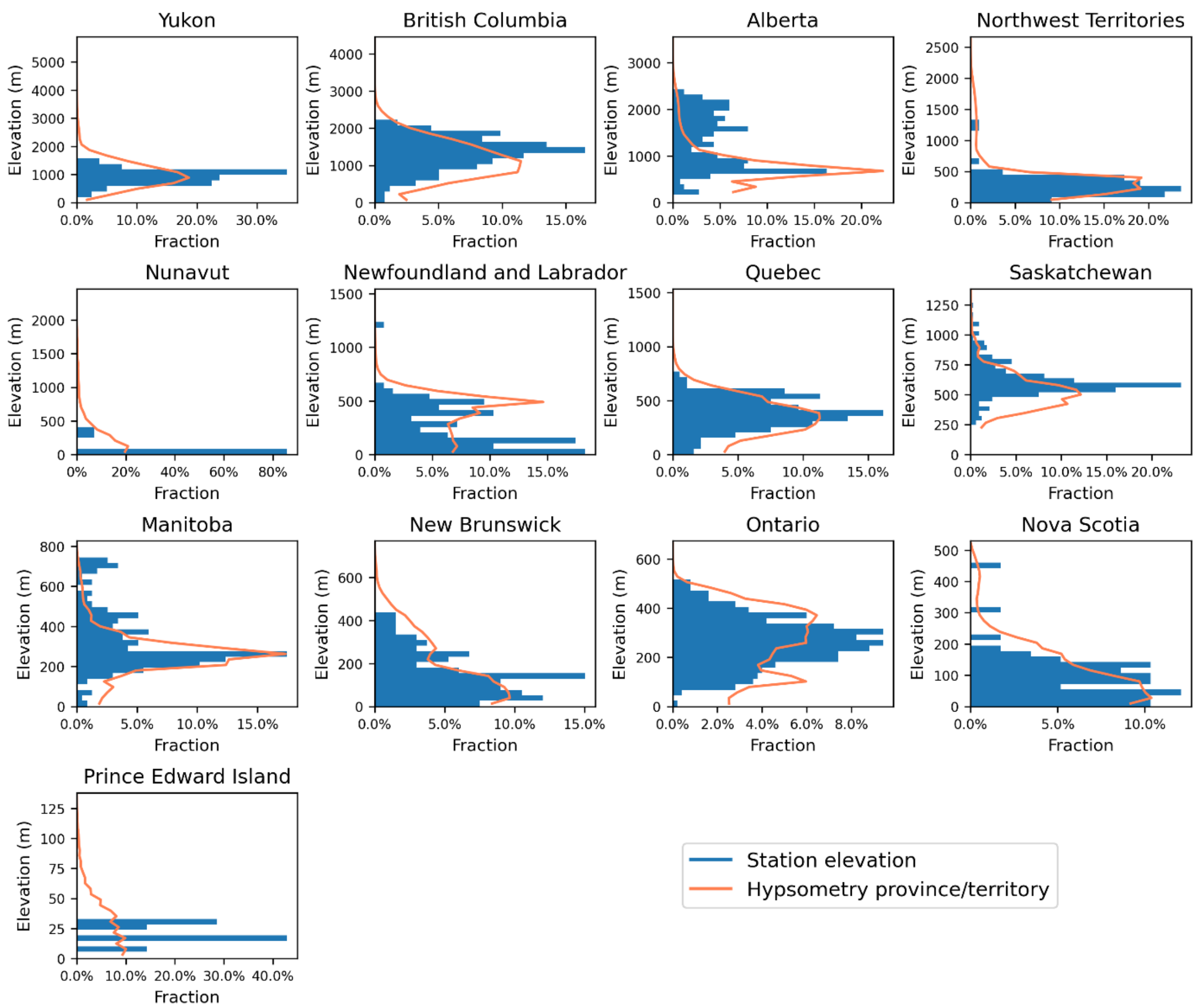
The typical different uses of SWE datasets were already described in the introduction of the initial paper (L46-L59). However, as pointed out by Reviewer 1, this description was not specific to CanSWE. As suggested, we added this information in the revised paper. The papers that cited and used the 2019 CHSSD update by Brown et al (2019) were identified using a search on Google Scholar (last access 20 July 2021) and listed in the table below. To limit the length of the introduction, this table has been added to Appendix A of the revised manuscript and the text in the introduction refers to this table.

Reference	Use of the 2019 CHSSD Update
Gasset et al. (2021)	Evaluation of snow simulations (SWE, SD, density) in a reanalysis product
Luojus et al. (2021)	Evaluation and bias-correction of a satellite-based SWE product over the Northern Hemisphere
Mortimer et al. (2020)	Evaluation of long term-gridded snow products over the Northern Hemisphere
Ntokas et al. (2021)	Estimation of SWE from SD using artificial neural networks
Pulliainen et al. (2020)	Evaluation of long term-gridded snow products over the Northern Hemisphere
Royer et al. (2021a)	Development of a new northern snowpack classification in Canada
Royer et al. (2021b)	Evaluation of snow simulations (SD, density) in the Arctic
Venäläinen et al. (2021)	Development of snow density field to improve gridded SWE products over the Northern Hemisphere

Text added to the introduction: ***The 2019 CHSSD update has been used in numerous studies (see Table A1 for a complete list). However,*** *researchers working with the 2019 CHSSD update …..*

Figures 4 to 7 provide a good overview of the spatial and temporal coverage that will be useful for potential users. The only suggestion I would have for additional figures would be one showing the elevational distribution of observations in relation to hypsometry, perhaps at a provincial or regional scale (e.g., based on the national level ecoregions; see https://open.canada.ca/data/en/dataset/ade80d26-61f5-439e-8966-73b352811fe6). As a researcher who focuses on the mountainous regions of western Canada, I believe that it is important for users of SWE data to appreciate that most of our observations represent mid-elevation locations below treeline.

Thanks for this suggestion. A new figure has been added to the revised manuscript (see below and Fig. 6 in the revised manuscript). For each province and territory, it compares the distribution of the elevation of the stations with the hypsometry of the province/territory. The hypsometry has been derived from the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010, https://www.usgs.gov/core-science-systems/eros/coastal-changes-and-impacts/gmted2010) at 30 arc-seconds reprojected to the Canada Albers Equal Area Conic projection at 250-m grid spacing.



A paragraph describing this figure has been added to the text:

Figure 6 compares the distribution of the station elevation with the hypsometry in each province and territory. The hypsometry has been derived from the Global Multi-resolution Terrain Elevation Data 2010 (https://www.usgs.gov/core-science-systems/eros/coastal-changes-and-impacts/gmted2010, last access 21 July 2020) at 30 arc-seconds reprojected to the Canada Albers Equal Area Conic projection at 250-m grid spacing. Figure 6 shows that the elevation coverage provided by the stations varies greatly from one region to another. A representative coverage is found in provinces of Eastern Canada (Quebec, New Brunswick, Nova Scotia). On the other hand, in British Columbia and Alberta, SWE measurement sites tend to be located at higher elevation than the average terrain to provide relevant information on snow cover in mountainous headwater catchments. Large differences between the station elevation coverage and the hypsometry are also found in Nunavut and Saskatchewan. They are associated with sparse spatial coverage in the elevated inland parts of Nunavut and in the low-elevation northern part of the province in Saskatchewan.

It would be useful for potential users to have information about the different types of snow samplers used in the different regions of Canada, If such information is available. For example, Goodison et al (1987, https://doi.org/10.4296/cwrj1202027) reported that many samplers used in Canada overmeasure by varying amounts.

The different agencies that provided snow data to CanSWE have been contacted to get information about the types of snow samplers that they are using. The information has been gathered in the table below. This table has been included in revised manuscript (Table 2 in the new version)

Table 2: Equipements for manual (snow samplers) and automatic SWE measurements used by each agency that provided snow measurements for CanSWE.

Agency	Manuel stations Snow samplers	Automatic stations
Yukon Water Resources Branch	Federal sampler	-
Government of Northwest Territories	ESC-30 sampler	-
Meteorological Service of Canada (ECCC)	ESC-30 sampler	-
British Columbia Ministry of Environment	Federal sampler	Snow pillows
Alberta Environment and Parks	Federal sampler	Snow pillows
Saskatchewan Water Security Agency	Prairie sampler	-
Manitoba Hydro	Federal sampler	-
Ontario Power Generation	Federal sampler (at most	-
Ontario Ministry of Natural Resources and Forestry	sites), ESC-30 sampler at some sites	-
Hydro Québec	Federal sampler	Passive gamma radiation sensors
Government of New Brunswick	Federal sampler	-
Government of Newfoundland and Labrador	Federal sampler	Passive gamma radiation sensors

The following text has been added to Section 2.1 and refers to papers discussing the impact of snow samplers on the accuracy of SWE measurements:

Most of the agencies use the Federal snow sampler whereas the Prairie and the ESC-30 samplers are used in regions of shallow snowpack such as the Prairies or the Arctic (Table 2). The Federal snow sampler is a small-diameter and multi-section sampler design to aid sampling in deep snowpack whereas the Prairie and the ESC-30 samplers present large diameters tubes to maximize snow collection in shallow snow cover and increase measurement accuracy (Dixon and Boon, 2012). More details about the impact of sampler type on uncertainties in SWE measurements are given in Godison et al. (1987) and Lopez Moreno et al. (2020).

Another methodological point that may be useful to mention, if information is available, relates to the siting of snow courses and snow pillows. For example, some snow pillows I have seen in British Columbia are located in small forest openings, such that I suspect that they tend to accumulate snow more like an open site and melt at rates more like forested sites.

We fully agree with Reviewer 1 that information about the location of snow measurement sites is crucial to better understand the snowpack dynamics at each site. In particular, this is critical when evaluating the output of a distributed snowpack model. However, such information is currently not available directly from the different agencies across Canada. Adding such information would require an extensive work in close collaboration with the agencies. It was not possible to complete this work during the time allocated for the review of this paper. Another solution would have been to extract the information about the vegetation cover from a high-resolution vegetation database such as the product from Hansen et al. (2013). However, uncertainty with the accuracy and precision of the station coordinates may affect this extraction (see our answer to the next comment). Therefore, at this stage, information about the sitting of snow measurement sites in CanSWE is not available. We will work to add this information into future versions of CanSWE.

The absence of information about the sitting of the snow measurements sites in CanSWE is now explicitly mentioned in the revised manuscript (Section 2.2):

Information about the sitting of the snow measurement sites (e.g., open terrain, below forest, clearing) is not available in the present version of CanSWE and will be added to future version of the dataset.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A. A., Tyukavina, A., and Kommareddy, A.: High-resolution global maps of 21st-century forest cover change, Science, 342, 850–853, https://doi.org/10.1126/science.1244693, 2013.

When comparing model output to SWE observations, it is important for users to understand the accuracy of the locational coordinates in order to extract simulated SWE from a model unit that is representative of the monitoring location. If possible, I suggest that the authors add some information about the typical horizontal and vertical accuracies of the coordinates.

Thank you for this comment. We agree that accurate coordinates and elevations underpin the usefulness of any in situ dataset, including CanSWE. Coordinates are provided by contributing agencies and may have been obtained from a variety of sources including topographic maps, handheld GPS or a differential GPS systems the accuracy of each method varies but this information is not provided by the contributing agencies. As such, we are only able to speak to coordinate precision and the accuracy of the USGS NED which is used when elevation is not provided by an agency.

That said, in terms of precision, coordinates are most often reported in decimal degrees with two to seven decimal places depending on the agency. However, the level of precision can be misleading if the original coordinates were reported in degrees, minutes, seconds. Elevations are reported to the nearest metre or tens of metres, depending on the agency.

Many agencies did not include elevation in their metadata. In these instances, elevations were obtained from the United States Geological Survey's National Elevation 190 Dataset (USGS NED) (Gesch et al. 2002). Vertical accuracy of the 1 arc second 2013 release over Canada is 3.53 m (Gesch et al. 2014). This Root Mean Squared Error value was obtained via comparisons with 578 reference control points. The vertical accuracy also varies by location and source data and the set of reference control points did not include any locations north of ~50°N except for a few rivers in Quebec and Labrador and some costal locations in Atlantic Canada. We took the elevation of the grid cell that intersected with each point, regardless of where the point fell within the grid cell. Topographic variability within a grid cell (below 1 arc second) would add additional uncertainty to the reported elevation. Despite these caveats, we have included the reported accuracy of 3.53 m in our revised manuscript.

Reference:

Gesch, D.B., Oimoen, M.J., and Evans, G.A., 2014, Accuracy assessment of the U.S. Geological Survey National Elevation Dataset, and comparison with other large-area elevation datasets—SRTM and ASTER: U.S. Geological Survey Open-File Report 2014–1008, 10 p., http://dx.doi.org/10.3133/ofr20141008.

Suggested revision:

When elevation was not present in the metadata from the originating agency it was extracted from the United States Geological Survey's National Elevation Dataset (USGS NED, Gesch et al., 2002) at the position corresponding to the location of the snow survey site. The USGS's NED covers all Northern America at 30-m resolution (except parts of Alaska) ***and has a vertical accuracy of 3.53 m over Canada (Gesch et al., 2014).***

Technical corrections

line 104. I suggest reorganizing the sentence to avoid beginning with "91." The revised sentence is written as follows: *A total of 91 ~~such~~ stations were identified and were manually checked*

line 192. Should "Northern America" be "North America" – i.e., Mexico, USA and Canada? Indeed, it was a mistake in the original version of the paper. It has been corrected.

line 192. Change "expect" to "except." Correction included

line 207. Change "was" to "were" to be consistent with earlier usage of "data" as plural. Correction included

line 283. Insert "of" between "majority" and "the." Correction included