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Interactive comment on "Meteorological observations collected during the Storms and Precipitation Across the continental Divide Experiment (SPADE), April–June 2019" *by* Julie M. Thériault et al.

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1. The SPADE was carried out by using existing weather instruments along with the setting up of new ones. As the focus of this experimental campaign is to monitor extreme precipitation events in areas of complex topography, I am particularly interested about why different types of rain gauges were chosen. I am wondering about this issue because it is well-known that tipping bucket rain gauges underestimate extreme rainfall intensities. Moreover, the response and uncertainty of both the HOBO and Davis is different, and also present biases when compared to e.g. Hellmann rain gauges. OTT

and Geonor are more accurate as measure continuous precipitation quantity both in rain and ice form. Therefore, the authors should better discuss why different brands (HOBO vs. Davis; OTT vs. Geonor) are used, instead of only one for data consistency.

Response: More remote locations on the western side of the divide were furnished with tipping bucket rain gauges instead of weighing gauges due to logistical challenges of installing such gauges on steep sloping terrains, as well as the lack of battery or AC power and additional weighing-type gauges. Mainly liquid precipitation was reported where the tipping buckets were installed, which reduces the issue of wind undercatch of solid precipitation.

We were aware of potential discrepancies between tipping bucket rain gauges and weighing gauges, so the HOBO tipping bucket rain gauge was deployed alongside the Geonor at the Nipika Mountain Resort field site for 8 days to conduct a comparison study. This period coincided with one of the more intense precipitation events at Nipika Mountain Resort. Cumulative precipitation amounts between the HOBO tipping bucket rain gauge and the Geonor were very similar over this period (difference of $\pm$3 mm) as shown in Figure 1.

We were not able to do a direct comparison of the two types of tipping buckets in the field as well as a comparison with the Davis tipping bucket and the Geonor at Nipika Mountain Resort; however we did not record any discrepancies between the two brands of tipping buckets during our calibrations and our experiments. All of our tipping buckets tipped at increments of 0.2 mm and had the same operating temperature range. To avoid brand-related differences, we only included one brand of tipping bucket in our gauge transect (Davis Tipping Buckets). HOBO data from this paper were only acquired at the Storm Mountain Lodge site and were used to verify MRR returns during one precipitation event which lasted approximately 25 hours.

As for the Geonor and OTT Pluvio, they have the same configuration for catching precipitation and very similar rates of wind induced undercatch (Milewska et al., 2018). These gauges are so similar in their performance that Environment and Climate Change Canada uses the same transfer functions to adjust accumulated precipitation.

A few sentences were added at the beginning of section 3.6 for clarity: "Several types of precipitation gauges were installed and used during the field campaign. At our three main field sites, we used shielded weighing gauges (OTT Pluvio and Geonor). These shielded-gauges are well-known for their accuracy and have been used interchangeably by Environment and Climate Change Canada (Milewska et al. 2018). Tipping bucket rain gauges were installed at our "secondary" field sites (HOBO and Davis tipping bucket rain gauges) due to the remoteness of the locations, logistical and power constraints. The HOBO tipping bucket had been previously tested and showed good accuracy when compared to the Geonor for rain. Additional efforts were made to reduce wind induced undercatch by placing the gauges in sheltered areas and to reduce evaporative losses by removing the debris screens."

Additional reference: Milewska, E. J., Vincent, L. A., Hartwell, M. M., Charlesworth, K., & Mekis, É.: Adjusting precipitation amounts from Geonor and Pluvio automated weighing gauges to preserve continuity of observations in Canada, Can. Water. Res. J., 44, 127-145, https://doi.org/10.1080/07011784.2018.1530611, 2019.

2. In relation to the first comment, did the authors apply a calibration of tipping bucket rain gauges in the lab? It is also well-known that the precision of these instruments is not 100% accurate when delivered from the factories; i.e., not always 0.2 mm tip-1. Therefore, it is mandatory to test the rain gauge calibrations before setting up them in the field. Moreover, data from the HOBO and Davis rain gauges was collected by means of dataloggers. However, this is not described in the manuscript. We implemented a testing procedure whereby we ensured that each rain gauge tipped at 0.2 mm over several repetitions and that each datalogger successfully recorded accurate amounts of water accumulation. These tipping buckets were not factory-issued, they were on loan from the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development where they had been previously used.

Response: Thank you for drawing attention to missing information regarding dataloggers. Odyssey rain gauge loggers were used to record precipitation accumulation from the Davis tipping buckets and Onset HOBO data loggers were used to record precipitation accumulation from the HOBO rain gauges.

A sentence has been updated in the manuscript in Section 3.6.1: "The HOBO tipping bucket rain gauge (RG3-M) measures liquid precipitation at a resolution of 0.2 mm tip-1 and was recorded using an Onset HOBO data logger."

A sentence has been updated in the manuscript in Section 3.6.2: "Liquid precipitation was measured at a resolution of 0.2 mm tip-1 and recorded using Odyssey rain gauge data loggers."

3. Precipitation has a strong dependence to wind speed in mountain areas. In this experiment, the research team used them without single alter shields (tipping bucket rain gauges). This wind screen can strongly minimize the losses of precipitation due to wind, which is commonly moderate to strong (downburst, outflows, etc.) under deep convection or heavy orographic precipitation. The underestimation of precipitation due to wind can directly affect not only the monitoring of these events, but also the climatology / hydrology.

Response: Thank you for this comment. Indeed, precipitation gauges are susceptible to wind undercatch in windy environments and so are often installed with an Alter or other type of wind shield. This is particularly an issue with solid or mixed precipitation rather than rainfall. Alter shields were installed for the two Pluvio and the Geonor precipitation gauges but not the tipping bucket rain gauges; however, the latter were placed in clearings near groups of trees to provide shelter and reduce wind in the area. Temperatures at these sites remained above freezing and only liquid precipitation likely fell during the measurement campaign. In addition, the tipping bucket rain gauges were not installed in alpine terrain where winds would be a more significant factor. As such, we believe the tipping bucket rain gauges provide an accurate account of the rainfall that occurred along this longitudinal transect where other in situ precipitation data are absent. The intercomparison between the cumulative precipitation recorded by the shielded Geonor and the unshielded HOBO tipping bucket rain gauge at Nipika Mountain Resort (see Fig. A) also suggests the latter operated reasonably well at catching liquid precipitation. Nonetheless, additional precautions are needed in the use and application of the data recorded by the tipping bucket rain gauges.

4. Figure 2 shows the instrumentation set up of the stations. I miss two things: (i) all instrument should be labelled in each picture; and (ii) a layout of the weather station(s) with the distance between instruments would be very informative. For instance, in (a) it looks like the weather mast is higher than the Geonor, so depending on the distance between both could be (or not) impact on the precipitation measurements.

Response: (i) We believe that all instruments are labelled in Figure 2 in the manuscript. However, the shielded Pluvio located at Fortress Junction Service (FJS) is shown in Figure 3f in the manuscript. We also noticed that a picture of the Fortress Mountain Powerline (FMP) MRR and Pluvio are missing. A picture has been added to Figure 2e showing them.

(ii) In Figure 2a, the Geonor is located approximately 10 m from the weather station mast. They are located at this distance to ensure that there is no interference between the sensors. Additionally, the placement of the instruments was constrained due to cable length and the remote nature of the Nipika Mountain Resort field site. A Pluvio was also used at FJS (Figure 2c) and was located approximately 7 m from the other instruments on the scaffold. The instruments in Figure 2d are located approximately 200 m from the instruments in Figure 2e. Only the Pluvio and the MRR-2 from Figure 2e are used in our research. All other instruments in the photo are not part of SPADE.

5. Authors published the collected meteorological data freely. However, they should better discuss the quality control checks they applied.

Response: The following sentence was added to section 3.1: “MRR 2 files were processed using the Maahn and Kollias (2012) algorithm. All other data files have not been processed nor quality controlled by the authors, and are the output of the instrument or manufacturer's software.".

6. The manuscript lacks of a discussion section about the "state-of-the-art". They concluded that their dataset is "valuable and unique", however, why? For instance, they do not compare their uniqueness against other field experimental campaigns conducted in other regions. This must be further improved in a revised version of the manuscript; it should be described in the Introduction, and discussed in a final discussion section.

Response: Thank you for the comment a paragraph was added to the introduction and in the discussion.

New paragraph in the introduction reads as follows: "Past field experiments focused on cold season precipitation such as rain-snow transitions and snowfall were held in mountainous regions around the world. In North America, the occurrence of rain-snow transitions has been studied in the Western Cordillera of the United States for many decades. This includes research in the Sierra Nevada Mountains (Marwitz, 1986) in Washington State called Improvement of Microphysical Parameterization through Observations Verification Experiment (IMPROVE, Stoelinga et al., 2003) as well as the Olympic Mountains Experiment (OLYMPEX, Houze et al. 2017), and in the Idaho Mountains to study orographic precipitation and weather modification (Tessendorf et al. 2018). Other projects around the world were also held to study cold season precipitation processes such as in the Swiss Alps (Steiner et al., 2003) as well as in China, where a recent field study occurred in the Haituo Mountains north of Beijing (Ma et al., 2017). Nevertheless, none focused specifically on collecting high-resolution automatic and manual precipitation data simultaneously across a major continental divide. In particular, the combination of sophisticated instruments such as the Micro Rain Radars, disdrometers and microphotography located on both sides of the continental divide as well as Doppler lidars measuring air flow at two elevations in mountainous terrain.

Additionally, a sentence was added at the end of the paragraph stating the goal of the paper: “It fills in the gaps in the well-instrumented hydrometeorological measurements and long-standing research conducted at Fortress Mountain, a Canadian Rockies Hydrological Observatory (https://research-groups.usask.ca/hydrology/science/research-facilities/crho.php#Overview).” A few sentences were added in the discussion (Section 6) that now reads as follows: “A valuable dataset was collected during the Storms and Precipitation Across the Continental Divide Experiment that was held in April–June 2019 in the Canadian Rockies. SPADE was initiated to enhance our knowledge of the atmospheric processes leading to storms and precipitation across a large orographic feature by gathering meteorological data. This leads to a unique dataset to specifically address this critical issue of water redistribution and availability over North America. Furthermore, it augmented the large effort in monitoring hydrometeorological conditions in the Canadian Rockies.”

7. The SPADE monitored 13 storms over a two-month period, and authors concluded that these events occurred under varying atmospheric conditions. Even though this is a paper focused on a description of the data, a brief summary (maybe in a table) of the triggers and atmospheric circulation (upslope vs. downslope flows) of these events should be described.

Response: Thank you for the suggestion but this information will be included in a publication about the scientific findings. The manuscript is currently in preparation.

8. Weather station was powered by a 12V battery; what is the AH of the battery?

Response: The weather station at Nipika Mountain Resort was powered by a BP42 12V 42AH battery supplied by Campbell Scientific Canada. The battery was continuously recharged during daytime by a 30 W solar panel (see Fig. 2a). A sentence was added to the revised manuscript for clarity in Section 3.2: “A CR1000X data logger powered by a 30 W solar panel and 12 V 42 AH battery was used to operate sensors and collect data.”

9. Another concern is about the time intervals of the average, which was changed by the beginning of May from 15 to 5 min averages. However, the SPADE field campaign was initiated on April 24th. Moreover, there are inconsistencies in the measuring intervals among instruments. For instance, WXT520 collected data at 1-minute resolution. A better justification and a table with a summary of the sample and average intervals used should be included and discussed.

Response: As outlined in Section 3.2 of the submitted manuscript, the weather station at Nipika Mountain Resort was deployed on 21 September 2018 to collect baseline data during the fall and winter seasons preceding the SPADE intensive observation period. Given the lack of AC power at this site and a reliance on a 12V battery recharged by a 30 W solar panel, a 15-minute interval was selected as a compromise between high temporal resolution and a limited power supply.

Once a team of researchers returned to the site in early May 2019, we increased the temporal resolution to 5-minute intervals for better comparisons with the data collection effort on the eastern side of the continental divide. This is possible at the time because daylight hours are much longer. In contrast, this was not an issue at Fortress Mountain sites (FMP and FMJ) because of the access to AC power.

We acknowledge that it would have been optimal to also collect data at 1-minute intervals at Nipika Mountain Resort but this could have led to power interruptions and loss of critical data. For our purposes, the 5-minute intervals provide sufficiently high temporal resolution data on atmospheric conditions on the western side of the continental divide, complementing the data collection efforts at Fortress Mountain.

A sentence was added in the manuscript in Section 3.2 “Given the reliance on a solar-charged battery, the 5-minute interval was chosen as a compromise between high temporal data and a limited power supply to ensure that there were no outages and resulting losses of critical data.”

10. I am wondering about the use of the “improvised radiation shield attached to a

wooden post". How reliable these air temperature and relative humidity measurements are? In principal, they are not protected against long- and short-wave radiation, precipitation, etc., as it is mandatory following the guidelines to methods of observations of the World Meteorological Organization. Can you please discuss and include a picture of this radiation shield?

Response: The radiation shield is pictured in Fig. 3d in the manuscript and it provided protection from precipitation and incoming solar radiation while allowing for sufficient air flow around the sensor. This sensor was primarily used for the Storm Mountain Lodge deployment as a means to differentiate whether air temperature was below freezing during a storm event, not to explicitly record high accuracy temperature and humidity values. As such these data are secondary to the primary data collection objectives of the deployment.

The word 'improvised' was replaced by 'temporary' and a sentence was added in section 3.6.1 for clarity. "The instrument was housed in a temporary radiation shield attached to a wooden post at 120 cm AGL in a clearing and was level to the ground. This sensor was primarily used for the Storm Lodge deployment as a means to differentiate whether air temperature was below freezing during a storm event, not to explicitly record high accuracy temperature and humidity values."

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Discussion paper

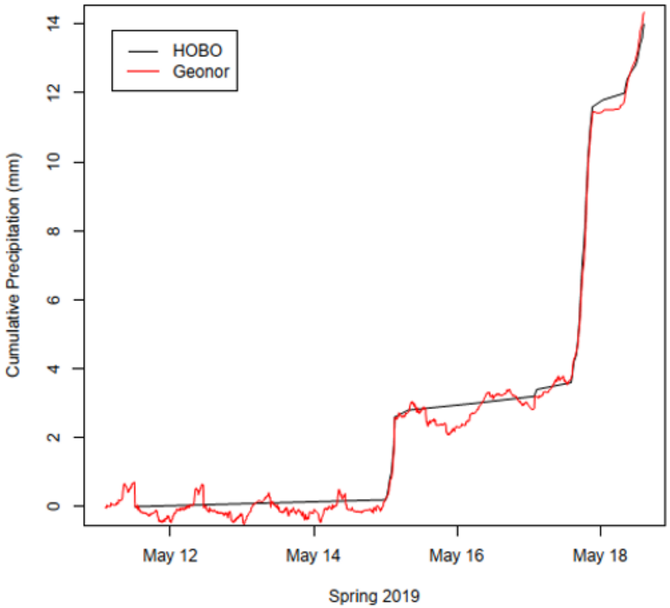

Fig. 1. Comparison between precipitation accumulation at a HOBO tipping bucket rain gauge and a Geonor weighing gauge at Nipika Mountain Resort, 11-19 May 2019.

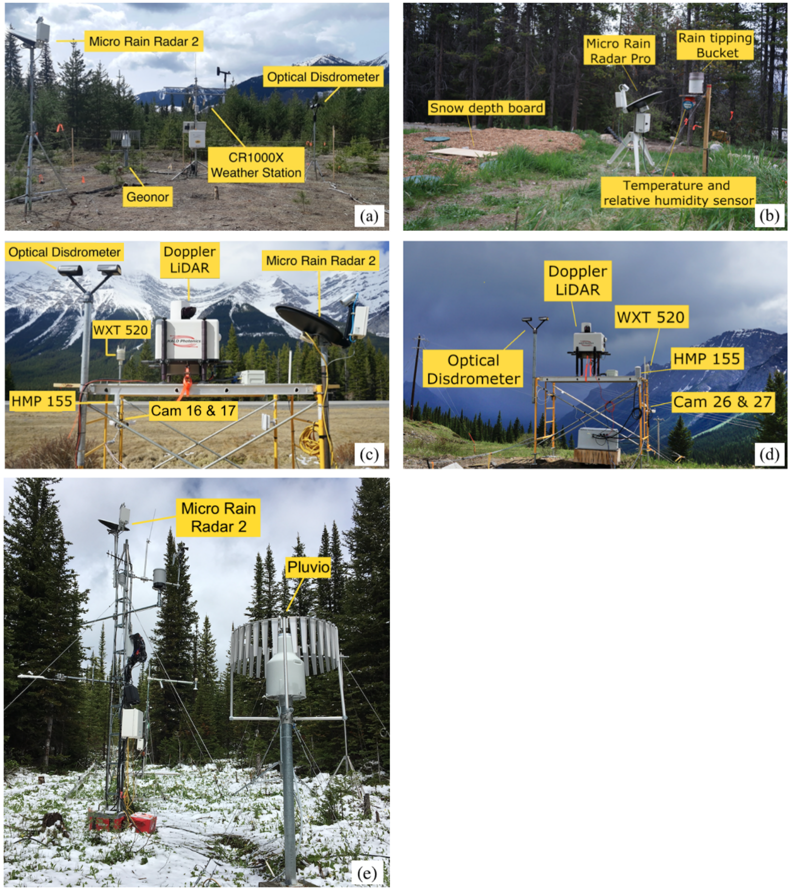

Fig. 2. Instrumentation set up at (a) Nipika Mountain Resort, (b) Storm Mountain Lodge, (c) Fortress Junction Service, and (d) and (e) Fortress Mountain Powerline with instruments labelled.