Intercomparison of solid precipitation measurements in New Zealand

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ABSTRACT

As part of the WMO Solid Precipitation Intercomparison Experiment (SPICE), the National Institute of Water and Atmospheric Research (NIWA) in New Zealand is carrying out an intercomparison of precipitation data over the period 2013-2015. The site was commissioned on 11 July 2013 and comprises two Geonor weighing bucket raingauges, one shielded and the other un-shielded, in association with a conventional tipping bucket raingauge and conventional climate measurements (temperature, wind, solar radiation, and relative humidity).

The installation is located in Aoraki/Mt Cook National Park in New Zealand's South Island, at an elevation of 1818m in a harsh alpine environment. The site is characterised with high amounts of precipitation (snow in winter and rain in summer) and often, very high winds (average wind speed up to 20m/s). In conjunction with the data comparison, the investigation aims to critique the installation method used with the objective of refining this technique for this type of environment.

This paper discusses the equipment set up at the field site, a comparison of the precipitation captured by the un-shielded with conventional rain gauge as well as operational experience gained.

Preliminary results (over the period July 2013–January 2014) indicate that the un-shielded gauge recorded less precipitation than the conventional rain gauge. In addition individual precipitation events analysis showed a large variance in the amount captured by each gauge and this inconsistency could be attributed to high wind velocity.

1 INTRODUCTION

Access to water is a key economic driver for New Zealand's land based economy (Ministry of Environment, 2013), primarily because of the potential for increases in production through irrigation from seasonal snow pack and hydropower generation available from alpine fed streams (over 50% of New Zealand's current electricity production - MBIE-2013). Despite its high economic importance, seasonal snow has historically been poorly monitored (Hendrikx, 2013). This lack of monitoring result in large uncertainties associated with the estimation of annual precipitation in alpine catchments in New Zealand. The current maximum recorded annual precipitation in the Southern Alps is in excess of 16m (Henderson and Thompson, 1999) however, with the current understanding about under catch of precipitation due to wind and the inability of tipping bucket gauges to adequately measure solid precipitation, significant uncertainty exists in recorded precipitation.

Reasons for the lack of monitoring in the past have included limitations in monitoring site accessibility, both in terms of being able to get to the locations as well as legal consents, limitations with remote monitoring due to consent conditions and also the high cost involved with operating in remote alpine environments.

In 2006, NIWA started to develop a National Snow and Ice Monitoring Network (SIN) with the aim of addressing the lack of high altitude, and in particular snow and ice, monitoring (Hendrikx and Harper, 2014). This was a long and slow process but ultimately successful, with thirteen SIN stations now established, generally with 30 year "Licence to Operate" land access concessions granted for the stations located on Crown Land and long-term easements obtained for those on private or lease-hold land (Figure 1).

SIN sites comprise of an electronic weather station (EWS) measuring wind, solar radiation, air temperature, and liquid precipitation. In addition to these parameters, snow information was added consisting of snow depth (all stations), snow pillow measuring snow water equivalent (SWE) that combines with snow depth provide snow density (five stations) and snow profile temperatures (four stations).

The SIN locations were selected using a multi criterion assessment, to maximise their representativeness and coverage in terms of the:

- Elevation
- Climate regions as defined by NIWA (2012)
- Distance east and west of the main divide
- Latitude
- Major river catchments with snowmelt
- Snow avalanche regions as defined by the Mountain Safety Council (2012) and
- Other research and operational needs (Hendrikx, 2013)

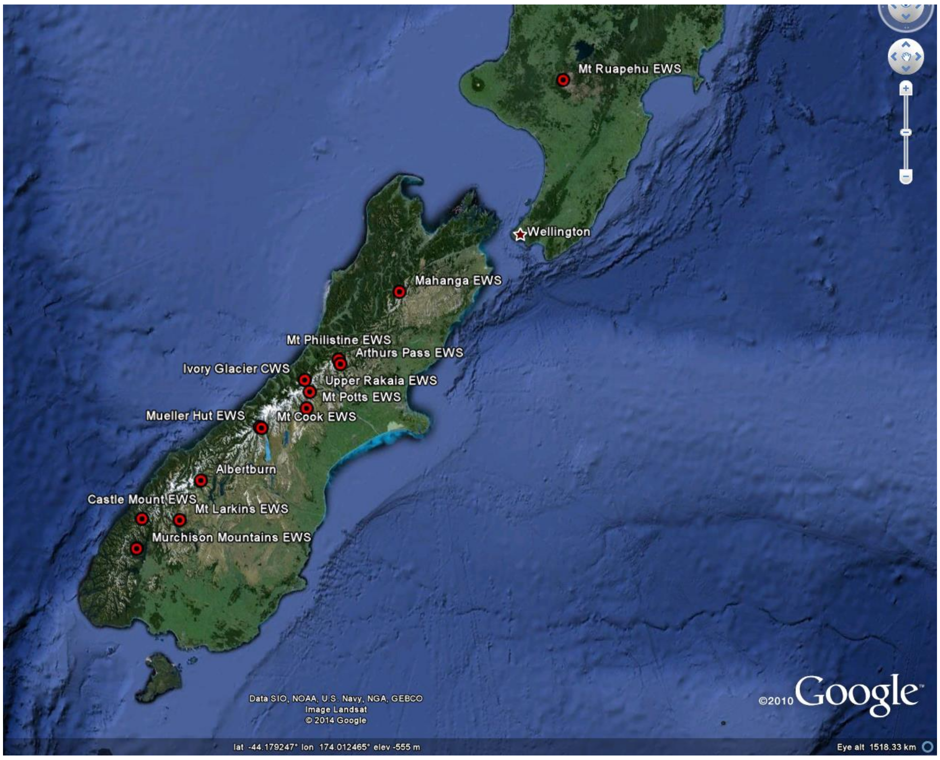

Figure 1: Current Snow and Ice Network

The Mueller Hut SIN location was selected as it fulfilled the criteria including elevation (1818m), contributing to a major river catchment with snow melt (Waitaki River catchment), is part of a snow avalanche region (Mackenzie) and is able to be used for National Park management needs (Aoraki/Mount Cook National Park). The site location is shown in Figure 2.

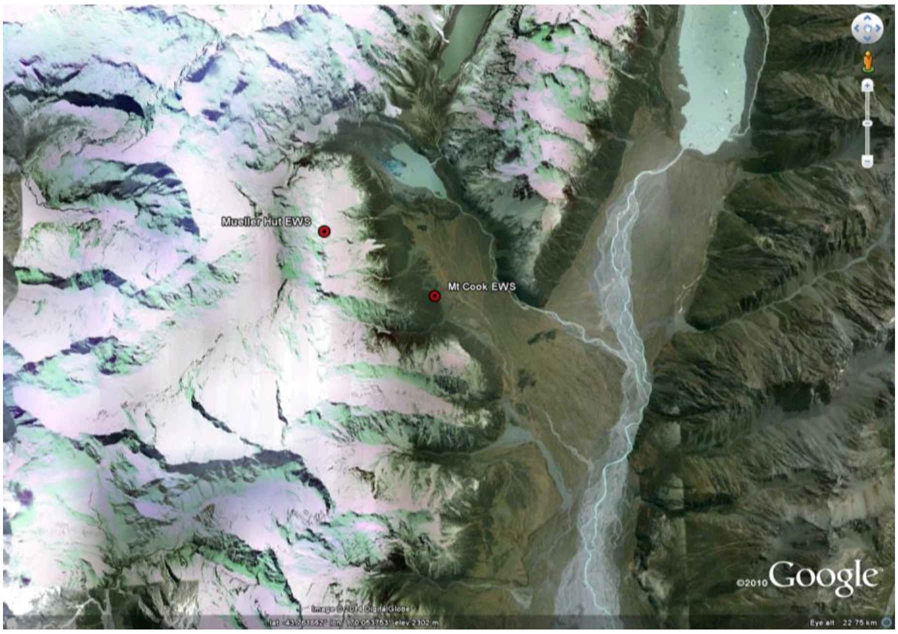

Figure 2: Location of Mueller Hut SIN site.

Within the SIN network, the reliable measurement of total precipitation has proved to be the most difficult. Liquid precipitation data is captured by a tipping bucket raingauge and solid precipitation is generally gathered via the combination of ultrasonic determined snow depth and/or snow weight using a snow pillow. As the division between the two states isn't clearly or simply defined, a considerable amount of under catch occurs – either as the tipping bucket becomes blocked with snow or as solid or mixed precipitation falls in amounts below the sensitivity of the snow depth/snow pillow sensor combination. In addition, SWE sensor failures cannot be rectified while they are under large snow pack (i.e. up to 4 m), resulting in large amounts of seasonal snow record potentially lost.

Finding a suitable precipitation gauge to deal with mixed precipitation has been difficult for many reasons. Some of the questions to consider are:

- What type gauge should be used?
- Should it be a weighing gauge or a tipping bucket?
- What height should the raingauge be installed at? Above or below snow pack? What implications will seasonal snow have?
- Is the objective to record absolute precipitation data or just observe if there is liquid precipitation?
- Should a wind shield be used? How can this be engineered and can it be achieved within the rules of the access concessions?
- Should the gauge be heated? Is there sufficient power capacity to do this?
- What capacity of weighing bucket should be used? How do we prevent over flow? Should anti-freeze be included in a weighing bucket thereby reducing total capacity?
- Is the site accessible possible as frequently as would be required to carry out gauge servicing?

- Can we afford to get to the site as often as required?
- How to prevent accidental capture or drowning of wildlife?

NIWA's participation in the SPICE programme has provided an opportunity to try answer these questions and to contribute to finding a "best practice" method for adequately measuring mixed precipitation operationally in a remote and difficult to access site.

2 MUELLER HUT SIN INSTALLATION

The Mueller Hut SIN site is situated in Aoraki/Mt Cook National Park, one of many areas in New Zealand administered by the Department of Conservation (DoC). Mueller Hutt falls under the South Island wide concession granted by DoC to NIWA to allow the operation of such monitoring stations. The concession process aims to maintain the conservation values of the area and while the conditions of the concession are strict, DoC has been found to be very supportive of this project and the SIN network.

Mueller Hut SIN presented many challenges that had to be overcome. Snow free the site is very rocky and finding suitable bed rock to anchor the installation meant it was difficult to conform to a standard weather station layout. The climate at Mueller is characterised by high precipitation (>6m/year, and just further up the divide >16m/year) and gusty, high wind speeds as shown in Figure 3, predominately from the west and south west, so instruments needed to have specifications appropriate for the site.

Based on informal observations, snow pack up to about 3.5m deep was expected, meaning all instruments needed to be well above this level, resulting in extra engineering for the mast. Access to the site generally only available by helicopter which dramatically increases the cost of servicing and limits the time available for site visits. An example of the difficulty getting to the site happened in 2013 when there was a 10 week window where access was not possible due to continuing poor weather conditions.

In addition to these factors, the area has a large population of the very intelligent and inquisitive native and protected parrot, the Kea, meaning the entire setup had to be protected from their destructive tendencies.

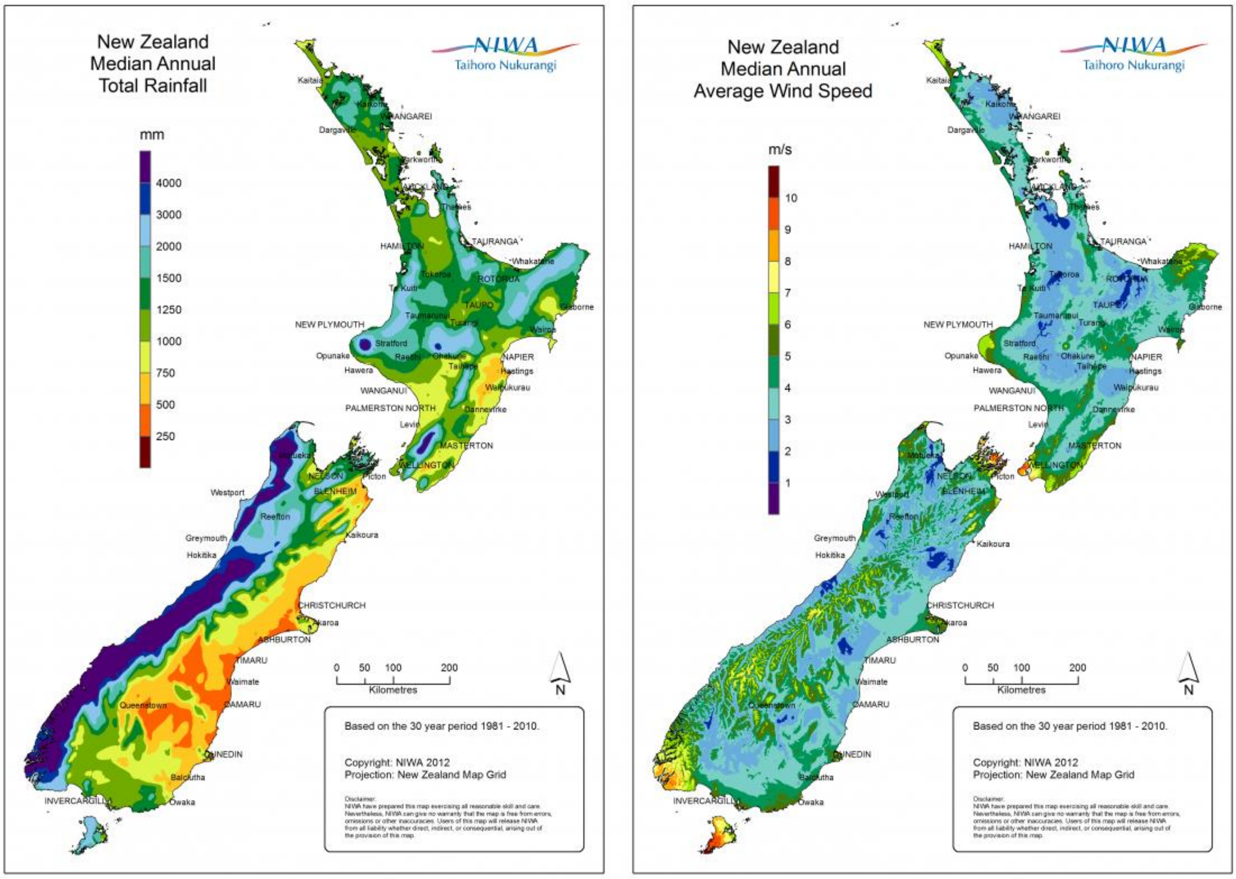

Figure 3: Median annual maps of total rainfall and average wind speed for New Zealand.

The station was operational on 8 April 2010 and is located approximately 40m to the south west of Mueller Hut, a DoC managed facility. One of the conditions of the concession is to minimise visual impacts, therefore, as the hut is regularly used by trampers the size of the station had to be limited and hence the station mast isn't at 10m. Also, shielding had to be installed on the lower half of the tower to prevent unwanted people climbing it during snow free periods. The mast itself is made of two 3.2m triangular lattice sections. The base of the mast was fixed to a levelling plate which is held in place by threaded steel rods epoxied into holes which were drilled into the bedrock. Guy wires set into the rock hold the mast upright and make it stable.

The core parameters measured are wind speed and direction, air temperature, relative humidity, solar radiation, snow profile temperature, liquid precipitation, snow depth and snow weight. All data is logged on a Campbell Scientific CR1000 data logger. Data are automatically transferred to a Unidata "Neon" satellite data logger for telemetry via the Globalstar, low earth orbiting satellite network. Generally, logged data is available from NIWA's Neon server each hour. The telemetry logger only has single buffer data capability therefore only hourly data has been logged and transmitted to-date.

As shown in Figure 4, starting at ground level, the EWS station layout consists of a Hypalon snow pillow (a bladder filled with antifreeze) to which a Unik 5000 pressure transducer is connected to in order to measure the snow weight. Snow profile temperature is measured at four depths from 10cm to 240cm by way of four Campbell Scientific Inc, CSI107 temperature probes. At 4m above ground, snow depth is measured with a Campbell Scientific Inc, SR50A Sonic Ranging Sensor. Air temperature and relative humidity are observed at this height also with a Vaisala HMP45D temperature/relative humidity sensor. A tipping bucket raingauge is also located at this level. Wind speed and direction is taken at the mast top using an RM Young Wind Monitor and solar radiation is also measured at this height using a Li-Cor Pyranometer. Figure 5 shows the degree of winter snow pack.

Figure 4: The Mueller Hut EWS as originally set up, with the Hut in the background. The snow pillow is visible at the base of the mast under the ultrasonic snow depth sensor.

The core maintenance programme plans to visit the station twice per year; once in the late summer to perform station maintenance and carry out routine sensor exchanges and during the winter to verify sensor operation.

Figure 5: Deep snow pack taken 23 October 2012. Snow depth sensor appeared to have malfunctioned until a site visit revealed that it was buried under snow.

3 SOLID PRECIPITATION INTERCOMPARISON EXPERIMENT - SPICE

3.1 SOME PRE-SPICE ISSUES AND LESSONS LEARNT

Additional station hardening has taken place since the station was installed. As much as possible, all cabling and fixtures are protected by stainless steel or alkathene tubing. Originally, plastic or PVC tubing was used however was not tough enough to withstand the harsh weather conditions or to prevent Kea from undoing fittings and chewing through any exposed rubber or screened cables. All sensors are now individually fused which prevents the entire station failing due to the short circuit of a sensor.

The galvanised steel guy wires initially used have been replaced by Parafil synthetic rope. This appears to provide more stability as well as allowing some “give” as the cables are loaded under snow or contract with the cold. During the first winter the steel ropes had over tensioned and caused the lines to pull through the mast fixtures.

Lightning strikes are common in this area and while lightning hasn’t appeared to be a problem for the station, an Eritech System 3000 lightening protection has now been installed. This wasn’t included originally on any of the SIN stations due to the already high cost of establishing the network.

There have been some issues with the pressure transducer on the snow pillow malfunctioning. The exact cause is unknown but it is believed to be moisture in the tubing freezing. Unfortunately with the limited time windows while on site and a narrow time band when the area is free of snow, diagnosis and repair is often delayed.

3.2 SPICE CONFIGURATION

This site was selected as a SPICE comparison site which includes a shielded and an unshielded Geonor T-200B weighing bucket gauge (Figure 6). What was going to be a seemingly simple exercise rapidly became a very challenging one for a variety of reasons related to the remoteness of the site. Designing, siting, obtaining the necessary permissions and then installing the two Geonor gauges and power supply for the gauge heating elements at a suitable height above the snow pack were major obstacles but have all been overcome. In addition, repeated trips to the site for emptying and calibration of the gauges have been required.

Figure 6: Layout of the Geonor gauges on site. The G1 gauge with alter shied is in the centre of the image with the un-shielded G2 gauge to the right of the photo. Note both gauges atop the lattice masts (rims 4.1m above ground level). Aoraki/Mt Cook is in the background, to the left of the picture.

The shielded Geonor (hereafter referred to as G1) has a 1500mm capacity and the un-shielded Geonor (hereafter referred to as G2) has a 1000mm capacity and both are mounted on top of triangular lattice mast sections. The top of both gauges are 4.1m above ground level and both gauges have heating elements fitted to their rims. Each gauge has three vibrating wire transducers operating independently, offering triple redundancy. Table 1 outlines the naming convention used with each transducer and its serial number. Fixing mast sections to the bedrock was same as for the original EWS mast (Figure 7).

Table 1: Naming convention adopted for vibrating wire transducers used in the investigation at the time if installation. Each gauge has three independent transducers.

Transducer naming convention	Shielded (G1) gauge (1500mm capacity) serial numbers	Unshielded (G2) gauge (1000mm capacity) serial numbers
S1	209-13	212-13
S2	210-13	213-13
S3	211-13	214-13

Figure 7: One metre threaded rod drilled and epoxied into bedrock with levelling plate.

For both practical and consent reasons the suggested change post installation to mount the alter-shield separate to the main structure was unable to be implemented. As a result the alter-shield is mounted as per original designs onto the gauge pedestal.

Adding sufficient solar power to maintain operation of the heating elements was also impractical and two EFOY methanol fuel cell generators have been installed. Originally these were going to be located at the base of the mast however access through the winter would not be possible due to snow pack depth so a separate enclosure was constructed to house these and was mounted on top of lattice mast sections (Figure 8). The fuel cells are only for powering the Geonor heaters and this power supply is isolated from the rest of the station. A temperature sensor and control data logger have been set up to control the heaters and is designed so the heaters are turned on for 4 minutes every 15 minutes when the air temperature is below 2 degrees.

Figure 8: Enclosure for EFOY fuel cells and generator. EWS mast is visible in the background also. Overall layout of Mueller Hut site with 1m snow pack. Shielded gauge is to left.

SMS alarms have been set up from the Neon web server to notify technicians when the Geonor gauges are nearing capacity with the intention of allowing time to get up to site and empty the gauges into containers for disposal. Depending on weather conditions this is not always successful and there has already had one instance with both gauges overflowing.

3.3 SITE VISITS AND INSTRUMENT CALIBRATION

A thorough pre-season maintenance and calibration check is carried out on all instruments. Thereafter, site visits are mostly scheduled around the capacity alarms. Both of the Geonor gauges have been calibrated at each site visit (to date: 17 Sept 2013, 7 Nov 2013, 20 Jan 2014 and 22 Mar 2014). Calibration is performed in accordance with the procedure outlined in the SPICE calibration and configuration recommendations for the Geonor precipitation gauge (Hoover, 2012) by firstly levelling the gauge and bucket, then establishing the zero (empty bucket) frequency and comparing this to that shown on the calibration certificate and amending the f0 and A constants if necessary, then adding increments of 1500.0g of water to the gauges, using precision electronic scales to measure the calibration loads (1500g of water = 75mm of precipitation in the Geonor gauges). Multiple point calibrations are performed across the range of the transducers. Time available on site dictates how many points are checked and has ranged from two to eight. The SPICE calibration tolerances are +/- 10Hz at zero precipitation (empty bucket) and +/- 0.5% for values greater than zero precipitation from the transducer calibration certificate. Although all consumable components of the gauge bucket (i.e. anti-freeze and oil) are of food grade and biodegradable, the liquid within the gauges must be collected and removed from site for disposal (Figure 9) as a condition of operating within a National Park.

Figure 9: Draining contents from Geonor. In order to avoid accidental shock loading on the transducers while trying to handle a full bucket, liquid is pumped out before removing the bucket from its cradle.

Please note that as the paper is focusing on the intercomparison between the tipping bucket raingauge and G2 and only these instruments are reported hereafter.

The gauges are re-commissioned with prescribed quantity ethylene glycol & Mobil SHC Cibus 32 oil. This added liquid decreases the collection capacity and therefore, time between visits.

The starting volume of anti-freeze is derived from the minimum temperature the gauge is expected to encounter which dictates the dilution rate when the gauge reaches capacity. At Mueller Hut, temperatures down to -12°C are allowed for meaning a 30% concentration of anti-freeze at full capacity is required.

This means that G2 starts at 320mm with a remaining capacity of 680mm.

The following are some examples of findings from three site visits under very different working conditions.

- 7 November 2013
  - Snow pack was about 3m deep which made for easy access to instruments.
  - G2 was full and had been overflowing. The small drain hole in the base of the gauge was clear so all overflow had drained away. Transducers and internal workings were clean.
  - G2 calibration consisted of four points and all three transducers performed within the suggested tolerances.
- 20 January 2014
  - Very little snow on the ground meaning all work was performed at height with full height access and work positioning equipment used. This made for a very awkward and time consuming exercise (Figure 10).
  - Conditions were windy and the gauge mounting towers were observed to be swaying.
  - G2 bucket was considerably off level, thereby loading the transducers un-evenly, and had to be adjusted. This was visible in the data, shown in Figure 11, as the three transducers began to record markedly different values.
  - G2 transducers all performed satisfactorily and no changes were necessary (after the gauge had been re-levelled)
  - One fuel cell was replaced.

Figure 10: Technician putting in antifreeze mix on G2. With no snow cover, height access and work positioning equipment must be used.

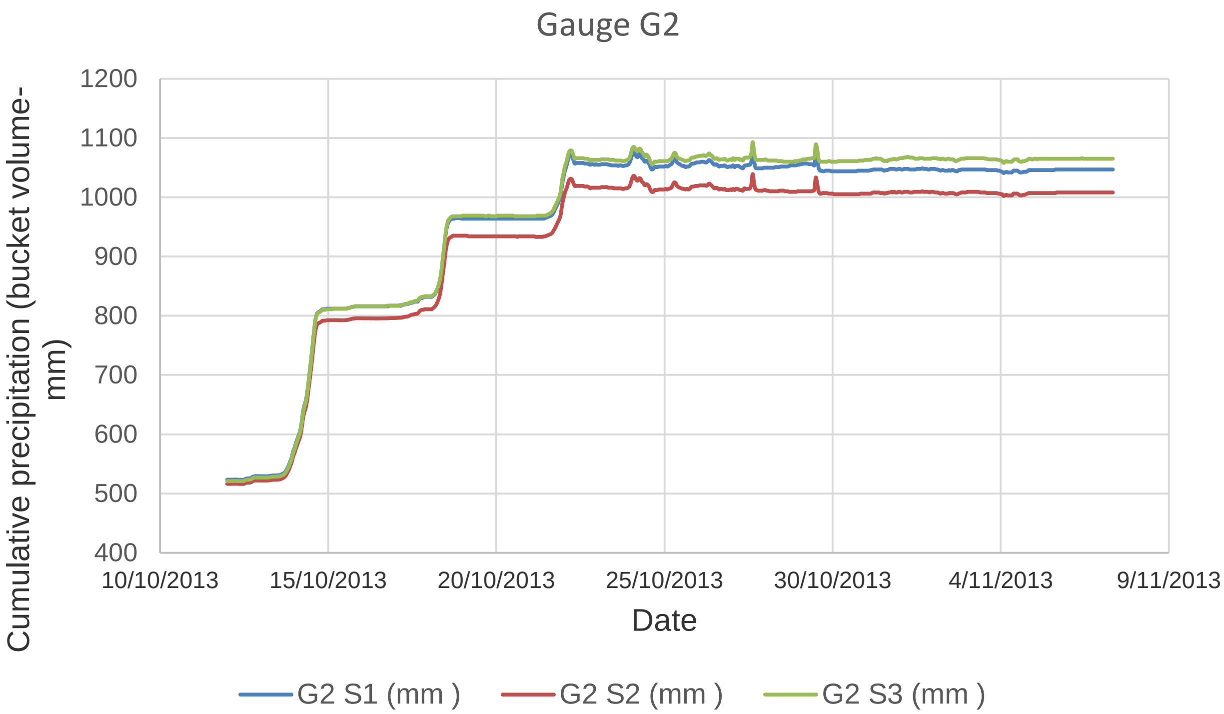

Figure 11: Plot of logged data from G2 showing the drift of the three signals as the bucket deviated from level.

- 20 -21 March 2014
    - Routine EWS calibration and sensor exchange. This included getting the snow pillow operational again after the transducer had malfunctioned during the previous winter.
    - Eritech 3000 lightening protection installed on EWS mast (Figure 12).
    - G2 inspected and calibrated with all transducers performing satisfactorily and no changes necessary.
    - The fuel cell generator was observed starting and charging the battery and the heating system was tested.

Figure 12: Earthing system, snow pillow, fuel cell housing and Aoraki/Mt Cook

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3.4 GEONOR CALIBRATION SENSITIVITY

Figure 13 shows the error curves, expressed as variance (estimated as 100*(observed-calibrated)/calibrated) from the calibration amount (mm) for one of the transducers on G2. Analysis of the calibration results indicates that the measurement uncertainties are consistent with the instrument specification for G2 across the site visits. This is further illustrated by the stability of the transducers calibration constant (A) and frequency (f0), which are re-estimated at each site visit for G2 (Figure 14).

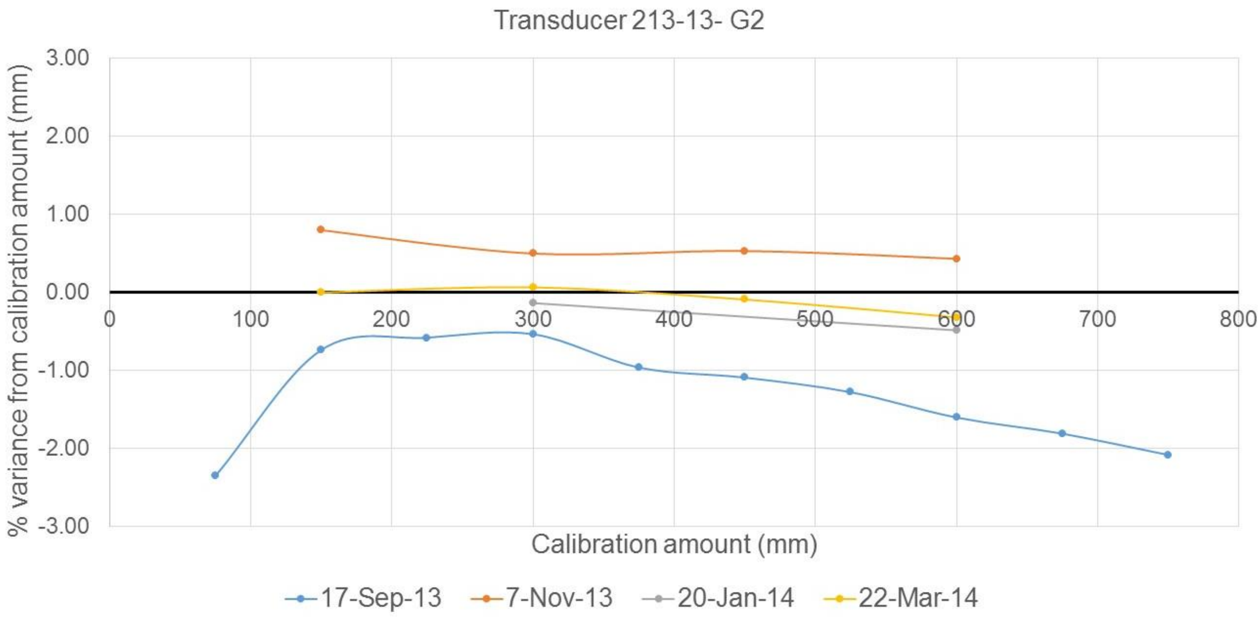


Figure 13: Variance for the calibration amount for transducer 213-13

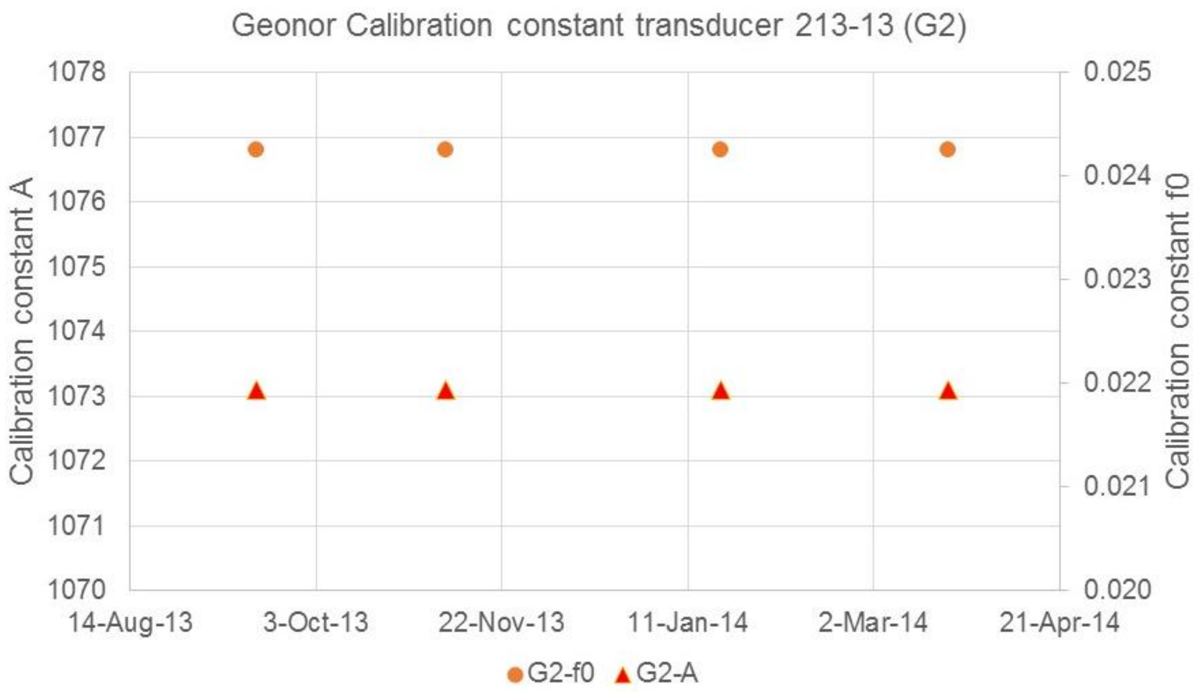


Figure 14: Geonor calibration parameters (A and f0) estimated for each site visit for transducer 213-13

Due to challenges with site access and the fact that weather conditions ultimately dictate when the site can be visited, the gauges have on occasion filled to overflowing before helicopter flights can be made to empty them. This has resulted in a non-continuous precipitation record from G2.

4. RESULTS

4.1 CUMULATIVE PRECIPITATION INTERCOMPARISON

Table 2 presents the cumulated precipitation recorded at the tipping bucket gauge and the cumulated load measured across the 3 transducers for unshielded G2 for the same measurement periods. These comparisons were carried out between the two gauge types across three time periods. These periods correspond to the time period between two site visits where no malfunction or failure of the precipitation gauges were detected. Figure 15 presents the cumulated precipitation/loading over each period in association with wind speed, while Figure 16 presents the loading for the period 18 September-20 October 2013 in comparison with snow depth and air temperature recorded at EWS.

Table 2: Cumulative precipitation observed for tipping bucket gauge G2 gauges. Range of cumulative observed load across the 3 transducers is provided.

	Cumulated Precipitation raingauge (mm)	Cumulated load G2 (mm)
18 Sept- 20 Oct 2013	719	673 (653-685)
7 Nov-19 Dec 2013	407	384(370-392)
20 Jan 2014-24 Feb 2014	283	269(267-272)

It was observed that:

- Bias between the loading information collected by the transducers (up to 32 mm over a 6-8 weeks period) independently of the season
- Bias between each transducer within each gauge is increasing with time. Preliminary analysis indicate no direct link between change in bias with extreme winds or extreme temperature, but bias increase tends to be linked with large loading events.
- Discrepancies occur between tipping bucket gauge and G2 for events below freezing point (e.g. 22 Jan 2014 when temperature where down to -2.7°C)
- Bias between each transducer within G2 increases if precipitation is in liquid form, and decreases if precipitation is in solid form.

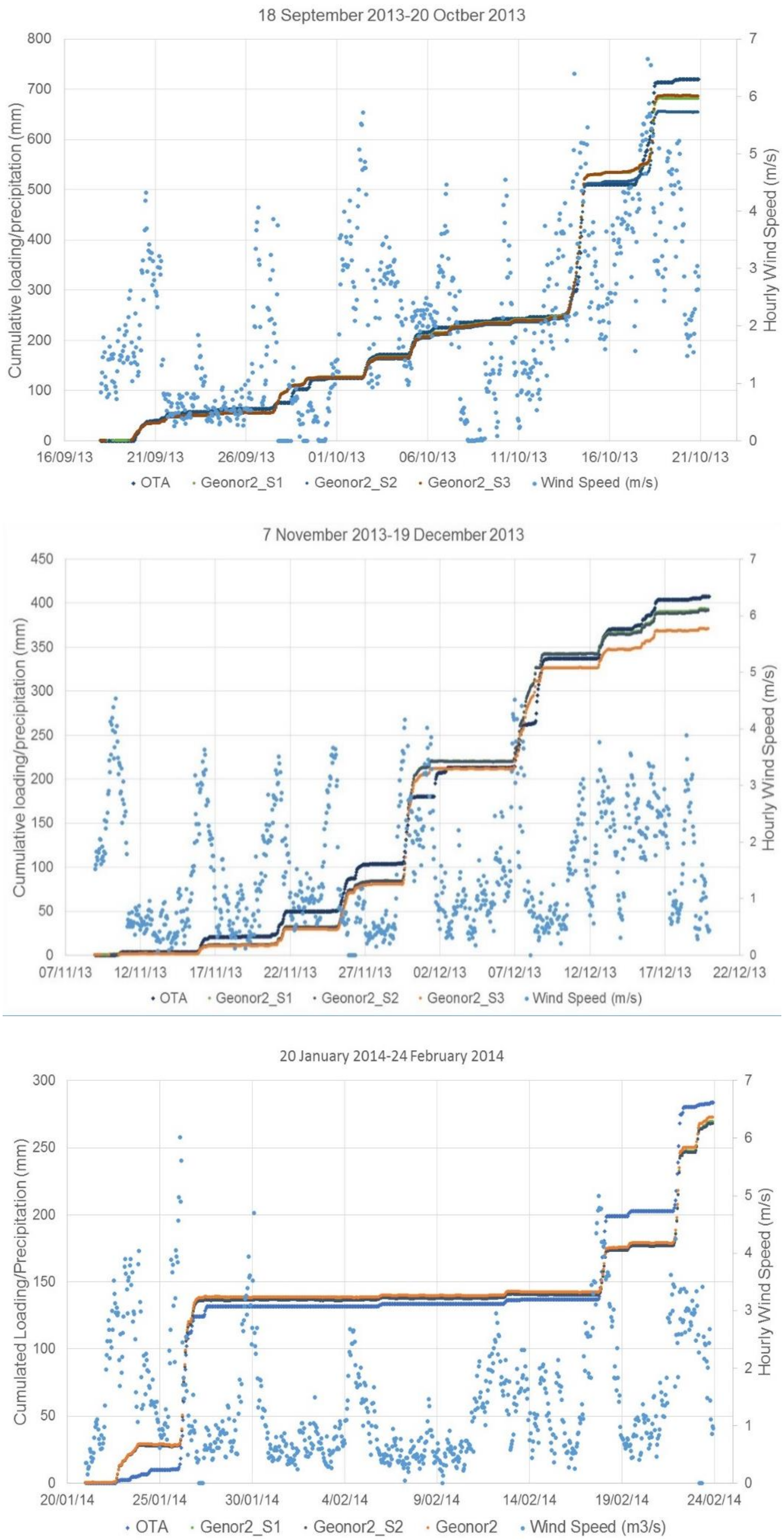
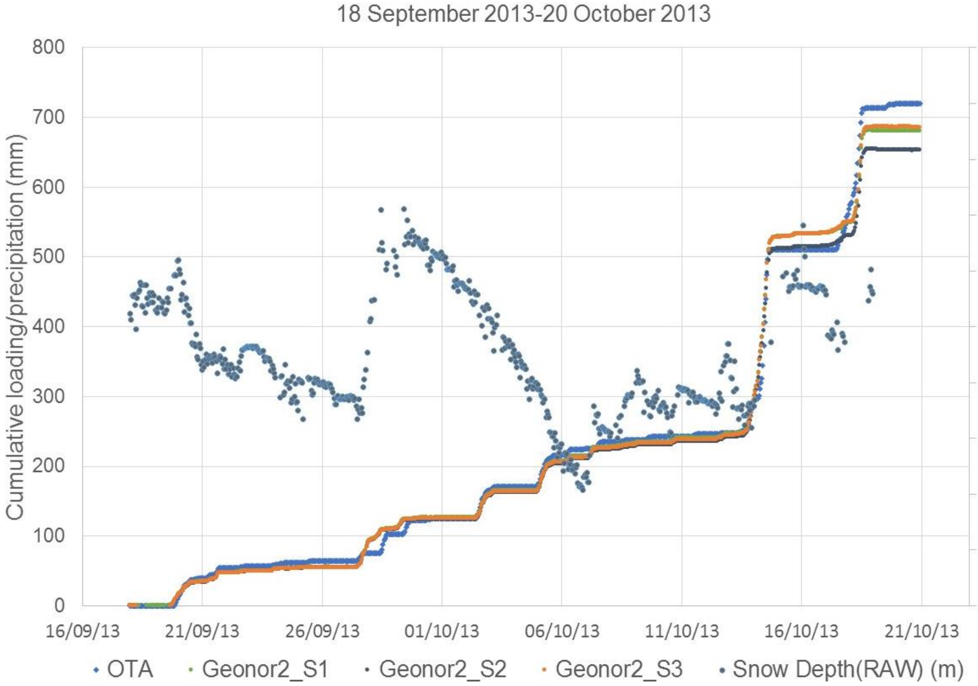


Figure 15: Tipping bucket gauge-G2 cumulated precipitation for all transducers for 3 separate time periods. Comparison is with hourly wind speed



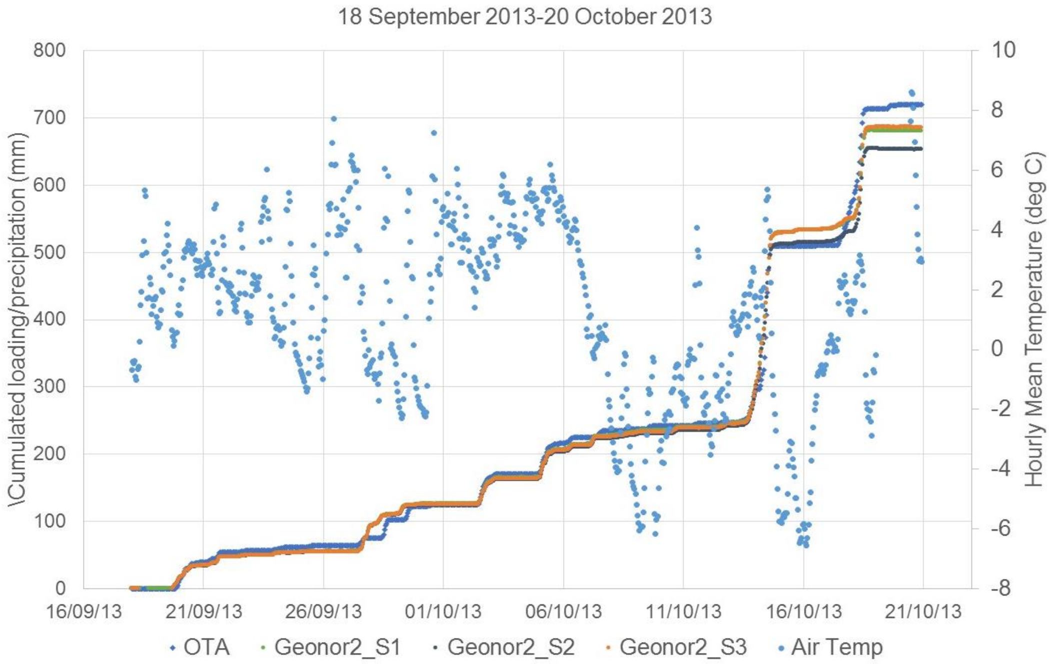


Figure 16: Tipping bucket gauge-G2 cumulated precipitation for all transducers during 18 September 2013-20 October 2013 compared with air temperature and snow depth recorded at the EWS.

4.2 SPECIFIC EVENTS

The data collected by the tipping bucket gauge and Gauge G2 during three independent events was compared with the results as follows:

4.2.1 Case 1: Winter event 16-20 October 2013

The following precipitation was observed:

- No precipitation was recorded at the tipping bucket gauge or G2 for the first 24 hr.

- Light precipitation (around 0.6mm/hr.) was recorded across all instruments over a period of 9 hours. No precipitation was recorded at tipping bucket gauge for the first 5 hours.
- Light precipitation was recorded by the G2, over a period of 6 hours (around 1mm/hr.), with no precipitation for the following 6 hours. However at the same time, the tipping bucket gauge is recording large amount of precipitation (around 60mm). This 6 hour period is associated with wind speed above 5m/s.
- Both the tipping bucket gauge and G2 record a large amount of precipitation (around 10mm/hr) with winds above 5m/s and positive temperature
- A plateau is then reached for the cumulative precipitation, indicating no further precipitation during the following 24 hours.

The total precipitation recorded over the 3 day period by the tipping bucket gauge is 209 mm, while G2 recorded a mean of 145 mm (138-152 mm). Figure 17 presents the cumulated loaded measured at tipping bucket gauge and G2 with air temperature, hourly average wind and snow depth.

The range of loading experienced by the transducers for G2 is around 5-10 mm (3 to 7% of the cumulated load experienced by G2). This range is assumed to be the result of the high wind experienced by the site at the time of the measurements.

While the under catch of the tipping bucket gauge is expected, and confirmed at the start of the event (17 October 2013), the resulting cumulated precipitation measured across the event (i.e. 209mm) is larger than the one measured by G2 (around 145mm) by over 140%. This result has been observed across all seasons for all type of weather conditions, but is not happening all the time. As yet we are not certain of the cause.

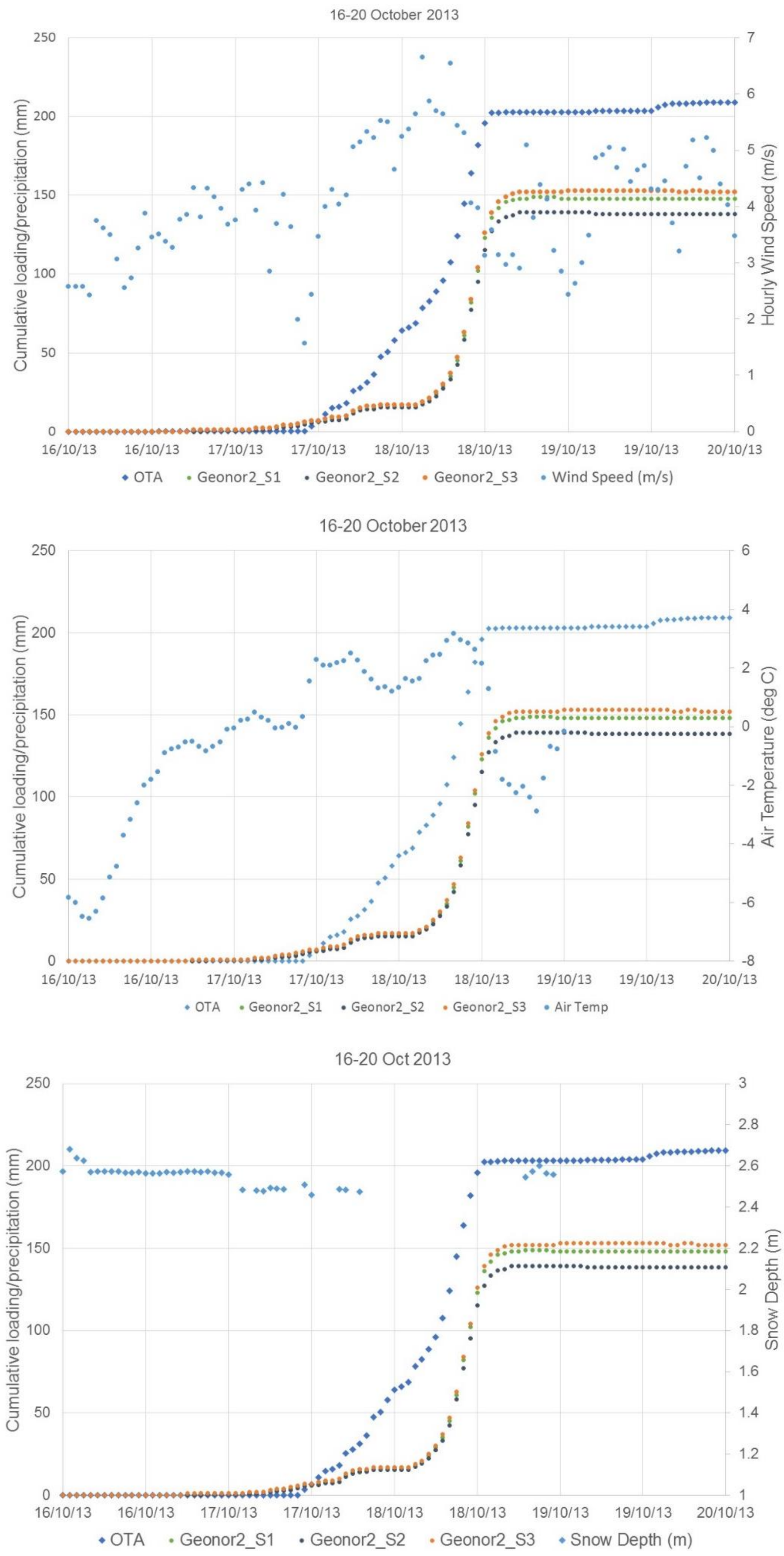


Figure 17: Tipping bucket gauge-G2 cumulated precipitation for all transducers during 16 October 2013-20 October 2013. Comparison with wind speed, air temperature and snow depth recorded at the EWS.

4.2.2 Case 2: Spring event: 28 November-10 December 2013

The following precipitation was observed:

- No precipitation was recorded at the tipping bucket gauge or G2 for the first 38 hr.
- Precipitation was recorded at the tipping bucket gauge for 8 hours (around 9mm/hr.), while the G2 recorded precipitation for a further 9 hours (totalling 17 hours - average rate around 6mm/hr.). No precipitation was recorded at tipping bucket gauge for the next 5 hours. Observed winds were below 4m/s, and snow depth increased by 40cm over that time period. No measurements were available from the snow pillow.
- As temperature increased, it is assumed that any snow accumulated in the orifice of the tipping bucket gauge melted over a period of 18 hours, causing an apparent rainfall signal.
- No precipitation is recorded at any gauge for the next 5 days. Snow depth reduced at a nearly constant rate.
- A precipitation event occurs over a period of 13 hours which, given the increase in snow depth, becomes a snowfall event.
- Snow melting occurred for the remainder of the event, characterised by an increase in precipitation recorded in the tipping bucket gauge.
- Cumulative precipitation measurement bias across the transducers (i.e. the total load on each transducer) from G2 seems to increase with solid precipitation. (3mm on 30 November- 20 mm on 2/12/2013-20mm on 7/12/2013-40 mm 10 December 2013)

The total precipitation recorded over the 3 day period by the tipping bucket gauge is 233 mm, while G2 recorded 253 mm (245-258 mm). Figure 18 presents the cumulated loaded measured at tipping bucket gauge and G2 with air temperature, hourly average wind and snow depth.

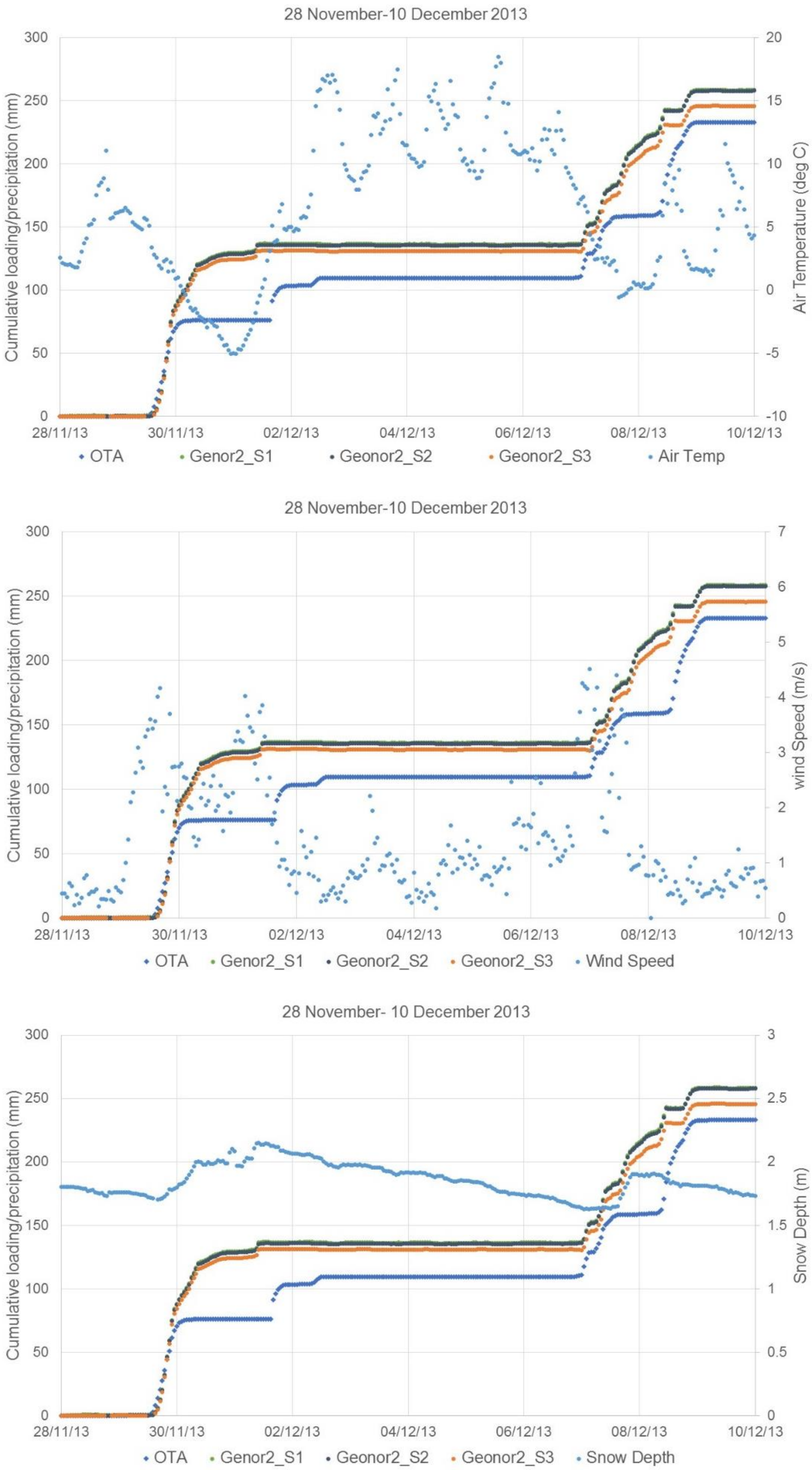


Figure 18: Tipping bucket gauge-G2cumulated precipitation for all transducers during 28 November 2013-10 December 2013. Comparison with wind speed, air temperature and snow depth recorded at the EWS.

The range of loading experienced by the transducers for G2 for this event is around 5-10 mm (7% - 21% of the cumulated load experienced by G2). Preliminary analysis of the information collected does not indicate any correlation between precipitation measurement bias, wind speed and temperature.

4.2.3 Case 3: Summer event 17-20 February 2014

The following precipitation was observed:

- No precipitation was recorded at the tipping bucket gauge or G2 for the first 19 hours.
- Both the tipping bucket gauge and G2 record a large amount of precipitation over a period of 8 hours, however the total amount recorded by the tipping bucket gauge is nearly twice as much as those recorded by G2. Wind conditions at the time were getting calmer and the air temperature was positive. No snow on the ground was measured at the time confirming that all the precipitation was liquid precipitation.
- A plateau is then reached for the cumulative precipitation, indicating no further precipitation during the following 28 hours

The total precipitation recorded over the 3 day period by the tipping bucket gauge is 66 mm, while G2 recorded 37 mm (37-37 mm). Figure 19 presents the cumulated loaded measured for tipping bucket gauge and G2 with air temperature and hourly average wind.

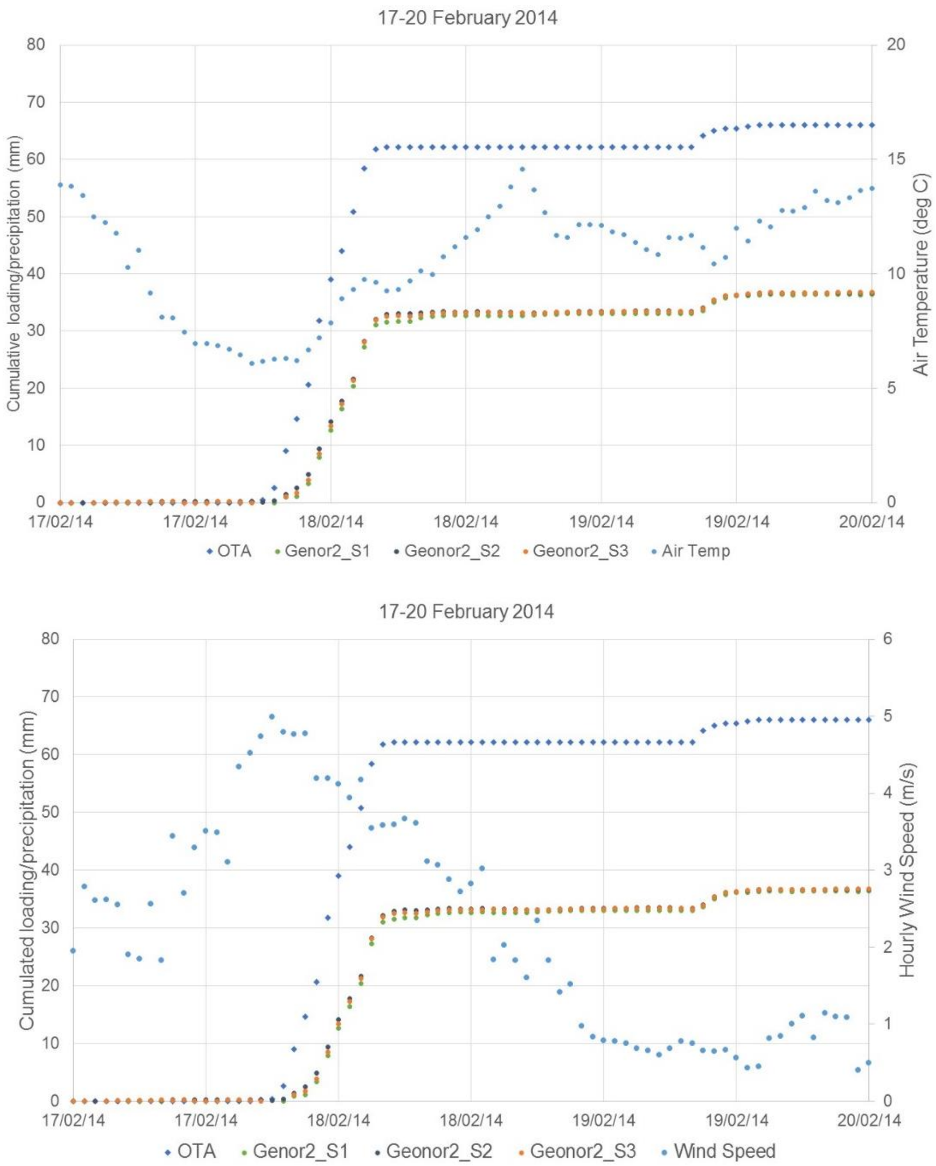


Figure 19: Tipping bucket gauge-G2 cumulated precipitation for all transducers during 17 February 2014-20 February 2014. Comparison with wind speed and air temperature recorded at the EWS.

5. DISCUSSION AND CONCLUSION

In this study, a preliminary assessment of the performance of solid precipitation gauges located in a remote location at high elevation in a harsh environment of the Southern Alps of New Zealand has been conducted. The study aims to assess the mixed precipitation measurement performance of an unshielded Geonor weighing bucket gauge, to perform inter-comparison with a tipping bucket gauge, to quantify the potential impact of wind and associated extreme weather on such measurements and the operational limitations of choosing such gauges for precipitation measurement in remote areas.

Snow and Ice monitoring stations in New Zealand are located in harsh environments with challenges of access, maintenance, installation engineering and cost, it is therefore extremely important to develop a proper testing procedure before an eventual roll out of replacement equipment nationally.

A number of issues have been identified and we are trying to work with manufacturers on these. For example, Geonor A/S is currently engaged to help understand why issues such as: i) bias in the information measured by each transducer within an instrument; ii) bias for transducer related information increases with solid precipitation are being encountered.

During large events significant amounts of precipitation fall, potentially resulting in the weighing bucket gauges over flowing. This situation has been occurring even with alarms when the gauges are nearing capacity before a specific event. Due to the amount of annual precipitation experienced by the Southern Alps of New Zealand the use of such gauges in remote locations will require either: i) increased frequency of site maintenance (such access is weather dependant and also related to maintenance budgets); ii) increase in the capacity of the weighing bucket gauge (issue with consent required for operation); or iii) establishment of an automatic siphon mechanism yet able to capture contents and allow replenishment of anti-freeze and oil.

Across the period of September 2013-February 2014, the tipping bucket gauge recorded slightly more cumulated precipitation that the unshielded G2 (-5%- -6%). The result of the tipping bucket gauge recording at least as much precipitation is different to what was expected at the start of the experiment where a tipping bucket gauge was expected to record less precipitation due to a larger under catch caused by wind effects, deposition of the snow in the funnel or on the structure, temperature effects with the build-up of an ice cap blocking any solid precipitation during extreme cold temperature. This first set of results will be investigated further during the second year of the experiment.

The tipping bucket gauge seems to record more total precipitation than the unshielded G2. This analysis was carried out on three events during different seasons and is illustrated above. This result is quite surprising and requires further investigation as larger under catch (either due to wind or temperature effects) was expected from the tipping bucket gauge.

G2 records precipitation as soon as it enters the weighting container. Delay in record from the tipping bucket gauge is due to below freezing temperatures experienced at the site meaning solid precipitation is recorded only after solar heating. The timing of delivery and measurement of the melted snow accumulation will be investigated later in the program.

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7. REFERENCES

Henderson RD, Thompson SM., 1999. Extreme rainfalls in the Southern Alps of New Zealand. *Journal of Hydrology (NZ)* 38 (2): 309 – 330

Hendrikx, J**.,** Harper, A., 2013. Development of a national snow and ice monitoring network for New Zealand. *Journal of Hydrology (NZ),* 52(2): 83-96.

Hoover, J, 2012. SPICE Calibration and Configuration Recommendations for the GEONOR Precipitation Gauge

Ministry of Business Innovation and Employment, 2013. Energy in New Zealand. Ministry of Business Innovation and Employment- Wellington- New Zealand. ISSN: 2324-5913

Ministry for the Environment, 2013. Freshwater reform 2013 and beyond. Wellington. Ministry for the Environment. ISBN 978-0-478-37298-4

Mountain Safety Council, 2012. The New Zealand Avalanche Centre Back Country Avalanche Advisory http://www.avalanche.net.nz

New Zealand's current electricity production - MBIE-2013 http://www.mbie.govt.nz/news-and-media/news-from-around-mbie/2013-news/august/energy-in-new-zealand-2013-report-released

NIWA 2012, Overview of New Zealand Climate. http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview