Snow Storm Data Collection: Mobilisation in September 2010

The remains of Stadium Southland's roof in Invercargill (Photo: Malcolm Gayfer, Weatherwatch.co.nz)

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Prepared for

Department of Building and Housing

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Executive Summary

This document has been prepared for the Department of Building and Housing to report on the snow storm, ground snow loading data collection campaign, undertaken by NIWA on the 19th of September 2010, following the large snow event in Invercargill and across Southland. This snow event started on the evening of the 17th of September and included 16 hours of heavy snowfall, followed by intermittent snow rain, hail and sleet, prior to the measurements being taken on the 19th of September. The snow event resulted in extensive damage to a number of buildings in Invercargill, including Stadium Southland and a number of other commercial buildings and structures. These data are intended to assist the Department of Building and Housing in assessing if the building standard (Australian/New Zealand Standard, 2003) is in line with observations of ground snow loading at lower elevations (<900m).

Using a simple and repeatable predefined methodology, snow storm ground snow loading data was collected in Invercargill for comparison with the ground snow loading building standard. Snow depth and density data were collected and these were then converted to the ground snow load (Sg). The September 2010 snow storm was a significant snow storm event in terms of observed ground snow load in Invercargill. The mean observed ground snow loading at both of the two selected locations within Invercargill exceeded the pre-2008[i] 1 in 50 year Sg of 0.38 kPa as calculated according to the building standards (AS/NZS 1170 Part 3) for sub-alpine areas in the N5 region of the South Island. The upper observed Sg in the field adjacent to Stadium Southland also exceeds the pre-2008 1 in 150 year Sg of 0.47 kPa and the 1 in 250 Sg of 0.51 kPa, as calculated according to the building standards (AS/NZS 1170 Part 3) for sub-alpine areas in the N5 region of the South Island. However, none of the observed Sg values exceed the new (post-2008[ii]) minimum snow load for the Canterbury, Otago and Southland regions of 0.9 kPa. This report does not make any conclusions regarding the snow loading experienced on the roofs of any buildings in Invercargill, or the return period of this event. It simply reports the observed ground snow loading and compares these to the building standards.

The NIWA snow data collection campaign was again successful in collecting ground snow loading data under trying conditions, for a snow event which exceeded the given snow depth thresholds. Recommendations include ongoing data collection, a more thorough analysis to be undertaken of the 1 in 50, 1 in 150, 1 in 250 and 1 in 500 year Sg, assessment of the density parameter, and potential automated monitoring of Sg.

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[i] Pre-2008 is defined as AS/NZS 1170 Part 3 (Australian/New Zealand Standard, 2003)
[ii] Post-2008 is defined as AS/NZS 1170 Part 3 as modified by the Department of Building and Housing's Compliance Document B1 Structure, in Verification Method B1/VM1, (including Amendment 8 December 2008) (Department of Building and Housing, 2008b).

1. Introduction

This document has been prepared for the Department of Building and Housing to report on the snow storm, ground snow loading data collection campaign undertaken by NIWA on the 19th of September 2010 in Invercargill. This snow event resulted in extensive damage to a number of buildings, including Stadium Southland, Windsor Street New World, Wrens decorating store, Evandale Gardens, and two workshops owned by Southern Transport, as well as many other structures. Furthermore, extensive stock losses were experienced by farmers in the wider Southland region.

Hendrikx (2007b) prepared a report for the Department of Building and Housing outlining a simple, repeatable methodology for the collection of ground snow loading data. Two methodologies were described, one for exceptional low elevation snowfall events, the other for snow loading at higher elevations. The data from these NIWA data collection campaigns will be appropriate for: setting or assessing the basis for snow loading requirements for buildings at low altitudes (<900m) in the eastern and southern (N4 & N5) regions of the South Island (where the buildings are most at risk); and ensuring that the building standard (Australian/New Zealand Standard, 2003) is in line with observations of ground snow loading at higher elevations (>900m).

For Invercargill and surrounding coastal regions in Otago and Southland the snow depth threshold for mobilisation was set at 0.10m. The event of 18 September, 2010 in Invercargill and Southland was the only exceptional low elevation snow storm which exceeded the suggested threshold depth for mobilisation (Hendrikx, 2007b) during the winter of 2010. This document presents the findings from this data collection campaign and comments on the alignment of the observations to the snow loading building standards (Australian/New Zealand Standard, 2003). Recommendations for further enhancement of the snow loading building standard are also made.

2. Objectives

The purpose of this document is:

- To provide background and a description of the snow storm event including records of the wind speeds and directions over the period 17 to 19 September, 2010.

- To present the field data for ground snow loading (Sg) for the 18th of September 2010 Invercargill snow event.

- To compare field observations of the ground snow loading to the building standard to help assess whether the building standard is in line with observations.

- To comment on the uncertainties, limitations and modifications of the methods and analysis used.

- To make suggestions for further enhancements to the building standard in relation to snow loading.

3. Description of the storm

This description of the snow event is intended to bring a general level of understanding of the meteorological processes at play that resulted in the snow event. It is not intended to be an in-depth meteorological discussion of the state of the atmosphere and the processes that operate therein.

The snowfall in Invercargill and Southland occurred due to an ideal combination of factors that were located in the right place at the right time. A very deep complex low pressure system tracked towards New Zealand in the days prior to the snow event. This low was described by the media as a “Massive storm heading for New Zealand” and “one of the largest storms on the planet”, although MetService Ltd was quick to distance itself from this hyperbole (Kreft, 2010). However, the location and size of the low pressure system was responsible for drawing very cold air and precipitation from very far south in the Southern Ocean. As this complex low moved south and east over the course of Friday and into the early hours of Saturday, it drew even colder air from as far south as Antarctica and the precipitation fell as rain, hail and snow (Figure 1). The location of the low was critical as it allowed a shallow pocket of cold NW air to flow into Invercargill. This air was sufficiently cold for the precipitation to fall as snow (Figure 2). Had this system been further east and the flow more SW or S (and directly off the ocean) it is likely that the precipitation would have fallen as sleet, as opposed to snow (Fraser *pers comm*., 2010).

Throughout Metservice Ltd was well aware of this system and while downplaying the exaggeration of the media regarding the size of the low pressure system, they had noted that this system would result in severe weather over much of the country and that there was a risk of snow to very low levels in the south of the South Island. The MetService outlook on the position for the weekend issued on 15/09/2010 was:

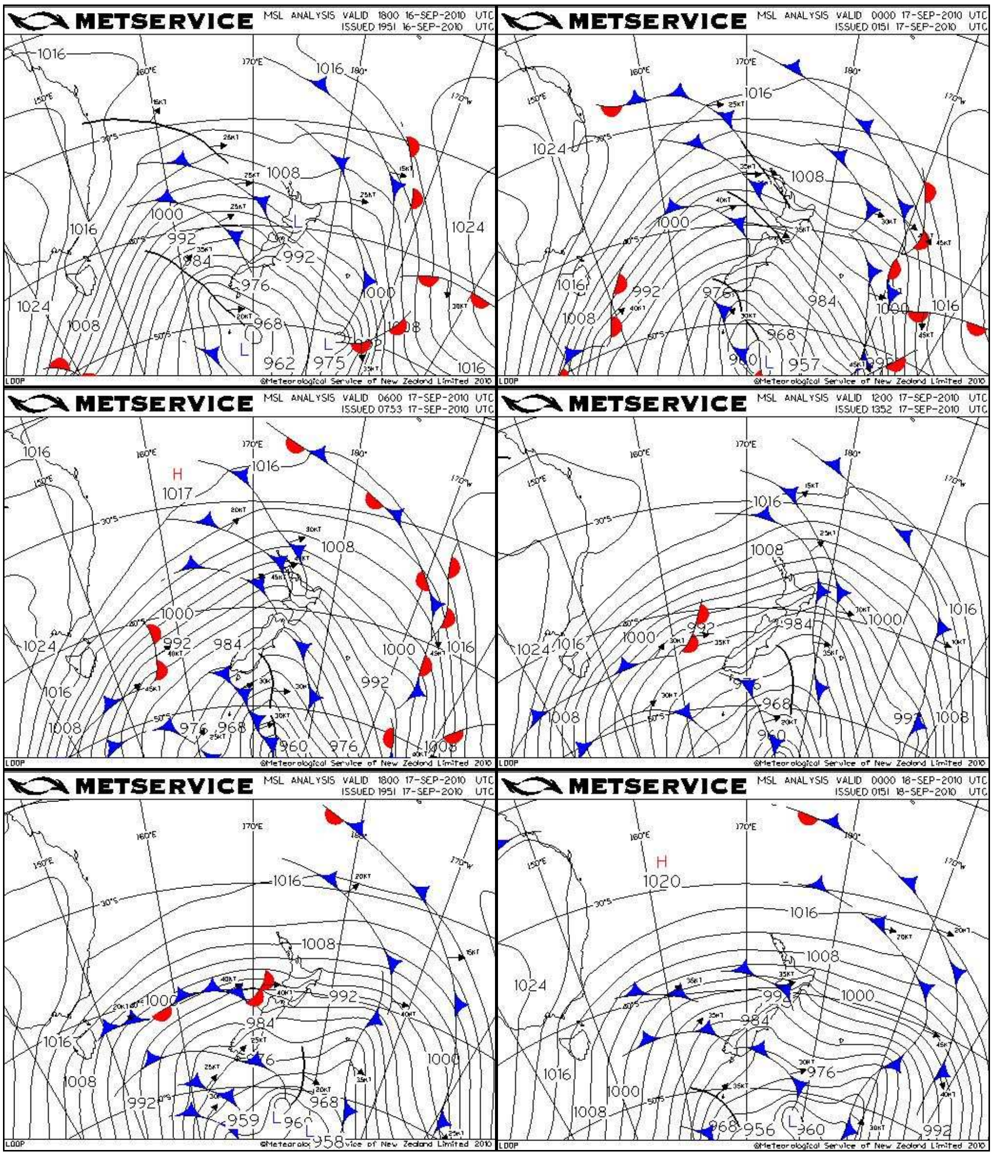

Figure 1: **Mean Sea Level charts from 0700 (NZDT) on 17/09/2010 to 1300 (NZDT) on 18/09/2010, showing the synoptic analysis of the situation that resulted in the snow event in Invercargill. (NZDT = UTC +13 hours). Maps courtesy of Metservice Ltd.**

"A very strong cold westerly flow is expected over New Zealand on Friday and there are watches and warnings valid for heavy rain, heavy snow and severe gales.

On Saturday a fast moving front in the westerlies should cross the South Island with winds again increasing over much of northern and central New Zealand. There is a moderate or high risk of westerly gales over all the North Island from Auckland southwards and for much of Marlborough and north Canterbury. Westerlies should ease somewhat on Sunday before strengthening again on

Monday. There is a chance of further severe gales in southern North Island areas on Monday.

Periods of heavy rain or showers are expected in the west of the South Island throughout the period from Saturday to Monday. However rainfall totals on a day by day basis are not extreme and are marginal for warning criteria. A heavy snow warning is in force for Fiordland on Friday. ***Further bursts of heavy snow are likely there during the weekend, though not to quite such low levels as are forecast on Friday. A southwest change will bring a brief period of strong winds and snow to low levels over Southland and South Otago on Saturday but with only a low risk of heavy falls****."* (Metservice, 2010)

The majority of the snowfall is thought to have occurred from approximately 2000 on 17/09/2010 to around 1200 on 18/09/2010, with the most intense snowfall occurring after 0600 on 18/09/2010. Further snow showers did occur after this time period in the hours and days after the main event, but the majority of the snowfall occurred in this initial 16 hour period. This is our estimate, based on the available meteorological data, media reports and discussions with the local meteorological observer (Fraser *pers comm*., 2010). Air temperature and relative humidity was automatically recorded during this event by the Metservice Ltd Automatic Weather Station (AWS) (Network #I68435) which is situated near Invercargill Airport (approx NZMG: 2151130E, 5411030N), at an approximate elevation of 1m AMSL. During this time period, hourly average air temperatures ranged from 1.7ºC at 2000 on 17/09/2010 to 0.3ºC at 1100 on 18/09/2010 and hourly average relative humidity was typically in the 90-99% range (see Appendix 1 for a table of relevant meteorological parameters).

Precipitation data from this site has not been reported on, as the type of gauge used at this site does not adequately deal with the solid phase of mixed phase precipitation (i.e. snow, sleet, hail). Therefore, the "observed hourly rainfall" from this site would likely be a combination of snowmelt, rain, melted hail and sleet and the observed amount cannot correctly be attributed to one hourly period of precipitation. Simply presenting the "observed hourly rainfall" from this site is not helpful and could be misleading unless the gauge type and its limits were properly understood.

Wind speed (average and maximum gust) and direction was also automatically recorded during this event by the Metservice Ltd AWS (Network #I68435). This site is a World Meteorological Organisation (WMO) standard site with wind speed and direction being recorded at the standard 10m above the ground. This site was actively maintained in accordance with the standards and the wind speed and direction was last calibrated on 27 March 2010 (NIWA, 2010). The chart shown in Figure 2 below shows the wind speed (average and gust) and wind direction for the period 17

September to 19 September inclusive (see Appendix 1 for a table of relevant meteorological parameters).

Wind can transport and redistribute snow that has been deposited, as well as lead to preferential snow deposition. According to a study of hourly average wind speed thresholds undertaken in western Canada (Li and Pomeroy 1997), the majority of recorded threshold wind speeds for the initiation of blowing snow (as measured at 10 m) range from 7 to 14 m s^{-1} with an average of 9.9 m s^{-1} for wet snow transport, and from 4 to 11 m s^{-1} with an average of 7.7 m s^{-1} for dry snow transport. Wet snow was defined as snow that had been subject to temperatures greater than 0ºC since the last snowfall, whereas dry snow had never been subjected to temperatures above the freezing point (Li and Pomeroy 1997).

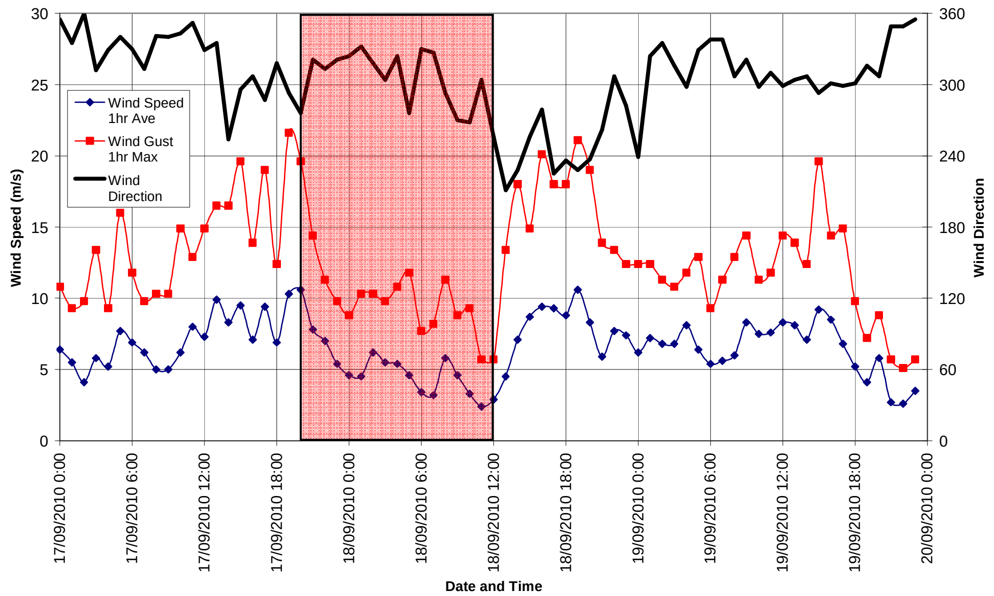

Figure 2: **Wind speed (hourly average and hourly maximum gust in m/s) and hourly average wind direction (east of north in degrees) recorded at Invercargill AWS (Network #I68435) for the period 17 September to 19 September inclusive. The shaded box indicates the time period when most of the snowfall occurred.**

The snow that was experienced in Invercargill can be categorised as wet snow, given the above freezing temperatures and density of the snow. The majority of observed average hourly wind speeds observed at Invercargill AWS were below the Li and Pomeroy (1997) lowest threshold range for wet snow of 7 m s^{-1}. Only the hourly average wind speeds at 2000, 2100 and 2200 on 17/09/2010 (when there was minimal snowfall) were at or above this lower threshold for blowing snow with wind speeds of 10.6, 7.8 and 7.0 m s^{-1} observed respectively. Therefore, while substantial blowing snow and redistribution of snow seems to have been unlikely during this event, an amount of preferential deposition may still have occurred in wind sheltered locations.

4. Methods: Snow Data Collection

A snow storm, ground snow loading data collection campaign was completed from 1130 to 1635 on the 19th of September 2010 in Invercargill, Southland. The general location of the campaign was selected to be in the region where snow depths had been reported to have exceeded the suggested snow depth threshold of 0.1m as outlined by Hendrikx (2007b). Within this region the focus was Invercargill City as there had already been a number of buildings collapse on the Saturday 18th of September, 2010. Two locations were selected to collect ground snow loading data, these were at the Queens Park Cricket Grounds (approx: WGS84 46 24 18.4 S, 168 21 29.4 E) and the field behind Stadium Southland (approx: WGS84 46 24 28.5 S, 168 22 54 E) (Figure 3). Additionally, we also have reliable reports from the meteorological observer at Invercargill (Fraser *pers comm*., 2010) that are consistent with our observations.

(A)

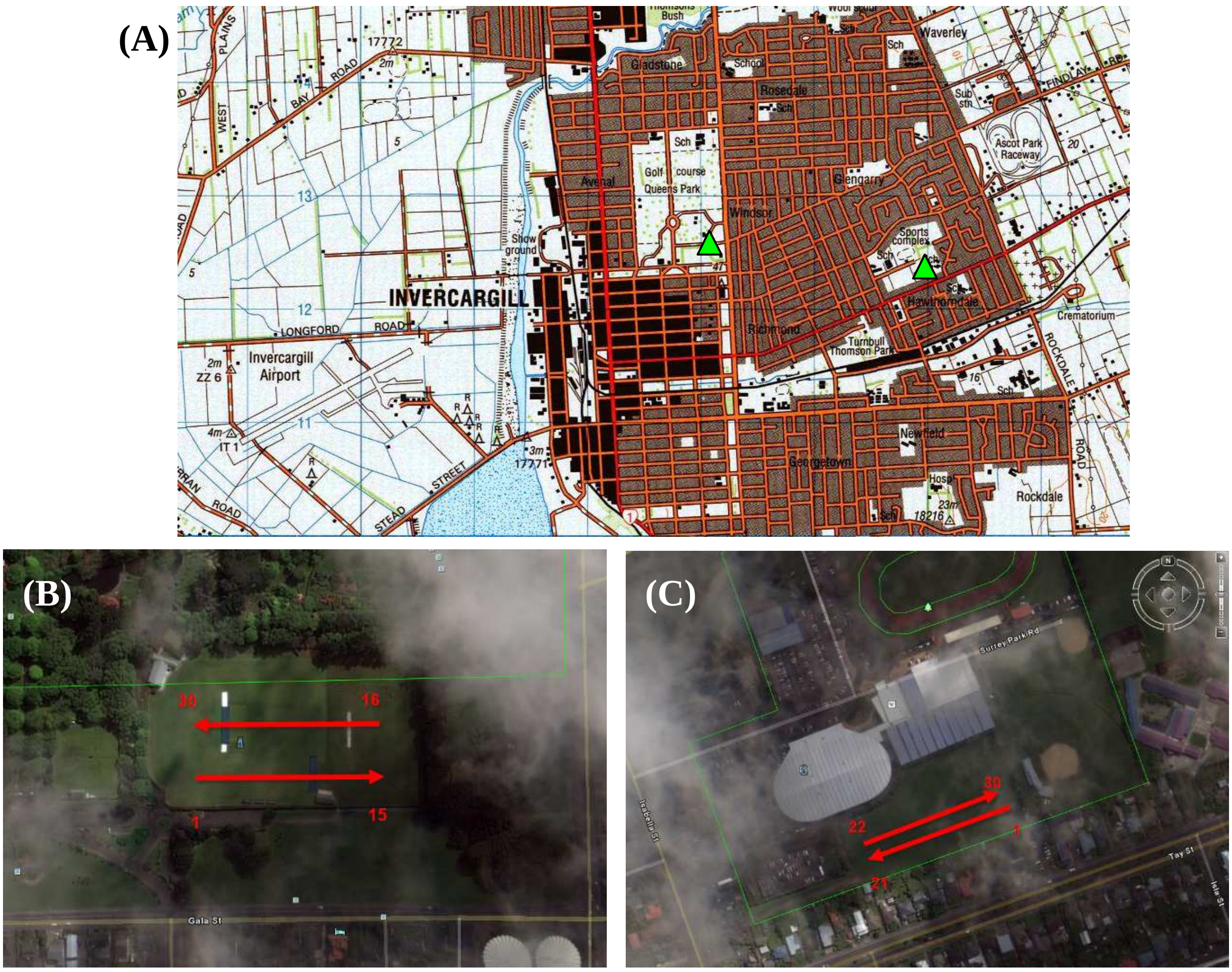

Figure 3: (A) Map of Invercargill showing the general location of the two sample sites for snow observations as green triangles, and (B) Satellite image of the Queens Park Cricket grounds and (C) Satellite image of the Stadium Southland field with the approximate locations of the data collection. Numbers relate to the approximate location of the snow observations. (Source: MapToaster, 2010 & Google Earth, 2010).

Snow data was collected at the two locations in Invercargill (Figure 3) using a slightly modified version to the prescribed methodology as outlined by Hendrikx (2007b). Instead of the recommended 57 snow depths and 5 sets of 3 snow density observations, 30 snow depth and 30 sets of snow density observations were made at each location. Additional snow density observations were made as these are critical for calculating the ground snow load and the density parameter has been an area of some debate (Hendrikx, 2007a).

At each location, snow depths and density observations were taken at 5-10m horizontal spacing. Snow density was recorded at different depths throughout the snowpack, using the snow density kit and a standard method (Figure 4). Given the depth of the snowpack and the size of the cutter in the snow density kit (37mm internal diameter) all locations permitted three density observations to be made. In total, over 60 snow depths and 180 individual snow density observations were made during the field campaign.

Figure 4: Snow density is measured by excavating a profile wall in the snowpack and then inserting the density cutter at different elevations in the profile. The cutter is then carefully removed and placed on a calibrated scale (Photo: Andrew Willsman).

5. Results: Data analysis and comparison to the building standards

The following section describes the data analysis for the data collected at the two locations in Invercargill on the 19th of September 2010. The full data set which was collected at each location is tabulated in Appendix 2.

5.1. Snow data from the field adjacent to Stadium Southland

The snow depth observations taken in the field behind Stadium Southland had a mean depth of 0.12m (N=30), and ranged from 0.12 to 0.13m. At each of the 30 points, three density measurements were taken at different elevations in the snowpack. The highest recorded mean density for one of these 30 sites (i.e. the mean of 3 observations at different depths) was 430kgm^{-3}, and the lowest was 350kgm^{-3}, and they had a mean of 380kgm^{-3} / 3.7kN/m^{2} (N=30). The upper, mean and lower density values from this set of 30 values will be used for the calculation of ground snow load. However it is worth noting that when we consider each of the individual densities at each site and at differing depths, the values ranged from 280kgm^{-3} to 480kgm^{-3}, but they still had a mean of 380kgm^{-3} (N=90).

5.2. Snow data from Queens Park Cricket ground

The snow depth observations taken at Queens Park cricket ground had a mean depth of 0.11m (N=30), and ranged from 0.11 to 0.12m. At each of the 30 points, three density measurements were taken at different elevations in the snowpack. The highest recorded mean density for one of these 30 sites (i.e. the mean of 3 observations at different depths) was 420kgm^{-3}, the lowest was 330kgm^{-3}, and they had a mean of 380kgm^{-3} / 3.7kN/m^{2} (N=30). The upper, mean and lower density values from this set of 30 values will be used for the calculation of ground snow load. However it is worth noting that when we consider each of the individual densities at each site and at differing depths, the values ranged from 230kgm^{-3} to 550kgm^{-3}, but they still had a mean of 380kgm^{-3} (N=90). In about 15 of the 30 point observations at this location the lowest 0.01m of the snowpack was showing signs of snowmelt, with clear translucent grains being evident. Assuming no substantial melt water had left the snowpack and percolated into the ground, this melt will have reduced the snow depth, but the density would have increased, thereby not changing the ground snow load measured.

5.3. Observed ground snow loading

For the calculation of the observed ground snow load (marked as Sg^1), the observed mean depth and observed mean density at each of the two locations were calculated and used in the equations as stated in the Australian/New Zealand Standard (2003).

This is the mean observed ground snow loading from this event. We have also used the highest observed snow depth at each location (N=30), with the highest observed snow density at each location (N=30) to calculate an upper Sg^1 for each location. Likewise we have used the lowest snow depth at each location (N=30) and lowest density at each location (N=30) to calculate a lower Sg^1 for each location. Both the lower and upper values of Sg^1 have been calculated to provide an envelope of possible observed ground snow load (Table 1).

A second ground snow load (marked as Sg^2) was calculated using the specified density value from the building standard (296 kgm^{-3} or 2.9 kN/m^2). This was done to illustrate the effect of the density of the snow on the ground snow loading. The 1 in 50 year return period, as calculated from the standards (pre 2008) has also been shown to permit comparison of this event to the standards. However it must be noted that since 2008 the minimum snow load for the Canterbury, Otago and Southland regions was set at 0.9 kPa (Department of Building and Housing, 2008a, 2008b). Pre-2008 is defined as AS/NZS 1170 Part 3, while Post-2008 is defined as AS/NZS1170 Part 3 as modified by the Department of Building and Housing's Compliance Document B1 Structure, in Verification Method B1/VM1 (Department of Building and Housing, 2008b). Table 1 presents a summary of the snow depths and densities at each of the two locations, the calculated Sg^1, the 1 in 50, 150, 250 and 500 year return period, Sg^2 from the standard, and the new 2008 minimum ground snow load.

As we can see from Table 1, the mean observed ground snow loading (Sg^1) at both of the two locations exceeded the pre-2008 1 in 50 year Sg of 0.38 kPa as calculated for sub-alpine areas of the N5 region of the South Island according to equation 5.4(8&9) (Australian/New Zealand Standard, 2003). The upper observed Sg in the field adjacent to Stadium Southland also exceeds the pre 2008 1 in 150 Sg of 0.47 kPa and the 1 in 250 Sg of 0.51 kPa, as calculated for sub-alpine areas of the N5 region of the South Island according to equation 5.4(8&9) (Australian/New Zealand Standard, 2003). None of the observed Sg exceeded the 1 in 500 Sg of 0.57 kPa. Furthermore, none of the observed Sg^1 values exceed the new (post 2008) (Department of Building and Housing, 2008b) minimum snow load for the Canterbury, Otago and Southland regions of 0.9 kPa.

If we had only used the observed snow depth information from this event and applied the prescribed density as stated in the standards (2.9 kN/m^2) to calculate Sg (this is marked as Sg^2 in the table), then both locations would have had a calculated ground snow load lower than the 1 in 50 Sg of 0.38 kPa as calculated for sub-alpine areas of the N5 region of the South Island according to equation 5.4(8&9) (Australian/New Zealand Standard, 2003). This underscores the need for improved understanding of snow density in low elevation snow events and may bring into question the value stated in the standard. However, again it must be noted that the new (post-2008) minimum snow load for the Canterbury, Otago and Southland regions is now 0.9 kPa.

Table 1: Location, elevation, mean snow depth, mean snow density, calculated mean, upper and lower observed Sg[1], calculated Sg[2] using observed depth and the specified density values from the standard, the 1 in 50 (1/50), 1 in 150 (1/150), 1 in 250 (1/250) and 1 in 500 (1/500) year return period Sg from the standard & new Sg.

Location	Elevation* (m)	Mean snow depth (m)	Mean snow density (kN/m^2)	Mean observed Sg [1] (kPa)	Upper** observed Sg [1] (kPa)	Lower** observed Sg [1] (kPa)	Calculated Sg [2] (kPa)	1/50 [3] Sg (kPa)	1/150 [3] Sg (kPa)	1/250 [3] Sg (kPa)	1/500 [3] Sg (kPa)	Post 2008[4] min Sg (kPa)
Stadium Southland	10	0.12	3.7	0.45	0.55	0.41	0.35	0.38	0.47	0.51	0.57	**0.90**
Queens Park Cricket Grounds	10	0.11	3.7	0.41	0.45	0.36	0.32	0.38	0.47	0.51	0.57	**0.90**

*Elevation has been estimated at 10m AMSL

**Upper and Lower observed Sg as defined in the text where the highest (lowest) mean snow density value and highest (lowest) snow depth value has been used from each location.

[1]Using the mean observed snow depths and snow densities.

[2]Using the mean observed snow depths and the snow density value (γ) of 296 kgm^{-3} (2.9 kN/m^2) as specified in AS/NZ 1170 Part 3: 2003

[3]Using equations 5.4(8) for Sg in AS/NZ 1170 Part 3: 2003.

[4]Using AS/NZS1170 Part 3 as modified by the Department of Building and Housing's Compliance Document B1 Structure, in Verification Method B1/VM1, (including Amendment 8 December 2008). (Department of Building and Housing, 2008b).

5.4. Spatial variability in snow depth and density

Variations in snow depth are partly due to the roughness of the surface topography and wind exposure of the site. However, many other factors (including micro scale winds, solar radiation and storm behaviour) also influence the variability. Given the flat terrain at each of the two locations, the variability in snow depth at each location was found to be low and within 0.01m.

Variations in snow density are mainly due to changes in temperature, relative humidity, wind speed and precipitation rates during the storm event. Post depositional melting and wind compaction also affects the snow density. In this event we observed different densities at differing elevations within the snowpack and spatially across the sampling domain. In general we observed higher density snow at the bottom and at the top of the snowpack. This is most likely due to the snow being warmed as it landed on the ground leading to settlement and sintering (increasing the density and reducing the depth). At the top of the snowpack, the higher density is also likely due to settlement, but potentially also wind, surface melt and sporadic sleet showers during the sampling. Regardless of the mechanisms, the different densities within the snowpack have been averaged for each of the 30 point observations, as this is the ground snow load experienced at each point. The spatial difference in density has been included and used with the depth values to calculate upper and lower bounds of possible ground snow load at each location.

5.5. Limitations and applications of this work

This report only documents the observed ground snow load as observed by NIWA on 19 September at two locations. Snow depth and snow density is spatially variable and other values may have been observed elsewhere by other parties. Use of the information in this report for extrapolation to other sites is done at the discretion of, and risk to the user.

This report has made no attempt to assess the return period of this snow event in Invercargill, or to comment on the return period as stated by the standards. This is outside the scope of this current report, but will be considered in future work.

6. Recommendations

The following are recommendations and suggestions for the further enhancement to the building standard in relation to snow loading:

- Undertake a return period analysis for this snow event, if the historical data is of sufficient quality and quantity to permit this with a reasonable level of accuracy.

- Continue the collection of ground snow loading in both the low elevation and alpine regions of New Zealand. As more data become available, more conclusive statements can be made about the relationship of ground snow loading observations to the current building standard.

- Use or create a long (i.e. 20+ year) data set from historical observations for one or more additional locations to provide for a more robust spatial assessment of the 1 in 50, 1 in 150, 1 in 250 and 1 in 500 year return period Sg.

- Consider the installation of snow monitoring equipment (e.g. Snow pillows) at a selection of key locations, (e.g. Canterbury Plains and Southland, Otago), to measure future Sg directly. This would provide an automated point record of Sg. The installation of snow pillows has a substantial capital cost for installation, but requires little ongoing maintenance in the 5-10 year time frame. These could be sited alongside existing meteorological infrastructure.

- Consider a review of the snow density parameter in the standard, especially for sub alpine regions. The current density value in the standards of 2.9 kN/m^2 has been shown to be lower than the observed densities in at least the most recent low elevation snow storms (Hendrikx, 2006 and this report).

While outside the scope of this report, a thorough review of the snow loading building standard may also be required as there are parameters within the standard that are poorly constrained and do not have sufficient observational data to support them. For example:

- Table 5.1 Probability factor (kP) in Section 5.2 Probability factor, shows that there is a lower probability factor for the same size events in New Zealand when compared to Australia. For example a 1 in 50 year event in New Zealand has a kP factor of 1.0 while it is 1.2 in Australia. What basis was this decided upon?

- Hendrikx (2006) suggests that the calculated Sg from the standards for the 1 in 150 year events seems to be too low and inconsistent with the available snow observations for New Zealand. On what basis was the 1 in 50, 1 in 150, 1 in 250 and 1 in 500 year return period event set? What confidence do we have in these return periods?

- In Australia a terrain multiplier (k_1) is applied and this ranges from 0.2 to 1.6, either further reducing or enhancing the expected Sg. Why is this parameter not also available for New Zealand?

- In section 6.2 figure 6.1 "balanced shape coefficient on a slope (μ_i)" shows that for a roof with a slope of less than 10º a μ_i value of 0.7 is to be used. This results in 30% less than the Sg on a roof with a pitch of less than 10 º. Why is this so? If this is to allow for loss due to sliding, then maybe this should be set at 1.0 for roofs less than 10º? What data is this coefficient based on? Another possible reason is that this coefficient μ_i is applied because the roof is substantially more wind exposed than the adjacent ground where the Sg was calculated? However, an exposure reduction coefficient (C_e) has already been factored into the calculation of roof snow load (Section 4.2.1 and 4.2.2) so this seems unnecessary. It is noted that this clause applies where snow is not prevented from sliding off the roof. Where the lower edge of the roof is terminated with a parapet, snow fence, or other obstruction, the shape coefficient shall be determined in accordance with Clause 6.5.

These and other matters should be addressed in future unless there are documented reasons for these parameters to remain. Additional new observations and research may be required to achieve this.

7. Conclusions

This document has presented, commented on and compared to the building standard the snow data which was collected during the snow storm, ground snow loading data collection campaign undertaken by NIWA on the 19th of September 2010 in Invercargill, Southland. This snow event started on the evening of the 17th of September and included 16 hours of heavy snowfall, followed by intermittent snow rain, hail and sleet, prior to the measurements being taken on the 19th of September. This snow event resulted in extensive damage to a number of buildings and structures in Invercargill, including Stadium Southland and a number of other commercial buildings and structures.

The mean observed ground snow loading (Sg^1) at both of the two selected locations exceeded the pre 2008 1 in 50 year Sg of 0.38 kPa as calculated according to the building standards for sub-alpine areas of the N5 region of the South Island. The upper observed Sg^1 in the field adjacent to Stadium Southland also exceeds the pre 2008 1 in 150 year Sg of 0.47 kPa and the 1 in 250 Sg of 0.51 kPa, as calculated according to the building standards for sub-alpine areas of the N5 region of the South Island. However, none of the observed Sg^1 values exceed the new (post 2008) minimum snow load for the Canterbury, Otago and Southland regions of 0.9 kPa. This report does not make any conclusions regarding the snow loading experienced on the roofs of any buildings in Invercargill. It simply reports the observed ground snow loading and compares these to the building standards.

The NIWA snow data collection campaign was again successful in collecting ground snow loading data under testing conditions, for a snow event which exceeded the given snow depth thresholds. These data will be used by the Department of Building and Housing for the purpose of assessing if the building standard (Australian/New Zealand Standard, 2003) is in line with observations of ground snow loading at lower elevations (<900m). Recommendations include ongoing data collection, a more thorough analysis to be undertaken of the 1 in 50 to 1 in 500+ year return period Sg, assessment of the density parameter and potential automated monitoring. Further issues are also identified.

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Appendix 1: Meteorological data

Data Name: Invercargill AWS Data (Network #I68435)

Date of Collection: 17-19 September 2010

Field Personnel: N/A

Client: Department of Building and Housing

NIWA Report Title: Snow Storm Data Collection: Mobilisation in September 2010

NIWA Project Code: DBH11501

Measurement Methods: Automatic

Accuracy of Measurement Methods: As per standards

Availability of data: Available via The National Climate Database (http://cliflo-niwa.niwa.co.nz/)

Meteorological data recorded at Invercargill AWS (Network #I68435).

Date and Time	Max Gust Speed (m/s)	Average Wind Speed (m/s)	Wind Direction (DegT)	Average Air Temperature (C)	RH(%)
17/09/2010 0:00	10.8	6.4	355	5.6	82.8
17/09/2010 1:00	9.3	5.5	335	5.9	84
17/09/2010 2:00	9.8	4.1	003	4.7	89.4
17/09/2010 3:00	13.4	5.8	312	4.5	88.1
17/09/2010 4:00	9.3	5.2	329	4	88.1
17/09/2010 5:00	16	7.7	340	3.7	83.1
17/09/2010 6:00	11.8	6.9	330	3.4	86.1
17/09/2010 7:00	9.8	6.2	313	3.4	88.1
17/09/2010 8:00	10.3	5	341	2	92.6
17/09/2010 9:00	10.3	5	340	3.3	92.4
17/09/2010 10:00	14.9	6.2	343	4.5	84.5
17/09/2010 11:00	12.9	8	352	4.4	84.8
17/09/2010 12:00	14.9	7.3	329	6.3	69.7
17/09/2010 13:00	16.5	9.9	335	1.6	94
17/09/2010 14:00	16.5	8.3	254	6.8	70.4
17/09/2010 15:00	19.6	9.5	296	4.3	66.8
17/09/2010 16:00	13.9	7.1	307	4	77
17/09/2010 17:00	19	9.4	287	3.9	79.5
17/09/2010 18:00	12.4	6.9	318	3.8	79.7
17/09/2010 19:00	21.6	10.3	293	2.8	75.4
17/09/2010 20:00	19.6	10.6	276	1.7	90.6
17/09/2010 21:00	14.4	7.8	321	0.7	97.1
17/09/2010 22:00	11.3	7	313	0.5	98.2
17/09/2010 23:00	9.8	5.4	321	0.4	99.1
18/09/2010 0:00	8.8	4.6	324	0.6	98
18/09/2010 1:00	10.3	4.5	332	1.1	95.2
18/09/2010 2:00	10.3	6.2	318	0.8	96
18/09/2010 3:00	9.8	5.5	304	0.8	95.2
18/09/2010 4:00	10.8	5.4	324	0.7	95.9
18/09/2010 5:00	11.8	4.6	276	0.9	95.8
18/09/2010 6:00	7.7	3.4	330	1.2	94.3
18/09/2010 7:00	8.2	3.2	327	1.6	92.7
18/09/2010 8:00	11.3	5.8	293	0.9	96.5
18/09/2010 9:00	8.8	4.6	270	1.4	96.6
18/09/2010 10:00	9.3	3.3	268	0.7	97.8
18/09/2010 11:00	5.7	2.4	304	0.3	98
18/09/2010 12:00	5.7	2.9	256	0.7	98.6
18/09/2010 13:00	13.4	4.5	211	0.8	97.9
18/09/2010 14:00	18	7.1	228	2.2	84.7
18/09/2010 15:00	14.9	8.7	256	4	68.3
18/09/2010 16:00	20.1	9.4	279	2.6	93.1
18/09/2010 17:00	18	9.3	225	2.5	79
18/09/2010 18:00	18	8.8	236	3.5	73.6
18/09/2010 19:00	21.1	10.6	228	1.6	90
18/09/2010 20:00	19	8.3	237	1.9	85.5
18/09/2010 21:00	13.9	5.9	262	2.4	77.2
18/09/2010 22:00	13.4	7.7	307	1.3	88.4
18/09/2010 23:00	12.4	7.4	282	3.1	74.6
19/09/2010 0:00	12.4	6.2	239	2.2	82.6
19/09/2010 1:00	12.4	7.2	324	0.7	93.8

19/09/2010 2:00	11.3	6.8	335	1	93.1
19/09/2010 3:00	10.8	6.8	316	0.7	89.8
19/09/2010 4:00	11.8	8.1	298	0.9	94.3
19/09/2010 5:00	12.9	6.4	329	0.4	97.5
19/09/2010 6:00	9.3	5.4	338	0.8	97
19/09/2010 7:00	11.3	5.6	338	0.7	97.5
19/09/2010 8:00	12.9	6	307	1.6	94
19/09/2010 9:00	14.4	8.3	321	1.5	93.1
19/09/2010 10:00	11.3	7.5	298	1.6	94.6
19/09/2010 11:00	11.8	7.6	310	2.3	93.3
19/09/2010 12:00	14.4	8.3	299	2.4	92.4
19/09/2010 13:00	13.9	8.1	304	3.1	84.9
19/09/2010 14:00	12.4	7.1	307	4	86.7
19/09/2010 15:00	19.6	9.2	293	3.8	90.1
19/09/2010 16:00	14.4	8.5	301	3.9	90.4
19/09/2010 17:00	14.9	6.8	299	5.1	80.3
19/09/2010 18:00	9.8	5.2	301	5.2	77
19/09/2010 19:00	7.2	4.1	316	4.4	79.7
19/09/2010 20:00	8.8	5.8	307	4.1	77
19/09/2010 21:00	5.7	2.7	349	3.2	83.2
19/09/2010 22:00	5.1	2.6	349	3.5	84.5
19/09/2010 23:00	5.7	3.5	355	3.2	85.3

Note: Precipitation data from this site has not been included in this table as the type of gauge used at this site does not adequately deal with the solid phase of mixed phase precipitation (i.e. snow, sleet, hail). Therefore, the "observed hourly rainfall" from this site would likely be a combination of snowmelt, rain, melted hail and sleet and the observed amount cannot correctly be attributed to one hourly period of precipitation. Simply presenting the "observed hourly rainfall" from this site is not helpful and could be misleading unless the gauge type and its limits were properly understood.

Appendix 2: Snow depth and density field data

Data Name: Invercargill Ground Snow Load Data

Date of Collection: 19 September 2010

Field Personnel: Andrew Willsman

Client: Department of Building and Housing

NIWA Report Title: Snow Storm Data Collection: Mobilisation in September 2010

NIWA Project Code: DBH11501

Measurement Methods: Snow depth was measured using a tape measure. Density was measured using the Winter Engineering water % density sampler (#1485). Tube internal diameter = 37mm, length = 92mm.

Accuracy of Measurement Methods: Snow depth observed to the nearest 0.01m. Snow Density to the nearest 1% of snow water equivalence or 10 kgm^{-3}.

Snow data from the field adjacent to Stadium Southland

Location: Stadium Southland	**Observer:** Andrew Willsman, NIWA
GPS: WGS84 46 24 28.5 S, 168 22 54 E	**Date:** 19 September 2010
Equipment: Winter Engineering water % density sampler #1485. Converted to kgm^{-3} Tube internal diameter = 37mm length=92mm	**Start time:** 1130 **End time:** 1440
Notes: On the grass field on the southern side of the stadium sampled along a 150m line with pits approximately 5 m apart	

Pit #	Snow Depth (m)	Horizontal core at base (kgm^{-3})	Horizontal core at midpit (kgm^{-3})	Horizontal core at top (kgm^{-3})	Mean horizontal cores (kgm^{-3})
1	0.12	400	380	360	380
2	0.12	440	380	380	400
3	0.13	430	380	380	400
4	0.13	440	350	370	390
5	0.13	420	360	450	410
6	0.12	390	290	450	380
7	0.12	360	340	460	390
8	0.12	390	350	430	390
9	0.12	420	420	360	400
10	0.12	390	340	460	400
11	0.12	420	350	480	420
12	0.13	360	340	470	390
13	0.13	360	380	460	400
14	0.12	380	300	430	370
15	0.12	330	320	440	360
16	0.12	350	280	420	350
17	0.12	370	320	430	370
18	0.12	380	300	450	380
19	0.12	370	280	420	360
20	0.13	320	340	400	350
21	0.13	340	380	420	380
22	0.12	380	320	400	370
23	0.12	380	390	450	410
24	0.12	420	320	460	400
25	0.12	350	380	400	380
26	0.12	380	350	420	380
27	0.12	370	310	360	350
28	0.12	420	410	450	430
29	0.12	360	340	360	350
30	0.12	370	330	380	360
Mean	**0.12**	**380**	**340**	**420**	**380**
Min	**0.12**	**320**	**280**	**360**	**350**
Max	**0.13**	**440**	**420**	**480**	**430**
StDev	**0.004**	**32**	**37**	**37**	**21**

*Mean, Minimum and Maximum are rounded to the nearest 10 kgm^{-3}.

Snow data from Queenspark Cricket ground

Location: Queens Park Cricket Ground	**Observer:** Andrew Willsman, NIWA
GPS: WGS84 46 24 18.4 S , 168 21 29.4 E	**Date:** 19 September 2010
Equipment: Winter Engineering water % density sampler #1485. Converted to kgm^{-3} Tube internal diameter = 37mm length=92mm	**Start time:** 1507
	End time: 1635
Notes: Sampling lines with pits equally spaced approximately 10m apart	

Pit #	Snow Depth (m)	Horizontal core at base (kgm^{-3})	Horizontal core at midpit (kgm^{-3})	Horizontal core at top (kgm^{-3})	Mean horizontal cores (kgm^{-3})
1	0.12	370	240	370	330
2	0.12	380	320	410	370
3	0.12	360	300	390	350
4	0.12	370	300	390	350
5	0.12	390	270	450	370
6	0.12	420	310	420	380
7	0.11	410	270	370	350
8	0.11	340	310	400	350
9	0.11	550	280	400	410
10	0.11	380	310	380	360
11	0.11	450	270	400	370
12	0.11	490	260	430	390
13	0.11	370	300	460	380
14	0.11	470	260	410	380
15	0.11	450	330	480	420
16	0.11	460	250	490	400
17	0.11	410	270	430	370
18	0.11	500	310	450	420
19	0.11	490	310	400	400
20	0.11	460	300	380	380
21	0.11	430	270	350	350
22	0.11	430	280	410	370
23	0.11	420	230	340	330
24	0.11	460	300	430	400
25	0.11	550	260	420	410
26	0.11	430	240	370	350
27	0.11	440	260	410	370
28	0.11	470	250	420	380
29	0.12	460	310	380	380
30	0.12	430	280	430	380
Mean	**0.11**	**430**	**280**	**410**	**380**
Min	**0.11**	**340**	**230**	**340**	**330**
Max	**0.12**	**550**	**330**	**490**	**420**
StDev	**0.004**	**52**	**27**	**35**	**24**

*Mean, Minimum and Maximum are rounded to the nearest 10 kgm^{-3}.