crown profiles

I'll have mine shaken, not loaded.

Earthquake-Induced Avalanching in Canterbury, New Zealand

Story by Jordy Hendrikx, Andrew Hobman, Karl Birkeland

Figure 5: Skiers make tracks between two earthquake-triggered avalanches on a southeast aspect in the Palmer Range, New Zealand. *Photo by L. Adams, Methven HeliSki*

A magnitude 7.1 earthquake occurred at 4:35am (New Zealand Time) on September 4, 2010. With an epicenter just 40km west of Christchurch city (43.55°S, 172.18°E) and a focal depth of only 10km *(Figure 1)*, the earthquake was widely felt through the entire South Island and the lower half of the North Island of New Zealand. Within the Canterbury region shaking intensities of 6 to 7 were widely felt, with a maximum shaking intensity 9 on the New Zealand Modified Mercalli Intensity Scale *(Figure 2)*. This earthquake is the most damaging earthquake in New Zealand since the 1931 Hawke's Bay earthquake, but there was fortunately no loss of life despite the extensive building damage *(Figure 3)*.

While much of the urban areas in Canterbury suffered damage to buildings, liquefaction, broken water and sewerage mains, and disruption to power supplies, it is the impact on the alpine areas and the snowpack in particular that this article will consider. It has long been known that avalanches can be induced by large seismic triggers with the May 1970 M7.8 in Peru and the March 1964 M9.2 in Alaska just a couple of the more notable events *(See Podolskiy et al., 2010 for a good review)*. With Canterbury in the middle of the Southern Hemisphere winter it was therefore not surprising to hear that this M7.1 had caused avalanche activity.

Figure 1: Earthquake location map shows the earthquake's location (star) and the surrounding region. *Source: GeoNet, 2010*

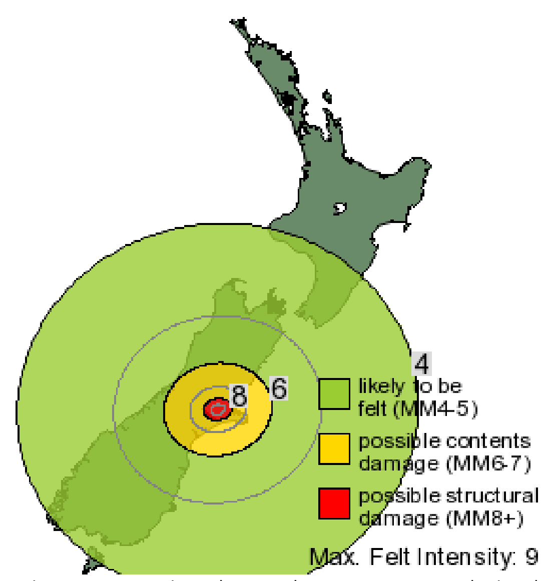

Figure 2: Isoseismal map shows contours, derived from a model, of equal MM shaking intensity for the earthquake. *Source: GeoNet, 2010*

Earthquake Data

The earthquake was widely felt through the entire South Island and the lower half of the North Island of New Zealand with maximum felt intensities of MM9. The observed shaking intensity was documented using the Modified Mercalli (MM) scale. Used in New Zealand, this scale has a 12-step ranking (opposed to 10), with 1 representing the weakest of shaking and 12 representing almost complete destruction.

The motion of the ground was also recorded by a series of instruments that document the movement in terms of ground displacement, velocity and acceleration. These instruments are located throughout Canterbury *(Figure 1)*, but we will look at the sites nearest the main alpine regions namely; Arthur's Pass, Castle Hill Village (inland from Springfield), Oxford and finally Christchurch.

Figure 3: Earthquake damage in central Christchurch. *Photo by C Cross*

The Peak Ground Acceleration (PGA) that was measured at each of the recoding stations is measured in units of percent-g (%g), where g is the acceleration due to the force of gravity (i.e. 9.8 m/s2). Values of 8%g to almost 30%g were recorded at Arthurs Pass to Christchurch *(Table 1)*. In studies of building damage a PGA value of 20%g is often used to define the lower damage limit, but recent work also shows substantial damage can occur to buildings at lower PGA values of 10-20%g *(e.g. Lee et al., 2003)*.The pattern of PGA can be quite complicated at smaller scales, showing variability over a few kilometers. This can be mostly explained by the differing soil types and topography near the stations that can significantly change the characteristics of the seismic waves. This small-scale variability will influence how PGA is experienced in the mountains.

The Peak Ground Velocity (PGV) was also measured at each of the recoding stations, measured in units of centimeters per second (cm/s). Values of about 4cm/s to over 30cm/s were recorded at Arthurs Pass to Christchurch *(Table 1)*. In studies of building damage there is a strong relation with increasing PGV, with considerable damage when the PGV exceeds 30cm/s *(Lee et al., 2003)*. Both PGA and PGV give a good correlation with reported shaking

Table 1: Earthquake recorders (see Figure 1 on previous page for locations). *Source: GeoNet, 2010*

Location	MM	Shaking instruments	
		PGA	PGV
Methven	4-7	-	-
Arthurs Pass	4	7.98 %g	4.08 cm/s
Castle Hill village	5	11.44 %g	10.52 cm/s
Lake Coleridge	5-6	-	-
Oxford	4-7	15.47 %g	9.88 cm/s
Christchurch	4-8	29.70 %g* 27.76 %g#	14.82 cm/s* 32.13 cm/s#

*Christchurch Aero Club #Papanui High School (both locations within Christchurch)

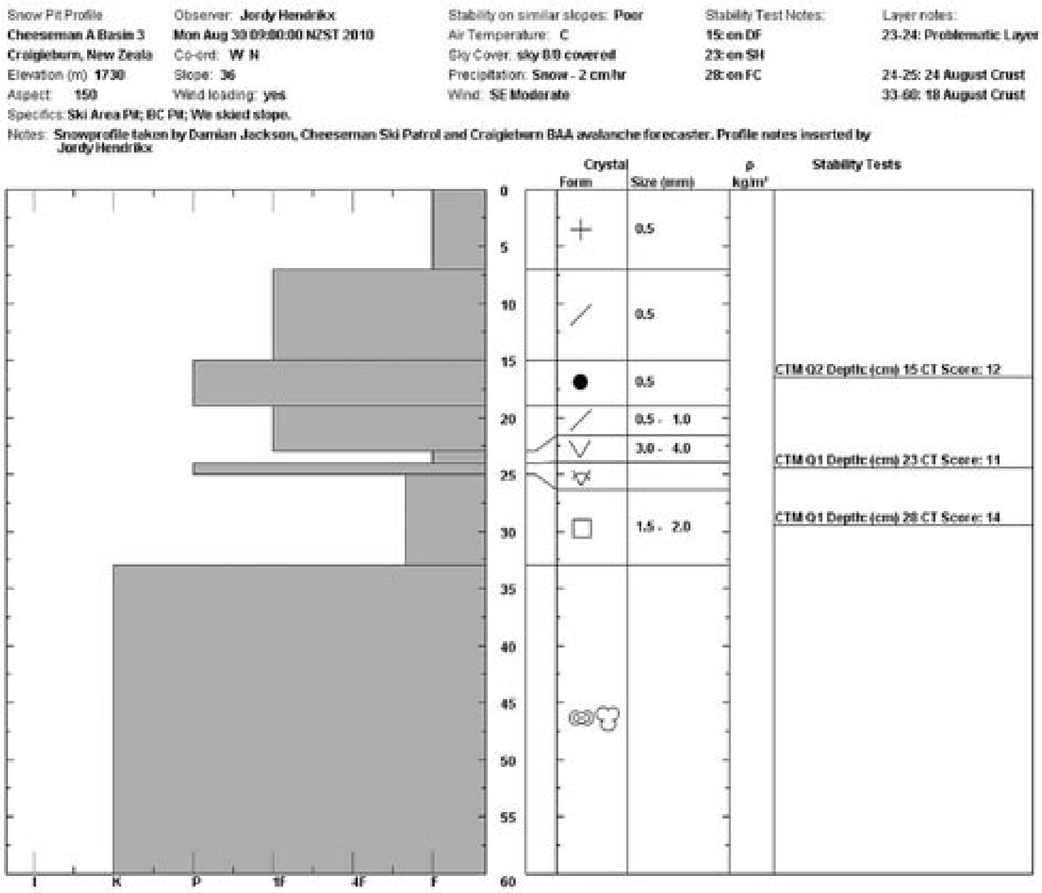

Figure 4: Snow profile in A Basin at Mt Cheeseman Skifield, Craigieburn Range *Source: D. Jackson*

for earthquakes larger than magnitude 5 and above *(GeoNet., 2010)*.

Snow Stability Prior to the Quake

In New Zealand the Mountain Safety Council (MSC) are responsible for daily public avalanche advisories for the key alpine regions *(see www.avalanche.net.nz)*. The two main regions impacted by this earthquake were the Craigieburn Range and Mt Hutt/Arrowsmiths Region. The forecasts for these are produced by assimilating data from a number of contributors and sources. The backcountry avalanche advisories on September 3 for the Craigieburn Range and for Mt Hutt/Arrowsmiths region were reporting a Considerable danger rating, according to the 5-step avalanche danger scale.

In the Craigieburn Range the forecaster noted that the snow was strong at depth on the northern half but remained weak on slopes facing SW-E with a host of persistent-type weaknesses (surface hoar, facets) having been buried by the past weeks accumulations (50cm or so with thicker wind deposits). They noted that the slopes with the persistent weak layer (SW-E) "…remain tender in areas and lack only a trigger."

In general, in the days preceding September 4, both of these regions were experiencing new snow and strong westerly winds. Reports of slab development on easterly facing slopes above 1600m of around 50-100cm were not uncommon. In the Mt Hutt/Arrowsmiths region a cycle of natural avalanche activity was anticipated. The forecasters had noted a surface hoar layer that might have been buried intact on certain aspects, but the main concern was the new snow and the wind loading, and only the deeper buried layers on particular aspects. Explosive control and ski cutting in the Craigieburn Range on the third had generally resulted in very limited activity on eastern half slopes. Reported snow-stability tests included a CTM14 RP down 5cm within low-density storm snow. The buried facets and surface hour (where present) had not been reported to show any sign of activity but was still of some concern.

Despite this new snow and strong wind loading, snowpack-stability assessments in these regions at elevations from 1500m to 2000m had generally improved from Fair-to-Poor on the second, to Good-to-Fair on the third. This was mainly because the bonding of the new storm snow was considered to be relatively strong, and the slabs had been mostly unresponsive in testing. The weaknesses deeper in the snowpack, such as the lower faceted layer, the crust, and the buried surface hoar were still a concern on a few aspects. While this layer had been unresponsive so far, the forecasters knew that the surface hoar layer (where buried) and faceted layer were both 5-out-of-5 scores on the lemon count for snow structure factors *(McCammon and Schweizer, 2002)*. A snow profile taken on August 30 (four days before the earthquake) shows the facets, crust, and surface hoar, but the new (and subsequent) wind loading is noted as the primary concern *(Figure 4)*. Further additional new snow load was added to this snowpack in the subsequent four days.

By the end of September 3, most locations were reporting the arrival of another westerly system with new snowfall and strong winds from the NW to W. In the Mt Hutt region soft-slab development with at least 40cm HST on sheltered slopes was reported by late afternoon of the third. Data from a remote climate station in the Mt Hutt/

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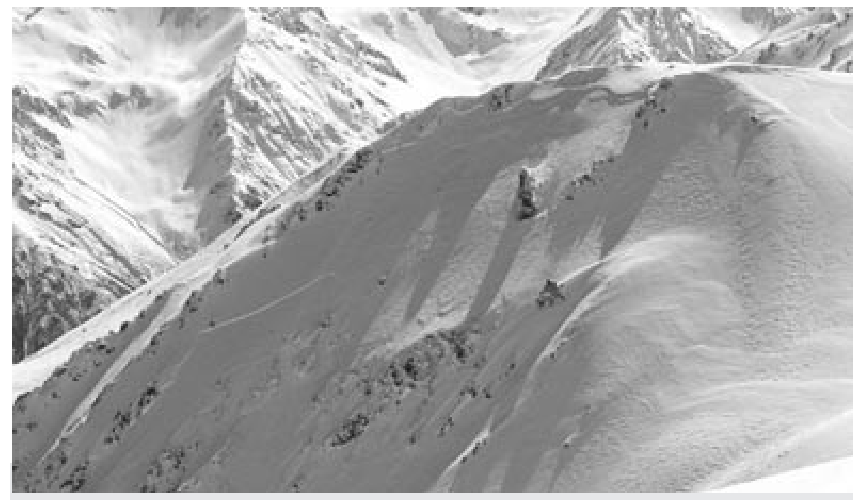


The west face of Porters ski area, which is out of bounds, slid during the New Zealand earthquake event this September. *Photo by Brad Carpenter*

Earthquake-Caused Avalanches: New Zealand

Story by Brad Carpenter

On September 4, 2010, a magnitude 7.1 earthquake shook the Canterbury region of New Zealand. The epicenter of the earthquake was located approximately 50km from Porters ski area, where I have worked as a ski patroller for three seasons, and 40km from downtown Christchurch, a city of 386,000 people.

Porters is located at the southern end of the Craigieburn Range, a 28km long SE-NW running ridge of mountains averaging around 2000m in elevation at the highest and dropping to around 700m at valley floor. Besides Porters there are three other ski areas located in the Craigieburn Range: Mt Cheeseman, Broken River, and Craigieburn ski areas.

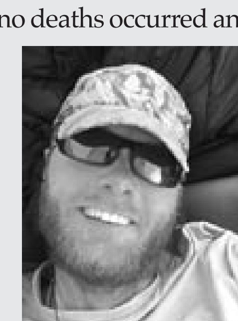
The earthquake struck at what was probably the most opportune time, 0430. At Porters, ski patrol stays in the employee housing building known as the Longframe, a triple-long, double-wide trailer, located at approximately 900m elevation and a quick five-minute drive to the base area. Everybody in the Longframe was asleep when the quake hit, and the only people on the mountain were one groomer driver and the road grader driver. The shaking started out slow and then grew in ferocity until the entire Longframe building was creaking and moaning; this lasted for over a minute. I remember holding onto my bed thinking it might be a good time to run for the closet when finally the tremors subsided and normalcy returned.

After ensuring the staff on the hill were safe, the snow safety director, Simon Morris, and I came up with our response plan to make sure all the staff buildings and the rest of the staff were okay, then work our way up the mountain to see what had occurred with the snowpack.

At first light it became very apparent that, at least inbounds, nothing had occurred. We could observe no new naturals, no signs of any instabilities, no visible cracking or collapsing. As we made our way higher on the mountain the same held true, but then at the top of the final T-bar lift, where the backcountry comes into full view, the extent of the earthquake became more apparent. Numerous size 2 to size 3 avalanches were visible along most ridgelines and in adjacent bowls. Most of these slides were from newly formed wind slabs from previous days of northwest wind transport. We had used explosives and ski cut these slabs inbounds the day prior to the quake with no results. Looking out into the adjacent ranges of the region we could see bowl after bowl filled with debris, even many kilometers to the west and well away from the earthquake epicenter.

Satisfied with what we were seeing inbounds, and considering that there could not have been a better test of our snowpack, we rated the stability for the ski hill Very Good and opened to the public. Over the next few hours and days the subsequent damage from the quake became all the more real. Much of the Craigieburn Range and the ranges around were reporting large out-of-bounds avalanches, some stepping down into old layers. This had been one of the largest natural avalanche events in the history of the region. There were, however, no reports of any inbounds avalanche activity and no major infrastructure damage.

In Christchurch the story was not so good. Many buildings and homes were destroyed or damaged beyond repair, and thousands of people were without power or water for several days after the quake. The magnitude of this earthquake was the same as the earthquake that struck Haiti on January 12, but in New Zealand no deaths occurred and only minor injuries were reported. Aftershocks continue to rattle the region, some as large as magnitude 5, and it will take some time before the region returns to normal.



Brad Carpenter is the snow safety director at Moonlight Basin ski area in Montana and spends his summer ski patrolling in New Zealand at Porters ski area.

EARTHQUAKE AVALANCHES

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Arrowsmiths region indicates that snow and wind continued throughout the night and that a substantial amount of new snow and loading would have occurred on the slopes lee to the western half. The lee slopes (S to E) were now primed and only lacked a trigger.

Avalanches Reported

In the Mount Hutt/Arrowsmiths region multiple slab avalanches from size D1 to D3 released on slopes above 1500m. These avalanches were mainly reported on slopes of the eastern half, but were reported to have occurred on all almost all aspects. The avalanches in the Mt Hutt region had particularly wide and jagged fractures, with one observer noting that they had propagated “differently” to that which was expected for these start zones.

Methven Heliski reported that they “observed a significant natural cycle in the Palmer Range that was caused by the earthquake. Most slides were in the 2000-1800m [elevation] range, mostly size 2, and all on S/SE aspects. Weak layers were the facet and surface hoar combination buried by 40cm HST on 3008 [August 30] and drifted to 140cm crown thickness in some areas. Observed no natural activity on solar aspects. Skied adjacent to slide paths and found good stability thanks to earthquake” *(Figure 5)*.

The surface hoar was thought to be the main sliding layer, and this had grown out of a hard crust and was considered to be quite resilient. The southern and southeastern aspects were the locations where the surface hoar was not destroyed by wind or solar radiation and was believed to be buried intact. In the Palmer Range it was estimated that around 95% of the avalanches observed were on the south and southeastern aspects *(Boekholt pers comm., 2010)*.

In the Craigieburn Range multiple slab avalanches from size D2 to D3 released on slopes above 1800m. These were all reported on southern and southeastern aspects and were thought to have either slid on the buried surface hoar layer (100824) or in the facets and rain crust layer of August 18 (100818). They were generally over 1m deep and 200-500m wide *(Figure 6)*. Numerous similar “Ne” (Natural trigger, Earthquake) occurrences were also observed across the wider Craigieburn, Torlesse, Grey and Black Ranges *(Jackson pers comm., 2010)*. In terms of overall scale, the maximum distance from the epicenter to a confirmed avalanche caused by the earthquake was approximately 100km, but unreported avalanche events might have occurred further away.

In addition to the reported avalanche events, large cracks to the full depth of the snowpack were observed in the Mt Hutt range. These cracks had the general appearance of glide cracks and extended over 30m on southeast through to southwest faces. These cracks were generally in the 1800-2000m elevation range but were also been observed at lower altitudes. Similar cracks were noted at Mt Dobson ski area, approximately 100km away. Unfortunately, new snow covered these cracks shortly after the earthquake and monitoring of them was not possible. Now with the spring melt, these cracks have re-emerged and the Mt Hutt ski patrol are watching them with great interest. While the cracks were initially observed on slopes with an angle of greater than 30 degrees, they are now appearing on much flatter terrain *(Figure 7)*. The Mt Hutt ski patrol has suggested that they may have been caused when the shingle bed surface was pulled away from the snowpack during the earthquake and the unsupported snowpack is now slumping and cracking. Likely these full depth cracks are not isolated to just this area. However, neighboring ski areas (such as those in the Craigieburn Range) have now closed for the season and no other reports of similar large cracks have been received.

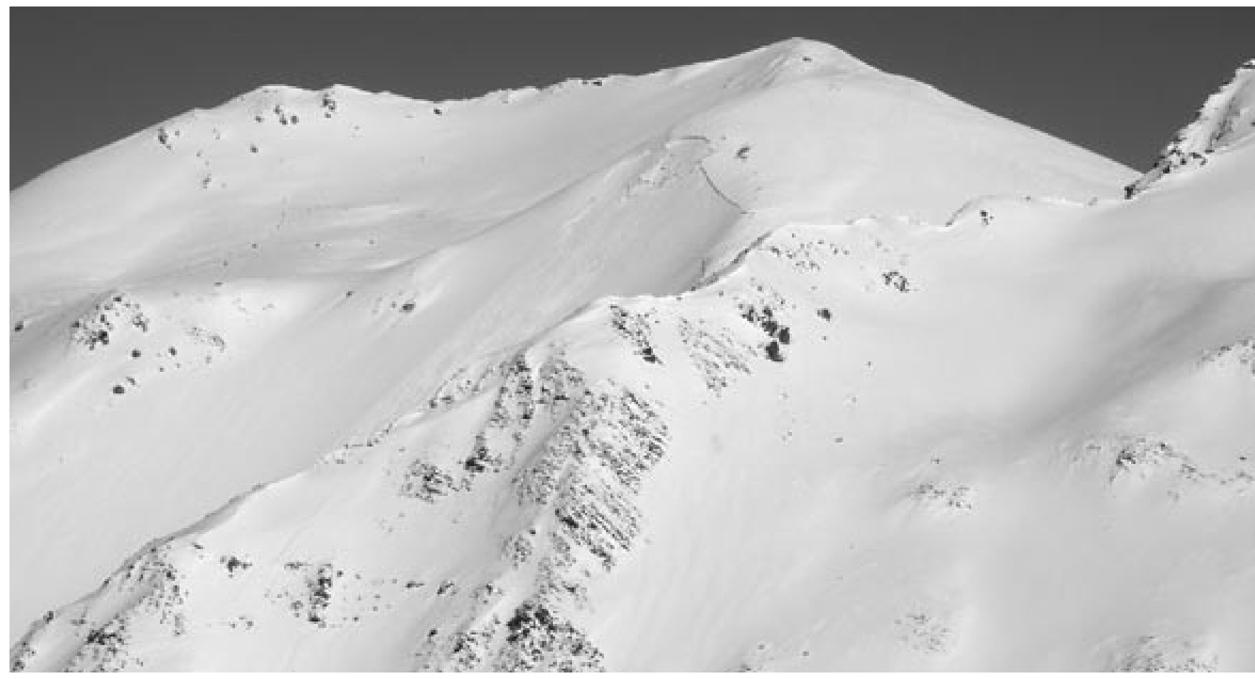

Figure 6: Looking southwest along the Craigieburn Range to Mt Cheeseman, with an example of one of the earthquake-induced slab avalanches (size D3, SE Aspect, 1910m) shown in the middle ground. *Photo by D. Jackson*

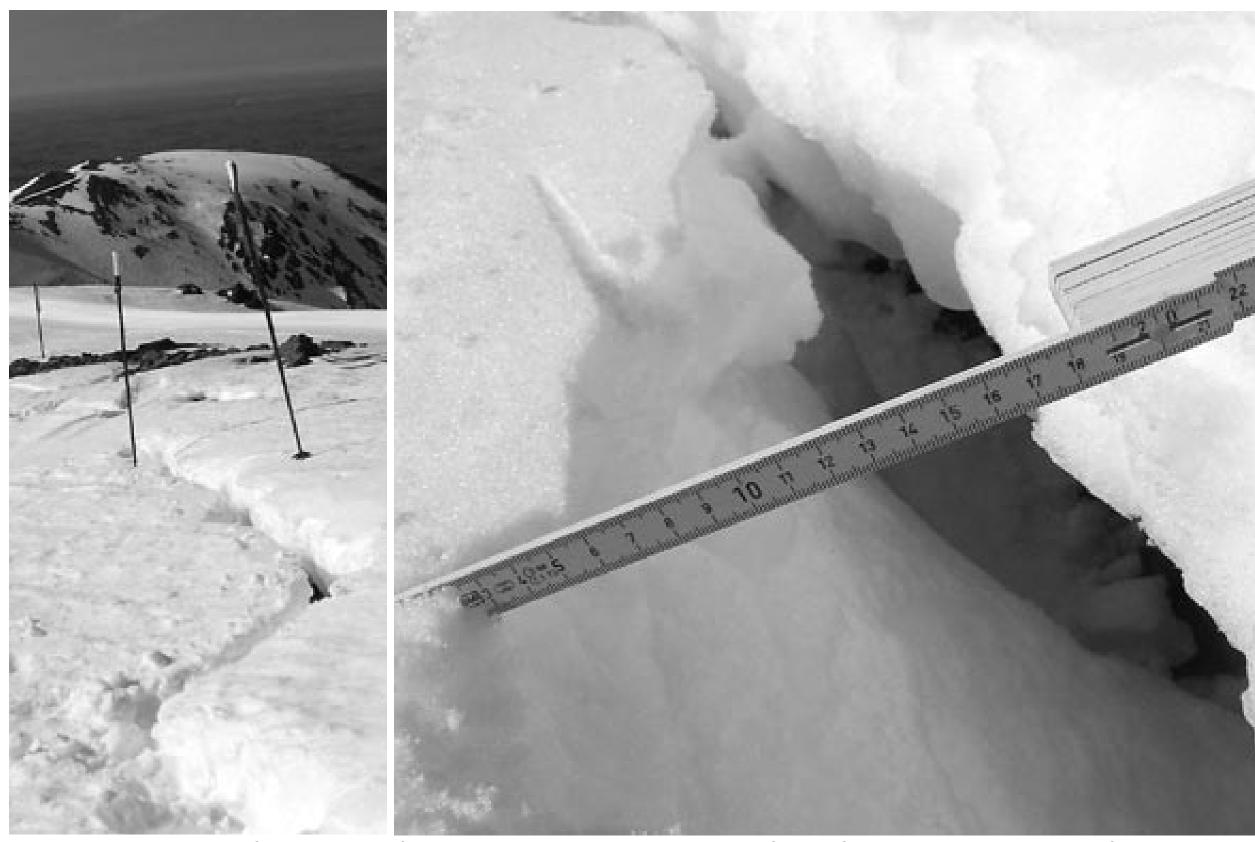

Figure 7: Looking south from the top of Mt Hutt ski area, with an example of one of the earthquake-induced, full-depth cracks shown in the foreground (left) and up close (right). *Photos by R. Mguire*

Discussion & Conclusions

The earthquake triggered widespread avalanche activity throughout both regions, with reported events ranging in size from D1 to D3. The avalanches were predominantly on south and southeastern aspects, but did occur elsewhere as well. Based on very limited observations, the consensus seems to suggest that the avalanches primarily occurred in the layer of buried surface hoar. The south and southeasterly aspects likely had the most developed facets and surface hoar due to their generally more shady exposure. They were also lee slopes during the prior storms and definitely experienced substantial new snow loading. Interestingly, western and northern slopes only saw isolated events, likely due to the general absence of the surface hoar layer on these aspects. Additional to the avalanche activity, full-depth cracks have also been observed in the Mt Hutt Range, and these are likely to be present elsewhere. These cracks may end up behaving like glide cracks as we progress into spring, but since no one has experienced them in these locations before (unlike a glide crack with a “normal” location), they remain a concern.

The modeled and reported forces exerted by the earthquake (as measured by the MM scale) were less over the alpine regions than those felt in Christchurch. Despite this, the PGA instruments still recorded values of between 8 and 15% gravity (at Arthur’s Pass and Oxford respectively), meaning that a horizontal force of about 0.08 to 0.15 times the normal load due to gravity was exerted on the snowpack. This shaking was clearly enough to cause substantial avalanche activity on aspects where the right mix of layers and loading was present. Given the nature of the weakness and the additional wind loading, these aspects may have avalanched anyway with further loading, but it seems very likely that the shaking from the earthquake triggered these avalanche events. This may be one of the first recorded events where we can identify the role of grain type on earthquake-induced avalanche activity, but further work will be needed to provide any further insight on this matter.

We were very fortunate that the earthquake occurred at 0430 in the morning and not at 1100 on a busy Saturday, as some of these slopes may not have seen active control and could have caught us unaware.

Acknowledgments

We acknowledge the New Zealand GeoNet project and its sponsors EQC, GNS Science and LINZ for providing data and images used in this study. We also acknowledge the ongoing snow, weather, and avalanche observations from all contributors to the New Zealand Mountain Safety Council Avalanche.net, but in particular the lead forecasters for the two regions (Kevin Boekholt and Damian Jackson), Methven Heliski, and Mt Hutt, Porters, Mt Cheeseman, Broken River and Craigieburn Valley ski areas.

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Jordy Hendrikx will be moving to Montana in late December to take up a professorship at Montana State University in Bozeman, where he will be leading the Snow Science program in the Department of Earth Sciences. In addition, he and his wife are the proud parents of daughter Sophie, who arrived on September 24. He relates that, “All is going well with her and us, albeit with less sleep.”