

A comparative assessment of the potential impact of climate change on the ski industry in New Zealand and Australia

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Abstract In this paper we assess the impact of climate change, at a micro-scale for a selection of four sites in New Zealand and Australia. These sites are representative of the key destination ski regions. In contrast to previous work, our work will for the first time, allow for a direct comparison between these two countries and enable both an estimate of the absolute impacts at a given site, as well as the relative impacts between the two countries. This direct comparison is possible because we have used exactly the same snow model, the same 3 global climate models (GCMs) and the same techniques to calibrate the model for all locations. We consider the changes in natural snow at these locations for the 2030–2049 and 2080–2099 time periods, for one mid-range emissions scenario (A1B). This future scenario is compared to simulations of current, 1980–1999, snow at these locations. We did not consider the snowmaking or economic components of the ski industry vulnerability, only the modelled changes in the natural snow component. At our New Zealand sites, our model indicates that by the 2040s there will be on average between 90 % and 102 % of the current maximum snow depth (on 31 August) and by the 2090s this will be on average reduced to between 46 % and 74 %. In Australia, our models estimates that by the 2040s there will be on average between 57 % and 78 % of the current maximum snow depth and by the 2090s this will be on average further reduced to between 21 % and 29 %. In

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terms of days with snowdepths equal to or exceeding a ski industry useable levels of 0.30 m, at our lowest elevation, and most sensitive sites, we observe a change from 125 days (current) to 99–126 (2040s) and 52–110 (2090s) in New Zealand. In Australia, a reduction from 94 to 155 days (current) to 81–114 (2040s) and 0–75 (2090s) is observed. In each case the changes are highly depended on the GCM used to drive the climate change scenario. While the absolute changes will have direct impacts at each location, so too will the relative changes with respect to future potential Australia–New Zealand tourism flows, and beyond. Our study provides an approach by which other regions or countries with climate sensitive tourism enterprises could assess the relative impacts and therefore the potential wider ranging ramifications with respect to destination attractiveness.

1 Introduction

Climate change will impact the extent, amount and duration of seasonal snow in New Zealand and Australia. This has been quantified at both a nationwide scale (Hendrikx et al. 2012), and for a selection of ski area (Hendrikx and Hreinsson 2012) for New Zealand, and in Australia at a range of scales by Hennessy et al. (2003), Bicknell and McManus (2006) and Hennessy et al. (2008). Elsewhere in a number of other countries, the impact of climate change on the ski industry has also been assessed, including the United States (e.g. Hayhoe et al. 2004; Scott et al. 2011); Switzerland (e.g. Elsasser and Messerli 2001; Scherrer et al. 2004; Rixen et al. 2011; Beniston et al. 2011); Sweden (e.g. Moen and Fredman 2007); Japan (e.g. Fukushima et al. 2003); Italy (e.g. Abegg et al. 2007); Germany (e.g. Abegg et al. 2007); France (e.g. Abegg et al. 2007); Canada (e.g. Scott et al. 2007) and Austria (e.g. Abegg et al. 2007; Steiger 2010). The results of these studies are unanimous and show a general decline in snow depth and duration with projected warming. However, the changes are not uniform across all regions and some areas see relatively more or less change depending on the various local and regional factors. Scott et al. (2011), for example, report that for Northeast United States there will be serious economic implications for businesses and tourism-dependent communities, with one climate change scenario indicating that reliable snowmobile seasons (at least 50 days of snowmobiling possible) will be rare by 2070–2099. The question however remains as to how much these differences are due to the different snow models being employed, the different climate scenario being used, and the various assumptions being made.

Further, decreases in snow availability and quality, as well as other climatic parameters, may result in different responses by snow users, depending on socio-economic contexts and recreationists' preferences. Empirical research in North America provides evidence that minimum and maximum temperature, snow depth and wind chill are statistically related to the ticket sales for downhill skiing (Shih et al. 2009). In Australia, in snow poor winters, 69 % of skiers would ski less often, 5 % would give up, and 16 % would ski overseas (Pickering et al. 2009). New Zealand is an important overseas ski destination for Australians, and in turn the Australian market (alongside with domestic skiers) constitutes the core demand at New Zealand ski fields. For example, in 2008 64 % of skiers at The Remarkables and 54 % at Coronet Peak (both are ski fields in the Central Otago region) were Australian (Hopkins et al. 2011). This thereby signifies the important relationship between these neighbouring countries for snow tourism markets, and the importance of understanding potential behavioural adaptations. In a follow up study Hopkins et al. 2012 interviewed Australian skiers in the Queenstown region and found that while a multitude of other factors

like destination activities, exchange rates and ease of travel form part of tourists' travel decision making, natural snow conditions are an important driver for visiting New Zealand. So, we propose that the relative change in snow conditions could be a key future factor in the Australia–New Zealand snow tourism industry. Importantly, Hopkins et al. (2012) also found that many Australian skiers consider the Northern Hemisphere as even more attractive than New Zealand in terms of snow conditions. Thus, changes in either Australian or New Zealand (or both) snow conditions are likely to influence Southern-Northern hemisphere tourist flows, especially to North America and Japan. More work on this aspect of the research will be needed, and this paper will only provide the snow and climate change component.

To address these issues, we present the results of running exactly the same snow model, calibrated in the same way, for two different regions, one in New Zealand, the other in Australia. We will comment and compare both the absolute changes, as well as the relative changes. We focus on both these metrics to examine our hypothesis on the resulting potential flow of tourism in the moderate, but regionally lucrative Australia–New Zealand ski market. While our study is specific to two regions in the Australia–New Zealand ski industry, we provide a lens and an approach by which other regions or countries with climate sensitive tourism enterprises could assess the relative impacts and therefore the potential wider ranging ramifications with respect to tourism flows.

2 Study areas

The two regions of interest are in southern, New Zealand and in the Snowy Mountain region of Australia. In New Zealand we examine two ski areas located in the Central Otago region of the South Island of New Zealand as this region is the main hub for Australia–New Zealand winter tourism and these ski areas are the primary “destination” locations for ski tourism (Hopkins et al. 2012). To support this strong destination tourism flow, there are now many daily direct flights from the main Australia cities to Queenstown (Figure 1). The New Zealand sites are located at approximately latitude 45°S and longitude 170°E. At these two sites, we consider a low elevation site (from 1,200 m to 1,640 m), representative of the lower portions of the ski area and a high elevation site (from 1,650 to 1,900 m), representative of the upper portions. The lower sites are at, or near the base elevation of the ski area, results from these sites can be viewed as a “worst-case” for each ski area, as these lower elevations typically have the least snow.

In Australia, we consider two sites in the Snowy Mountains, which are located in southern New South Wales (Fig. 1). The two Australian sites are not ski areas specifically, but rather long term snow course sites, which are frequently used as independent and reliable proxies for the adjacent ski areas. The Snowy Mountains are located in the southern part of New South Wales and approximately 200 km inland from the Tasman Sea. The two Australia sites are located at approximately 36.0°S latitude and longitude 150°E and at each location we consider just the one elevation, which is representative of the snow course data (i.e. 1,615 m and 1,830 m).

It is worth noting that these two groups of sites, in New Zealand and Australia are not particularly representative of the entire alpine regions in their respective countries. For example, the sites in Central Otago, are typical of the inter-mountain snow region of New Zealand and are typified by relatively shallow snowpack, in contrast to the Main Divide which exhibits more typical maritime snowpack conditions which are much deeper (however there are no ski fields in these areas). By contrast, the two Australian sites are in the relatively more snowy area, compared with other sites located in the Australian Alps.

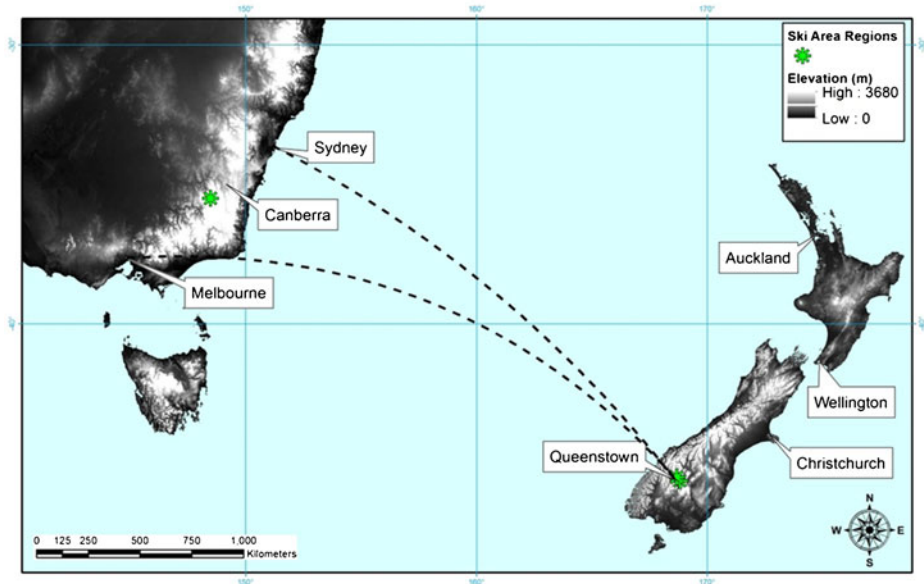


Fig. 1 Location map, showing New Zealand the south eastern corner of Australia with their respective elevations. The two areas of focus are shown, with the Queenstown region in New Zealand and the Snowy Mountains in Australia. Indicative flight paths of direct flights from Melbourne and Sydney to Queenstown are also shown

Therefore, it is important to note that this study does not reflect the mountain wide impacts of climate change in these two countries, merely the absolute and relative changes for these specific groups of snow tourism-significant sites. Nevertheless, this study has potential implications for regions beyond the specific case study sites through the development of the methods and approach. However, further research would be required on these other regions to enable analyses of relative vulnerability (Hopkins et al. 2012).

3 Methods

3.1 Climate data

To simulate the snowpack and snow making potential at each location, climate information is required for the current climate, and for two future scenarios, referred to in this work as the 2040s and 2090s time periods. In both regions we used only daily maximum and minimum temperatures, and daily precipitation as our input data to drive the snow models.

For the New Zealand sites, we used the data contained within the Virtual Climate Network (VCN), a 0.05° grid for all of New Zealand using a thin-plate spline (Tait et al. 2006). For each ski area location, the nearest grid point from the VCN was selected. Each VCN point has a mean elevation attributed, so to ensure that the nearest VCN grid point reflected the climate of the selected location as closely as possible, the VCN temperature was lapsed either up or down using a standard $5^\circ\text{C}/\text{km}$ lapse rate. Precipitation was unmodified at this stage, but was used as one of the key calibration parameters.

For the Australian sites, we also used a gridded temperature and precipitation surface, which was obtained from the Australian Bureau of Meteorology. This grid has been

generated from station observations of precipitation and temperature to a 0.025° grid for all of Australia using a thin-plate spline (Hutchinson 1998a, b). In an identical approach to the above for New Zealand, we lapsed the temperatures of the nearest grid points to more closely resemble the temperatures of our desired locations.

3.2 Snow model calibration for current climate

Clark et al. (2009) and Hendrikx et al. (2012) have described and used a simple temperature index snow model for New Zealand-wide snow modelling applications and for this work, we have used the same snow model, but used only point input data from the nearest grid point(s) as described above. As the snow/rain threshold remains within a tight range in our model, and this is physically controlled, we have confidence in our ability to use this simple temperature index model for future climate change scenarios.

Due to the scale of this analysis we re-calibrated the snow model for each selected ski area in both New Zealand and Australia. We have used up to 20 years of observations of snow depth to calibrate the snow model output for the current climate. In our calibration, we have only permitted ourselves to alter two parameters, namely the temperature threshold (for snow accumulation and melt), and the gauge under-catch parameters. We consider that these two parameters can be justifiably modified, based on our understanding of processes for snow accumulation and the limitations in the gridded input data that we are using.

The gauge under-catch is the parameter which allows us to enhance or reduce the precipitation experienced at a location. Woods et al. (2006) has documented that the VCN precipitation grid for New Zealand is deficient in the mountains, so adjustment of this parameter is justifiable in our calibration as it allows us to fit the precipitation data to the available snow depth observations. The temperature threshold parameter in the model distinguishes between rain and snow. While this is unlikely to change substantially from one site to another, we are using point data from an interpolated temperature surface for the snow model, so adjusting this parameter is akin to updating the temperature field where we may not have sufficient reliable observations to constrain the spline. It is also worth noting that we use a fixed lapse rate, so calibration of the temperature threshold in the snow model accounts for this variability and uncertainty as well.

In all cases, our starting calibration point was our “default” parameter set as defined by Clark et al. (2009) (T Accumulation, T_a , and T melt, $T_m=274.150$ K, and Gauge Undercatch ratio, $G_u=1.0$). The local calibration is desirable to improve the confidence in our modelling, as it essentially accounts for the processes that the model cannot resolve at this fine scale (e.g. local scale re-distribution of snow) and for potential errors in our input data. This calibration was necessary to ensure that the model could simulate the current snow conditions as accurately as possible at each of the selected sites. Our final calibration resulted in all sites using a T_m of 273.150K, while the two New Zealand sites used a T_a of 275.650K and G_u of 2.250, Australia 1 used a T_a of 275.785K and a G_u of 1.850 and Australia 2 used a T_a of 275.223K and a G_u of 3.438.

In a similar approach as used by Hendrikx and Hreinsson (2012), SWE has been converted to snow depth using a varying snow density to snow depth relationship. This relationship captures our general understanding of snow processes, in that the early season snowpack has a low density, which gradually increases over time as the snowpack “ripens” and becomes isothermal. Our simple snow density to snow depth function starts on 01 April with 200 mm of SWE representing 1 m of snowdepth, increasing at a linear rate to 400 mm of SWE representing 1 m of snowdepth by 01 December of that year. This time period

(April–December) covers all available snow depth observations that were available for the calibration.

3.3 Climate change

Climate change data available for New Zealand has been described briefly in Hendrikx et al. (2012), these data have also been used for this study. Climate change scenarios for Australia were developed by CSIRO and BoM (2007) from the output of 23 CMIP3 global climate models. Projections of temperature and precipitation for 2030 and 2070 were summarised by Suppiah et al. (2007).

In brief; statistically downscaled GCM delta-change projections were developed for 12 different models for each VCN grid point for New Zealand (Ministry for the Environment (MfE) 2008). We also used downscaled projections for 3 models for Australia. A list of the models used is shown in Table 1. For the New Zealand sites, we have used only the same 3 models as used for Australia, to ensure that our inputs are driven by the same models, and are therefore directly comparable. The three models used are representative of the upper, middle and lower ranges of warming and precipitation change, so capture the approximate same range as the average of the 12 models used for previous work for New Zealand (e.g. MfE 2008, Hendrikx et al. 2012). A review of the three selected GCMs was undertaken by assessing the snowmodel results by Hendrikx et al. (2012) and we found that for at least New Zealand, these three models were consistent with the overall average trend of the 12 models, and did not represent outliers in the distribution of the individual results.

The directly downscaled changes were for monthly mean values of temperature and precipitation. The change referred to is the average difference between the period 2030–2049 (2040s), and 2080–2099 (2090s), when compared with the base period 1980–1999

Table 1 Annual temperature changes (in °C) relative to 1980–1999 for 12 General Circulation Models forced by the SRES A1B scenario. Changes are shown for different end periods for the global and downscaled New Zealand average (Modified from, MfE 2008, p121). Models marked with a * and in bold are the only three which have been used for this study

Model (Country)	Global change to 2090–2099	Change to 2030–49		Change to 2080–99	
		Global avg	NZ avg	Global avg	NZ avg
cccma_cgcm3 (Canada)	3.10	1.47	1.27	2.99	2.69
cnrm_cm3 (France) *	2.75	1.30	0.87	2.60	1.83
csiro_mk30 (Australia) *	1.98	0.65	0.54	1.84	1.13
gfdl_cm20 (USA)	2.90	1.29	0.82	2.83	1.96
gfdl_cm21 (USA)	2.53	1.31	1.22	2.44	2.16
miroc32_hires (Japan) *	4.34	2.00	1.35	4.15	3.44
miub_echo5 (Germany/Korea)	2.86	1.19	1.12	2.76	2.23
mpi_echam5 (Germany)	3.31	1.09	0.33	3.15	1.75
mri_cgcm232 (Japan)	2.20	0.97	0.71	2.16	2.07
ncar_ccsm30 (USA)	2.71	1.57	1.19	2.63	2.11
ukmo_hadcm3 (UK)	2.90	1.24	0.66	2.79	1.56
ukmo_hadgem1 (UK)	3.36	1.35	1.14	3.22	2.21
12 model average	2.91	1.29	0.94	2.80	2.10
3 model average	3.02	1.32	0.92	2.86	2.13

(1990s or current) (MfE 2008). The period 1980–1999 spans the 1971–2000 and 1981–2010 30 year climate normals. Analysis of the monthly mean precipitation and temperature data from the nearest climate station (Queenstown Aero AWS ID: 5451/158075) indicated that there was less than 0.1°C in temperature and less than 4 % precipitation difference in values between these two 30 year normal periods (The National Climate Database 2013). From the downscaled precipitation and temperature changes, change projections for the 2040s and 2090s periods were developed for use as input for the snow model. In all cases the daily future climate was developed by applying the downscaled changes to the current climate VCN (New Zealand) or gridded (Australia) data. We only consider the A1B emission scenario (i.e. mid-range) for this study, however we note that CO₂ emissions have recently been tracking between SRES A1B and A1FI emissions scenarios, and close to the new RCP8.5 emission scenario (Peters et al. 2012)

We have empirically adjusted daily precipitation so that there is more precipitation in the future climate on days with high precipitation, and an increased number of days without precipitation. The magnitudes of these changes are proportional to the temperature change and this captures the concept and current understanding of a future climate with larger extreme precipitation events, especially in areas with an increase in the mean precipitation (i.e. New Zealand Southern Alps). The methodology used in this study has been described fully by the MfE (2010).

To simulate future snow at our selected sites in New Zealand and Australia, for the two time periods (2040s and 2090s), for the future climate change scenario we repeated the described snow simulation for the current climate, altering only the temperature and precipitation input data in line with the emissions scenarios for the two time periods. The snow model and model parameter set were unchanged from the calibrated parameter set when used for the future snow simulations. Future estimates of snow were then compared to the current baseline, so we compare modelled snow, with modelled future snow. For each site we modelled the 20 year average snow depth for the current, 2040s and 2090s for all three future scenarios.

3.4 Limitations and uncertainties

All of the site-specific snow modelling and snowmaking potential is calculated from the nearest grid cell in the interpolated gridded data. The daily temperature and rainfall VCN data for New Zealand for the current climate come with the caveats noted in the associated publications (Tait et al. 2006; Tait 2008). Particularly relevant are the well-known challenges in estimating precipitation and temperature in alpine regions from a sparse station network (Clark and Slater 2006). To some extent, the limitations in the gridded data are reduced in their impact as the snow model has been calibrated to each individual site. Furthermore, it is also known that MIROC_hires has a poor simulation of ENSO (Irving et al. 2011).

4 Results

In this section we present the results from our snow models, both as the absolute modelled snow depths (in m), the relative change (expressed as a %) and the number of ‘snow-days’ within a season where the snow depth exceeds 0.30 m, for the 2040s and 2090s, for each of the three GCMs and as an average of the three. These results are summarised in Table 2, and Fig. 2.

Table 2 Modelled snow for the four locations, showing the current modelled snow depths (m) and relative change (as a %), and average annual number of “snowdays” with snowdepth greater than or equal to 0.30 m, for individual GCMs and the 3 model average for the 2040s and 2090s

Site	Elevation (m)	Metric	Current	2040s			2090s			3-model average	3-model Average
				MIROC32	CNRM_CM3	CSIRO_MK30	MIROC32	CNRM_CM3	CSIRO_MK30		
New Zealand 1 Upper	1,650	Depth (m)	1.95	1.89	1.67	2.24	1.93	0.98	1.02	1.87	1.29
		%	100	97	86	115	99	50	53	96	66
		Snowdays	213	197	183	221	200	114	112	188	138
New Zealand 1 Lower	1,200	Depth (m)	1.07	0.93	0.78	1.19	0.96	0.29	0.29	0.89	0.49
		%	100	87	73	111	90	28	28	83	46
		Snowdays	125	108	99	126	111	52	41	110	68
New Zealand 2 Upper	1,900	Depth (m)	2.09	2.12	1.92	2.34	2.13	1.24	1.33	2.10	1.56
		%	100	101	92	112	102	59	64	101	74
		Snowdays	254	233	216	247	232	139	149	225	171
New Zealand 2 Lower	1,640	Depth (m)	1.68	1.66	1.44	1.94	1.68	0.84	0.88	1.60	1.11
		%	100	99	86	116	100	50	52	96	66
		Snowdays	198	181	160	201	181	106	101	166	124
Australia 1	1,615	Depth (m)	0.97	0.84	0.71	0.71	0.75	0.42	0.21	0.20	0.28
		%	100	87	73	73	78	43	22	21	29
		Snowdays	94	91	83	81	85	48	14	0	21
Australia 2	1,830	Depth (m)	2.06	1.32	1.12	1.10	1.18	0.67	0.34	0.30	0.44
		%	100	64	55	53	57	33	16	14	21
		Snowdays	155	114	101	102	106	75	51	42	56

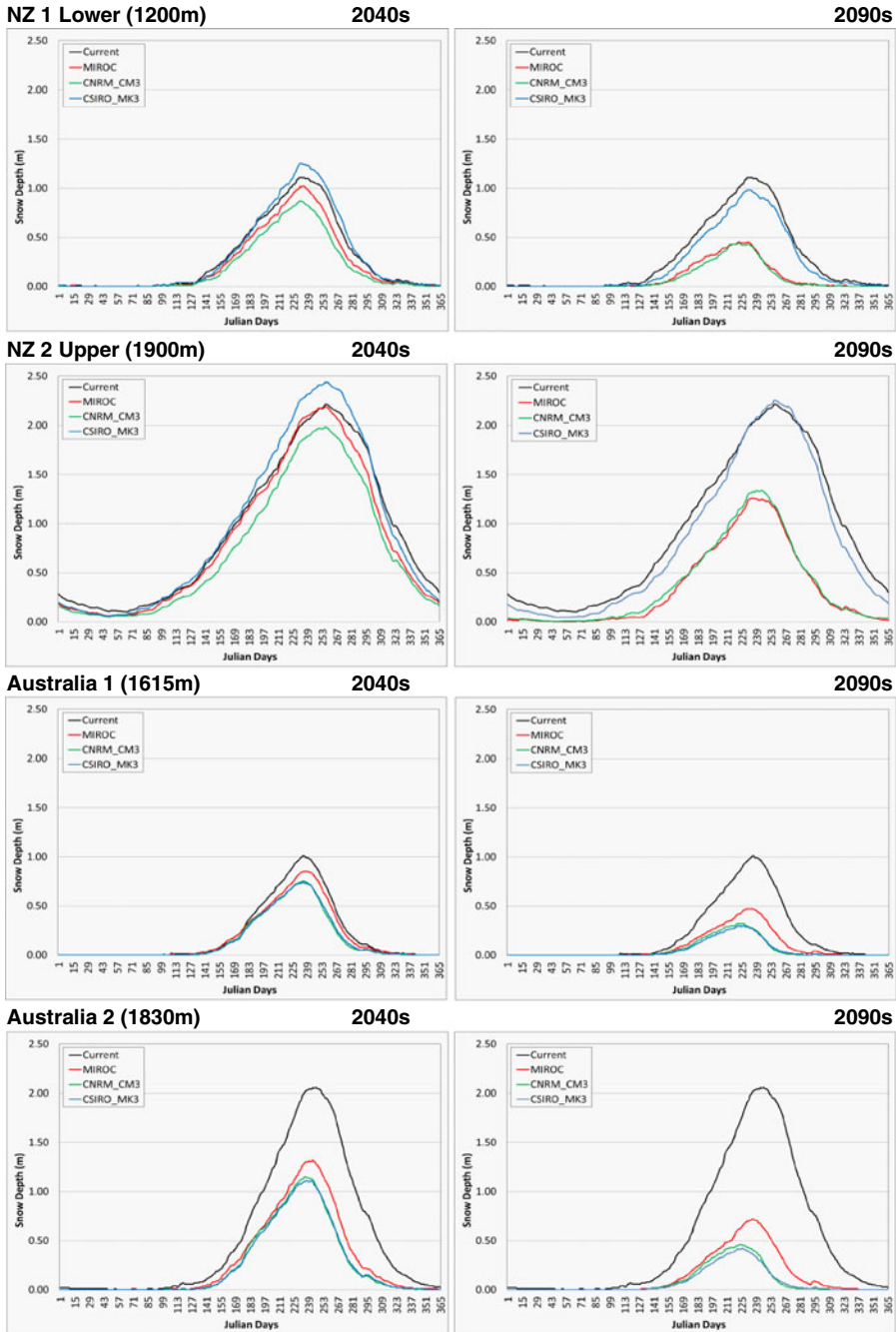
These results indicate that for the two New Zealand sites our analysis shows that under our mid-range scenario (A1B), by 2040 there will be between 73 % and 116 % of the current maximum snow depth (on 31 August) and by 2090 this will be reduced to between 28 % and 101 % of the current maximum snow depth. At the lowest site at NZ1 (1,200 m), by the 2090s there will on average be a maximum snow depth of 0.49 m (range from 0.29 m to 0.89 m). The higher site in New Zealand (NZ2) is less impacted overall, and this is most likely due to delimitation of the snow/rain line. For the two Australian sites, our analysis shows that under our mid-range scenario (A1B), by 2040 there will be between 53 % and 87 % of the current maximum snow depth (on 31 August) and by 2090 this will be reduced to between 14 % and 43 % of the current maximum snow depth. At the lowest site (Australia 1 at 1,600 m), by the 2090s there will on average be a maximum snow depth of 0.28 m (range from 0.20 m to 0.42 m). These metrics clearly show that the two sites in Australia will be more impacted than the New Zealand sites considered, both in terms of absolute snow depths, but also when considered as a percentage change.

Another important metric to review these results by are the number of ‘snow-days’ within a season (i.e. days that snow depths exceed a minimum useable threshold as defined by industry, in this case 0.30 m). Abegg et al. (2007) note that the ‘100-day rule’ (i.e. snow cover sufficient for skiing for at least 100 days) has been widely used as a tool to assess the susceptibility of ski areas to climate variability and change. Hendriks and Hreinsson (2012) used this rule and a 0.30 m threshold in a nationwide assessment for New Zealand ski industry, as did Hennessy et al. (2008) in Australia. When we consider this metric, we observe, on average a reduction in the number of snow-days at all of our sites, with the greatest reductions occurring in the 2090s. However, at least for the New Zealand sites in the 2040s, the individual GCMs provide a range from substantial reductions to slight increases in snow-days depending on the site in question.

5 Discussion and conclusions

Our results show that on average, across the three different GCMs considered, climate change will reduce the natural snow which is available at all the sites considered in this study. These are the first directly comparable and quantitative assessments of the potential effects of climate change on seasonal snow in New Zealand and Australia at a ski area site scale. The results are mostly expected and are generally consistent with our understanding of snow processes. The magnitude of the reduction in natural snow cover is negatively correlated to the elevation of the site, with lower elevation sites showing the greatest change and high elevation sites the least. Latitude is also of significance, with the New Zealand sites being situated 9° further poleward than the Australian sites. However, while elevation and latitude are clearly important factors in determining the potential impact of climate change on seasonal snow, other factors such as the local climatology of each site also play an important role.

If we consider these two locations in both countries, it is clearly evident that both the New Zealand and Australian sites show a similar tendency with a decrease in the maximum SWE and the number of snow-days, which increases in magnitude towards the 2090s. The Australian sites also show a more marked decrease than the New Zealand sites. This is not unexpected, and in keeping with previous work (e.g. Hennessy et al. 2003, 2008). The climate change projections for this part of Australia indicate that the temperatures will rise faster than in New Zealand, and the winter



precipitation is projected to decrease (Suppiah et al. 2007). By contrast, this area of New Zealand is projected to see a slower rate of temperature increase, and an increase in winter precipitation (MfE 2008).

◀ **Fig. 2** Average daily changes in snow storage for the 2040s and 2090s, in m for the four sites, with the greatest elevation differences shown for the two New Zealand sites. NZ1 lower (*top row*) is the lowest site considered at an elevation of 1,200 m, while NZ2 upper (*second row*), and is the highest site at 1,900 m. Australia 1 (*third row*) is the lowest Australian site considered at an elevation of 1,615 m, while Australia 2 (*bottom row*), is the highest Australian site at 1,830 m. The left column is the 2040s projection, while the right column is the 2090s projection, with the current (*black*), the miroc32_hires model (*red*), the cnrm_cm3 model (*green*) and the csiro_mk3.0 (*blue*) also shown for the an A1B emissions scenario

Furthermore, when we consider the magnitude of the change shown in previous work (Hennessy et al. 2003, 2008) for Australia sites, we see that our modelled changes for the 2090s are roughly consistent with these and approximately at a mid-point between their “low impact” and their “high impact” results for their 2050 scenario. However, it must be noted that their “high impact” scenario for the 2090s had a similar level of warming (2.9 °C vs. our average 2.8 °C), but their scenario had a much greater decline in winter precipitation. With the different snow models and scenarios used, a direct comparison is problematic. However, this comparison does provide some assurance that our model presents similar gross scale changes as previously published for these Australian sites. We consider that our results are of greatest value for their use in comparing to the relative changes observed in New Zealand, rather than purely for estimating changes in maximum snow at these locations.

When we consider the number of days with snow depth ≥ 0.30 m at each site, even in the current climate, the lowest sites only just achieve the generally accepted “100 day” threshold for a viable industry. This is in part due to our model not considering snow making, which is already a significant part of both New Zealand and Australian ski industry. We have not considered the impact of snowmaking on this analysis, as clearly identified by Scott et al. (2007) and Hennessy et al. (2003, 2008) as an important consideration when examining the impacts of climate change on the ski industry. The literature indicates that the ski industry has been successful in their adaptation efforts and that increased snow making capacity reduces the impacts of warm winters, as shown in an analogue analysis of ski fields in the United States (Dawson et al. 2009). However, a study by Pickering and Buckley (2010) examining snowmaking requirements in Australia has suggested that at the lowest elevations the required snow making would be too costly there, even just to meet the 2020s projected demand (based on the Hennessy et al. 2008 work). The work by Hendriks and Hreinsson (2012) for New Zealand ski areas shows that all sites that they examined in New Zealand (including the two presented here) would still be physically capable of making snow, even by the 2090s under an A1FI emissions scenario. While they did not provide any economic assessment of the ability for the areas to do this, this suggests that at least in the mid-term (out to the 2040s) that snowmaking is still a viable option for these two New Zealand sites. This clear difference can likely be attributed to the relatively modest increase in temperature (and increased, opposed to decreased precipitation) in the New Zealand sites, when compared to the Australian sites.

Based on the results presented in this paper, and if our hypotheses is correct that the relative change in maximum SWE and reduction in snow-days will be a key driver in the Australia–New Zealand tourism industry (with preferential flow in the direction of the region of relative greater snow) then the New Zealand snow industry is likely to see a positive response to the impacts of climate change, at least initially. However, this is likely an overly simplistic view, as the domestic New Zealand market may reduce with decreased

snow, and the relative snow differences alone may not be the only, or most important variable for driving Australia–New Zealand ski tourism flows. In fact, Pickering et al. (2009) found that the Australian skiers surveyed have become less likely to ski as often, and less likely to go overseas in a season of low natural snowfall, compared to research undertaken 11 years earlier. Further, Hopkins et al. (2011) suggest that Australian skiers already identify the Northern Hemisphere as the preferred destination for snow-reliability, and this could pose the most substantial threat to the Central Otago ski areas. On the other hand, interviews with Australian skiers revealed that motivations for Australian snow-tourists to New Zealand go beyond just weather and snow availability, including a diversity of activities which they can do in addition to skiing (Hopkins et al. 2012). Thus, diversification of both snow-based and non-snow-based activities is a key adaptation measure for winter sport destinations (Hoy et al. 2011). While our study is specific to these two regions in the Australia–New Zealand ski industry, we have also provided a framework by which other regions or countries with climate sensitive tourism enterprises could assess the relative impacts and therefore the potential wider ranging ramifications with respect to tourism flows. For example, understanding the relative vulnerability and changes in attractiveness of island destinations would also be of great importance, not only for the international tourism business, but also for national development goals that often depend on a healthy and growing tourism industry (Becken and Hay 2012).

While the results we present are consistent with our understanding of snow processes, we must still urge some caution in their use. The change scenario methodology employed is a relatively simple delta-change approach; in particular that only makes simple empirical allowance for changes in the extremes. These extreme events are of great importance, particularly for ski-areas as often one large and well-timed storm can be more beneficial for a ski-area than the same amount of snow arriving in small amounts over the space of a few weeks. Future work should investigate this through the coupling of a regional climate model with the snow model and a tourism model, to better simulate future climates and their potential impacts on this industry and the resulting tourism flows.

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