

# PAST, PRESENT AND FUTURE OF SEASONAL SNOW FOR CARDRONA AND TREBLE CONE SKI AREAS



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# 1 Executive summary

Cardrona Alpine Resorts require a data-backed assessment of climate change effects on the ski field covering the period of commercial activity (decadal) with the aim to estimate the past, present and likely future snow presence on the ski field. This will provide a crude lifetime remaining for the ski field operation, for restoration programmes and so on.

The climate is changing, and the record of Queenstown mean temperatures show an increase of 1.1 °C from 1930 – 2020. It is accepted internationally that further changes will result from increasing amounts of greenhouse gases in the atmosphere. The climate will also vary on interannual and decadal due to natural processes such as El Niño/Southern Oscillation, which also affects Otago.

Climate change effects over the next decades are predictable with some level of certainty and varies from place to place throughout New Zealand. This report addresses those expected changes in the higher elevations in the ski areas of the Queenstown-Lakes District out to 2090 and draws heavily on the report “Climate change projections for New Zealand 2<sup>nd</sup> Edition (Ministry for the Environment 2018) which uses climate model simulations from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, using not only predictions from interpreting global climate models but also those from a detailed New Zealand regional climate model run on the NIWA supercomputer. This allows a much-improved level of detail and more certainty in the information provided.

The mid-range estimate temperature projections for the June – September season the ski areas are an expected increase of about 0.5 °C by 2030, and 1°C by 2040. Owing to the different possible pathways for the concentrations of greenhouse gases in the atmosphere and the differences in climate model response to these, the projections for warming span a range: 0.8–1.1°C by 2040 with the upper range of 1.5°C, and 2-3°C by 2090.

For projected precipitation it is *highly likely* that for winter there will be an increase in precipitation for the Otago ski areas, caused by robust predictions of increased westerly winds during the June to September season. The mid-range projection is for an increase of 7 percent by 2030 and 14 percent. Precipitation change ranges from decreases of 9 percent to increases of 33 percent by 2040.

From observations of short-term temperature and precipitation data from Cardrona and Treble Cone daily observations from longer term temperature and precipitation stations in the region were calibrated to produce daily data for the period 2000-2019. These were then used as input to the SnowSim model to derive monthly and seasonal snow depths for the Cardrona and Treble Cone ski areas.

SnowSim output only show decreases in seasonal snow depths for the June to September season, when no precipitation is assumed, ranging from 5 percent by and 8 percent by 2040. When applying mid-range precipitation projections, seasonal snow depths **increase** by 3 percent by 2030 and 5 to 9 percent by 2040. Under these circumstances the ski field operations are **viable for at least the next two decades**. More risk is posed by **year-to-year variability** in snow precipitation. Only with more warming (2 to 3°C) do snow depths decrease, from 14 percent (RCP 6.0), and 31 percent (RCP8.5) by 2090.

## 2 Climate Change Scenarios –

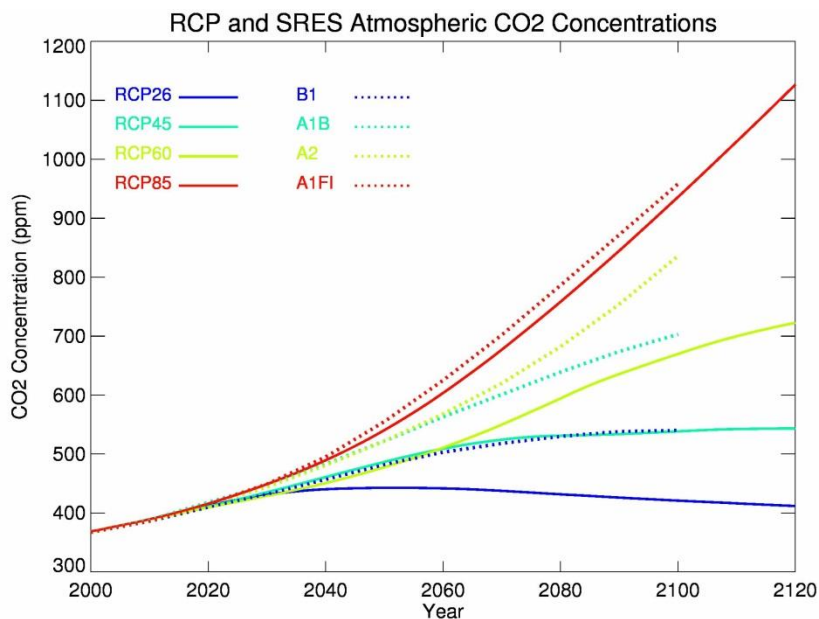
### Representative Concentration Pathways

For the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment, four forcing scenarios have been developed, known as representative concentration pathways (RCPs) (van Vuuren et al, 2011a). These pathways are identified by their approximate total (accumulated) radiative forcing at 2100 relative to 1750 owing to increases in Greenhouse Gases:

- 4.5 W m<sup>-2</sup> for RCP4.5
- 6.0 W m<sup>-2</sup> for RCP6.0
- 8.5 W m<sup>-2</sup> for RCP8.5.

For our analysis the two stabilisation pathways (RCP4.5 and RCP6.0), and one pathway (essentially ‘business as usual’) with very high greenhouse gas concentrations by 2100 and beyond are used. The lowest (RCP2.6) was not considered as Greenhouse Gases are highly likely to exceed this pathway.

Figure 1 compares the RCP atmospheric carbon dioxide concentrations with an earlier scenario. Although the IPCC Assessment Report 4 and Assessment Report 5 concentrations do not correspond directly to each other, CO<sub>2</sub> concentrations under RCP4.5 and RCP8.5 are similar to those of the earlier scenarios B1 and A1FI, respectively.

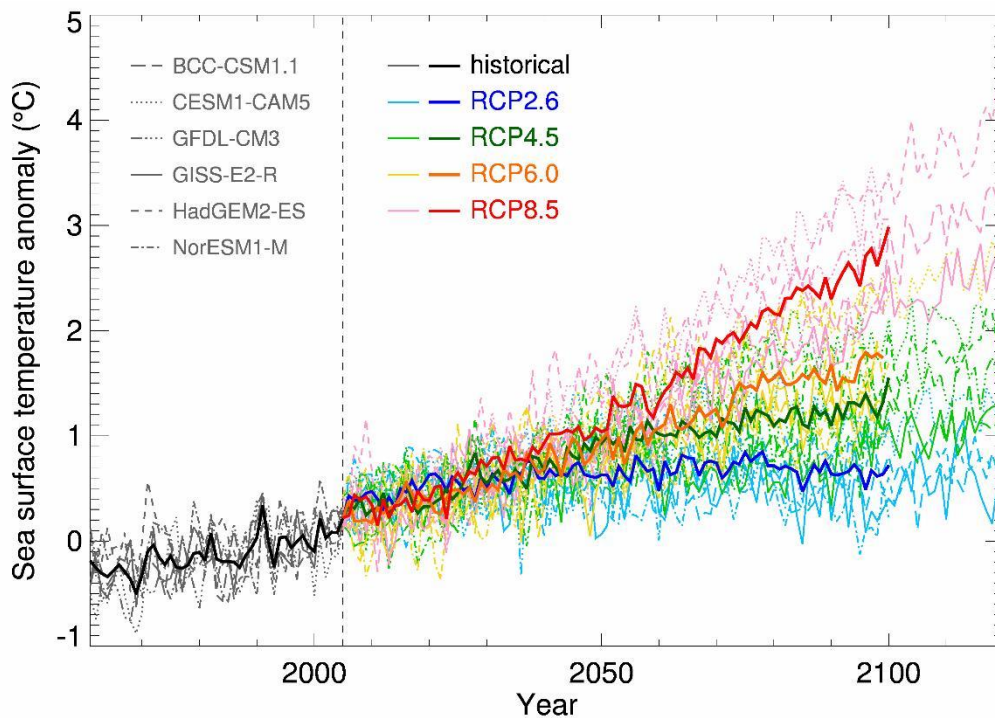


**Figure 1: Atmospheric carbon dioxide concentrations for the IPCC Fourth Assessment (dotted lines, SRES concentrations) and for the IPCC Fifth Assessment (solid lines, RCP concentrations)**

## 3 Temperature and precipitation projections

### 3.1 New Zealand

Figure 2 shows the bias-adjusted sea surface temperatures used to force the NIWA General Circulation Model and Regional Circulation Model, presented here only for the average over the RCM domain (Ackerley et al, 2012). For the pathways, except RCP2.6, sea temperatures continue to increase throughout the twenty-first century, with a much larger rate of change from the high greenhouse gas pathway (RCP8.5).



**Figure 2: Bias-adjusted sea surface temperatures, averaged over the Regional Climate Model domain, for six CMIP5 global climate models, and for the historical simulations (here 1960–2005) and four future simulations (RCPs 2.6, 4.5, 6.0 and 8.5), relative to 1986–2005**

Individual models are shown by thin dotted or dashed or solid lines (as described in the inset legend), and the six-model ensemble-average by thicker solid lines, all of which are coloured according to the RCP pathway.

## 3.2 Otago

### 3.2.1 Temperature

The bias correction and downscaling procedures were performed separately by NIWA on regional climate model (RCM) data for the primary climate variables of minimum and maximum temperature and precipitation.

**Table 1: Projected changes in winter and spring mean temperature (in °C) from NIWA, between 1986–2005 and 2031–2050 for Otago, as derived from statistical downscaling. The changes are given for three RCPs (8.5, 6.0, and 4.5), where the ensemble-average is taken over (41, 18, 37) models respectively.**

Otago	Winter	Spring
rcp 8.5	1.1 (0.7 to 1.5)	0.8 (0.3 to 1.3)
rcp 6.0	0.8 (0.3 to 1.3)	0.6 (0.0 to 1.0)
rcp 4.5	0.9 (0.6 to 1.4)	0.7 (0.3 to 1.1)

The values in each column represent the ensemble average, and in brackets the range (5th percentile to 95th percentile) over all models within that ensemble. As the season for the ski areas is principally winter (June, July and August), the winter values were used to perturb the SnowSim Model. The three RCPs show a temperature mean increase of between 0.8 to 1.0°C, with the range of 0.3 to 1.5°C. The SnowSim model (Fitzharris and Garr, 1995) and was perturbed by 0.5, 1.0 and 1.5°C.

### 3.2.2 Precipitation

As with temperature, climate change precipitation projections are now presented for 2040 in Table 2. For projected precipitation it is *highly likely* that for winter there will be an increase for the Otago ski areas, caused by robust predictions of increased westerly winds during the June to September season. The mid-range projections are for an increase of 14 percent for 2040 and 8 percent for 2030. However, there is a wide range of precipitation change ranging from decreases of 12 percent to increases of 36 percent for 2040.

**Table 2: Projected changes in seasonal and annual precipitation (in percentage) between 1986–2005 and 2031–50 for Queenstown, as derived from statistical downscaling. The changes are given for three RCPs (8.5, 6.0 and 4.5), where the ensemble-average is taken over (41, 18 and 37) models respectively.**

Queenstown	Winter	Spring
rcp 8.5	16 (-4 to + 36)	16 (-4 to +36)
rcp 6.0	13 (-11 to + 35)	13 (-11 to +35)
rcp 4.5	13 (-12 to +28)	13 (-12 to + 28)



Table 2 shows projections for Queenstown precipitation for RCPs 8.5, 6.0 and 4.5 after NIWA. Queenstown is representative of the ski areas nearby.

The values in each column represent the ensemble average, and in brackets the range (5th percentile to 95th percentile) over all models within that ensemble. Projections for Queenstown are a direct interpolation by NIWA from the global CMIP5 models.

## 4 SnowSim Simulations

### 4.1 Inputs

Cardrona daily mean temperature data were available for much of the 2000 – 2019 period. Missing values were infilled by mean temperatures from Frankton Airport, the nearest climate station, with an adjustment of  $-7.0^{\circ}\text{C}$ . This time series was suitable for both Cardrona and Treble Cone.

Although there are some rainfall measurements for several years at both Cardrona and Treble Cone ski areas from the June to September ski areas, these were incomplete so daily rainfall was used from reliable observations which correlate well with each ski area.

For Cardrona, Frankton Airport data was used from 2000 – 2004, then Arrowtown from 2005 – 2019. Glenfinnan daily rainfall data was available for the entire 2000 – 2019 period. Glenfinnan was much wetter, so values were adjusted to 40 percent of the measured values.

Finally, the rain/snow threshold was taken to be  $2^{\circ}\text{C}$ : temperatures of  $2^{\circ}\text{C}$  or more precipitation was taken as rain, whereas below this threshold snow. The SnowSim model was perturbed by adjusting the rain/snow threshold, i.e. no warming rain/snow threshold  $2^{\circ}\text{C}$ , warming of  $+0.5^{\circ}\text{C}$ , a threshold of  $1.5^{\circ}\text{C}$ ; warming of  $1^{\circ}\text{C}$ , rain/snow threshold of  $1^{\circ}\text{C}$ ; and finally, an increase of  $1.5^{\circ}\text{C}$  a threshold of  $0.5^{\circ}\text{C}$ .

Finally snow precipitation is much less dense than rain precipitation, with resulting snow depths about 10 times that of rainfall depths. Snow Water Equivalents were derived by multiplying rainfall depth in mm by 10.

The calibrated simulations from the SnowSim model for current climate were verified against actual snow depth observations for Cardrona snow depth for means over 2008 – 2019 seasons, and for Treble Cone the means over 2012-2015 and 2018 seasons, from data supplied by Cardrona Alpine Resorts Ltd.

## 5 Results

The results of the SnowSim model simulations for current climate are shown in Table 3 for the period 2000-2019. On a seasonal basis the SnowSim model estimated snow depth at 2130 mm compared with actual measurements of 2220 mm. For Treble Cone values were estimated at 2550 mm compared with 2500 mm actual.

Monthly projections are shown in Tables 4 – 7. Table 4 shows projections where only the rain/snow threshold is adjusted with no change in total precipitation (rain and snow). With warming up to 1.5°C this equates to a rise in snowlines of about 100 metres. This is shown in the decreases of about 5 percent by 2030, and 8 percent by 2040 in monthly snow depths with a warming of 1°C. With more warming (+1.5°C) there is a decrease of 20 percent.

However mid-range projections of precipitation (Table 5) give increases. This translates to increases in monthly snow depths by 2030 of 3 percent, 5 percent at 2040 with 1°C warming, and decreases of 5 percent at 2040 with 1.5°C warming.

Of more significance is the seasonal projections (Tables 8-11). The no precipitation cases illustrated the influence of **temperature** alone. Seasonal snow depths decrease by 5 percent with 0.5°C warming by 2030, and 8 percent by 2040 with 1°C warming. With the upper range warming of 1.5°C by 2040 the decrease is 20 percent in snow depths.

By applying the **mid-range precipitation** projections in all cases seasonal snow depths **increase**. By 2030 seasonal snow depths increase by 3 percent, and between 5 and 9 percent. Of note interannual variability for snow depths is 800 mm, about a third of the average.

Further increases in warming of 2 and 3°C (Tables 12 and 13) are only attained several decades later by 2090 for the two higher RCP scenarios: 2°C for RCP 6.0, and 3°C for RCP 8.5. By applying the mid-range precipitation projections snow depths do **decrease**. For Cardrona this amounts to 12 percent (RCP 6.0) and 34 percent (RCP 8.5), and Treble Cone 16 percent (RCP 6.0) and 28 percent (RCP 8.5). However, such RCP levels are not attained for another six decades (2090). RCP 8.5, the 'business as usual' scenario is less likely.



**Table 3: Monthly snow depths, in mm, from the SnowSim model for current climate over the period 2000-2019.**

<b>Monthly Snow Depths (mm)</b>			
	Current Climate		
	Date	Monthly	
		Cardrona	Treble Cone
2000	June	1432.0	1523.6
	July	382.0	682.4
	August	412.0	375.2
	September	788.0	848.0
2001	June	686.0	991.6
	July	296.0	160.4
	August	714.0	717.6
	September	90.0	121.6
2002	June	1254.0	1241.6
	July	190.0	339.2
	August	672.0	920.0
	September	1166.0	1704.8
2003	June	742.0	788.0
	July	534.0	550.8
	August	339.0	631.6
	September	780.0	1442.0
2004	June	1023.0	1272.8
	July	218.0	382.8
	August	815.0	1149.6
	September	746.0	833.6
2005	June	214.0	389.6
	July	223.0	548.8
	August	436.0	762.4
	September	92.0	160.4
2006	June	638.0	611.6
	July	354.0	614.0
	August	688.0	502.4
	September	759.0	647.2
2007	June	514.0	528.0
	July	412.0	563.6
	August	847.0	598.4
	September	335.0	529.6
2008	June	391.0	416.4
	July	670.0	763.6
	August	501.0	263.6
	September	976.0	734.4

2009	June	136.0	340.4
	July	516.0	643.6
	August	925.0	1452.4
	September	238.0	325.6
2010	June	466.0	322.8
	July	215.0	177.2
	August	1251.0	1043.2
	September	936.0	1256.0
2011	June	278.0	432.0
	July	793.0	1033.6
	August	312.0	174.4
	September	314.0	266.4
2012	June	930.0	691.2
	July	520.0	414.8
	August	261.0	274.0
	September	866.0	1352.4
2013	June	1588.0	1034.8
	July	951.0	919.2
	August	333.0	562.8
	September	802.0	778.0
2014	June	265.0	444.4
	July	553.0	668.4
	August	705.0	571.2
	September	288.0	535.2
2015	June	768.0	952.4
	July	411.0	670.0
	August	482.0	1116.8
	September	188.0	323.6
2016	June	293.0	426.4
	July	1002.0	1566.0
	August	58.0	329.6
	September	384.0	228.0
2017	June	322.0	295.6
	July	493.0	612.0
	August	717.0	945.6
	September	556.0	728.8
2018	June	362.0	249.2
	July	1168.0	1025.2
	August	321.0	637.2
	September	677.0	632.4
2019	June	245.0	255.6
	July	399.0	711.2
	August	331.0	568.8
	September	259.0	231.2

	Averages	565.1	669.1
	St Dev	326.7	368.3
Averages	June	627.4	660.4
	July	515.0	652.3
	August	556.0	679.8
	September	562.0	684.0
	Average	565.1	669.1
St Dev	June	408.8	376.4
	July	276.5	319.1
	August	268.8	284.5
	September	316.2	447.5
Maximum	June	1588.0	1523.6
	July	1168.0	1566.0
	August	1251.0	1452.4
	September	1166.0	1704.8
Minimum	June	136.0	249.2
	July	190.0	160.4
	August	58.0	174.4
	September	90.0	121.6

**Table 4: Current snow depths and projected changes in monthly snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model.**

	Current Climate			Warming + 0.5 deg C		Warming + 1.0 degC		Warming + 1.5 deg C	
	Date	Monthly		No precipitation change		No precipitation change		No precipitation change	
	Month	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
Averages	June	627.4	660.4	607.8	650.3	585.7	599.7	542.9	518.2
	July	515.0	652.3	511.6	649.4	481.1	600.0	412.9	505.1
	August	556.0	679.8	524.9	603.7	507.0	587.2	506.7	541.1
	September	562.0	684.0	531.1	628.6	540.7	635.2	439.1	468.5
	Average	565.1	669.1	543.8	633.0	528.6	605.5	475.4	508.2
St Dev	June	408.8	376.4	416.4	383.3	387.1	323.3	363.4	271.1
	July	276.5	319.1	278.3	309.5	276.6	364.0	202.7	318.7
	August	268.8	284.5	274.6	295.5	275.4	308.8	244.0	276.2
	September	316.2	447.5	307.7	455.5	313.5	389.2	207.2	355.8
Maximum	June	1588.0	1523.6	1588.0	1544.4	1565.0	1272.8	1412.0	1116.4
	July	1168.0	1566.0	1168.0	1566.0	1190.0	1508.4	1001.0	1493.2
	August	1251.0	1452.4	1251.0	1149.6	1251.0	1149.6	1018.0	1149.6
	September	1166.0	1704.8	1166.0	1704.8	1136.0	1524.8	772.0	1337.2
Minimum	June	136.0	249.2	33.0	238.8	33.0	188.4	33.0	101.2
	July	190.0	160.4	190.0	160.4	177.0	47.6	190.0	47.6
	August	58.0	174.4	58.0	98.0	32.0	98.0	58.0	98.0
	September	90.0	121.6	14.0	35.6	90.0	105.2	76.0	0.0

**Table 5: Current snow depths and projected changes in monthly snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the mid-range precipitation projections.**

Current Climate			Warming + 0.5 deg C		Warming + 1.0 degC		Warming +1.5 deg C	
			Mid-range + 8%		Mid-range + 14%		Mid-range + 14%	
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
June	627.4	660.4	656.4	702.3	667.6	683.6	618.8	590.7
July	515.0	652.3	552.5	701.4	548.4	684.0	470.7	575.8
August	556.0	679.8	566.9	652.0	577.9	669.4	577.6	616.8
September	562.0	684.0	573.5	678.9	616.3	724.1	500.5	534.1
Average	565.1	669.1	587.3	683.6	602.6	690.3	541.9	579.4

**Table 6: Current snow depths and projected changes in monthly snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the low (5 percentile) precipitation projections.**

Current Climate			Warming + 0.5 deg C		Warming + 1.0 degC		Warming +1.5 deg C	
			Low -5%		Low -9%		Low -9%	
Low	627.4	660.4	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
June	515.0	652.3	577.4	617.8	607.6	622.1	618.8	590.7
July	556.0	679.8	486.0	616.9	499.0	622.4	470.7	575.8
August	562.0	684.0	498.7	573.5	525.9	609.1	577.6	616.8
September	565.1	669.1	504.5	597.2	560.9	659.0	500.5	534.1
Average	565.1	669.1	516.6	601.3	548.3	628.2	541.9	579.4

**Table 7: Current snow depths and projected changes in monthly snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the high (95 percentile) precipitation projections.**

Current Climate			Warming + 0.5 deg C		Warming + 1.0 degC		Warming +1.5 deg C	
			High + 14%		High +33%		High +33%	
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
June	627.4	660.4	711.1	760.8	778.9	797.6	722.0	689.2
July	515.0	652.3	598.6	759.8	639.8	798.0	549.2	671.7
August	556.0	679.8	614.1	706.3	674.2	780.9	673.8	719.6
September	562.0	684.0	621.3	735.5	719.1	844.8	583.9	623.1
Average	565.1	669.1	636.3	740.6	703.0	805.3	632.2	675.9



**Table 8: Current snow depths and projected changes in seasonal snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for no change in precipitation.**

Seasonal Snow Depths (mm)								
	Current		Seasonal +0.5 deg C		Seasonal +1 deg C		Seasonal +1.5 deg C	
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
2000	3014.0	3429.2	2922.0	3562.0	2738.0	2919.2	2438.0	1852.4
2001	1786.0	1991.2	1652.0	1905.2	1614.0	1567.6	1578.0	1430.8
2002	3282.0	4205.6	3266.0	4131.6	3088.0	3836.8	2550.0	3045.6
2003	2395.0	3412.4	2291.0	3307.6	2259.0	3121.6	2085.0	2951.6
2004	2802.0	3638.8	2788.0	3638.8	2761.0	3522.8	2772.0	3360.8
2005	965.0	1861.2	960.0	1636.8	950.0	1729.2	1590.0	1552.8
2006	2439.0	2375.2	2328.0	2100.0	2030.0	2105.6	2105.0	1889.2
2007	2108.0	2219.6	1749.0	1395.6	1712.0	1734.8	1591.0	1185.6
2008	2538.0	2178.0	2536.0	1980.8	2578.0	2172.4	1974.0	954.4
2009	1815.0	2762.0	1690.0	2391.6	1636.0	2385.2	1585.0	2068.8
2010	2868.0	2799.2	2710.0	2657.6	2709.0	2577.2	2302.0	2426.4
2011	1697.0	1906.4	1387.0	1627.6	1402.0	1619.2	1387.0	1610.0
2012	2577.0	2732.4	2399.0	2598.8	2228.0	1991.2	1934.0	1771.6
2013	3674.0	3294.8	3674.0	3294.8	3363.0	3027.2	2454.0	1975.2
2014	1811.0	2219.2	1803.0	2047.2	1781.0	1973.6	1555.0	1896.8
2015	1849.0	3062.8	1840.0	3062.8	1686.0	2803.2	1512.0	2349.2
2016	1737.0	2550.0	1737.0	2548.4	1711.0	2465.6	1598.0	2375.2
2017	2088.0	2582.0	2088.0	2502.8	2063.0	2352.4	1959.0	2324.8
2018	2528.0	2544.0	2528.0	2538.0	2829.0	2846.8	1902.0	1987.2
2019	1234.0	1766.8	1158.0	1711.6	1148.0	1688.8	1158.0	1648.0
Average	2260.4	2676.5	2175.3	2532.0	2114.3	2422.0	1901.5	2032.8
St Dev	661.1	643.6	680.8	743.4	645.5	635.9	424.0	593.2
High	3674.0	4205.6	3674.0	4131.6	3363.0	3836.8	2772.0	3360.8
Low	965.0	1766.8	960.0	1395.6	950.0	1567.6	1158.0	954.4

**Table 9: Current snow depths and projected changes in seasonal snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the mid-range precipitation projections.**

Seasonal Snow Depths (mm)		Warming + 0.5 deg C		Warming + 1.0 degC		Warming + 1.5 deg C		
	Current	Mid-range +7%		Mid-range + 14%		Mid-range + 14%		
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
	3014.0	3429.2	3155.8	3847.0	3331.1	4060.7	3121.3	3327.9
	1786.0	1991.2	1784.2	2057.6	1883.3	2171.9	1840.0	1787.1
	3282.0	4205.6	3527.3	4462.1	3723.2	4710.0	3520.3	4374.0
	2395.0	3412.4	2474.3	3572.2	2611.7	3770.7	2575.3	3558.6
	2802.0	3638.8	3011.0	3929.9	3178.3	4148.2	3147.5	4016.0
	965.0	1861.2	1036.8	1767.7	1094.4	1866.0	1083.0	1971.3
	2439.0	2375.2	2514.2	2268.0	2653.9	2394.0	2314.2	2400.4
	2108.0	2219.6	1888.9	1507.2	1993.9	1591.0	1951.7	1977.7
	2538.0	2178.0	2738.9	2139.3	2891.0	2258.1	2938.9	2476.5
	1815.0	2762.0	1825.2	2582.9	1926.6	2726.4	1865.0	2719.1
	2868.0	2799.2	2926.8	2870.2	3089.4	3029.7	3088.3	2938.0
	1697.0	1906.4	1498.0	1757.8	1581.2	1855.5	1598.3	1845.9
	2577.0	2732.4	2590.9	2806.7	2734.9	2962.6	2539.9	2270.0
	3674.0	3294.8	3967.9	3558.4	4188.4	3756.1	3833.8	3451.0
	1811.0	2219.2	1947.2	2211.0	2055.4	2333.8	2030.3	2249.9
	1849.0	3062.8	1987.2	3307.8	2097.6	3491.6	1922.0	3195.6
	1737.0	2550.0	1876.0	2752.3	1980.2	2905.2	1950.5	2810.8
	2088.0	2582.0	2255.0	2703.0	2380.3	2853.2	2351.8	2681.7
	2528.0	2544.0	2730.2	2741.0	2881.9	2893.3	3225.1	3245.4
	1234.0	1766.8	1250.6	1848.5	1320.1	1951.2	1308.7	1925.2
Average	2260.4	2676.5	2349.3	2734.5	2479.8	2886.5	2410.3	2761.1
StDev	733.4	735.8	776.5	848.1	788.1	842.2	696.2	813.1
Max	3674.0	4205.6	3967.9	4462.1	4188.4	4710.0	3833.8	4374.0
Min	965.0	1766.8	1036.8	1507.2	1094.4	1591.0	1083.0	1787.1

**Table 10: Current snow depths and projected changes in seasonal snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the low (5 percentile) precipitation projections.**

Seasonal Snow Depths (mm)		Warming + 0.5 deg C		Warming + 1.0 degC		Warming + 1.5 deg C		
	Current	Low - 5%		Low -9%		Low - 9%		
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
	3014.0	3429.2	2775.9	3383.9	2491.6	2656.5	2218.6	1685.7
	1786.0	1991.2	1569.4	1809.9	1468.7	1426.5	1436.0	1302.0
	3282.0	4205.6	3102.7	3925.0	2810.1	3491.5	2320.5	2771.5
	2395.0	3412.4	2176.5	3142.2	2055.7	2840.7	1897.4	2686.0
	2802.0	3638.8	2648.6	3456.9	2512.5	3205.7	2522.5	3058.3
	965.0	1861.2	912.0	1555.0	864.5	1573.6	1446.9	1413.0
	2439.0	2375.2	2211.6	1995.0	1847.3	1916.1	1915.6	1719.2
	2108.0	2219.6	1661.6	1325.8	1557.9	1578.7	1447.8	1078.9
	2538.0	2178.0	2409.2	1881.8	2346.0	1976.9	1796.3	868.5
	1815.0	2762.0	1605.5	2272.0	1488.8	2170.5	1442.4	1882.6
	2868.0	2799.2	2574.5	2524.7	2465.2	2345.3	2094.8	2208.0
	1697.0	1906.4	1317.7	1546.2	1275.8	1473.5	1262.2	1465.1
	2577.0	2732.4	2279.1	2468.9	2027.5	1812.0	1759.9	1612.2
	3674.0	3294.8	3490.3	3130.1	3060.3	2754.8	2233.1	1797.4
	1811.0	2219.2	1712.9	1944.8	1620.7	1796.0	1415.1	1726.1
	1849.0	3062.8	1748.0	2909.7	1534.3	2550.9	1375.9	2137.8
	1737.0	2550.0	1650.2	2421.0	1557.0	2243.7	1454.2	2161.4
	2088.0	2582.0	1983.6	2377.7	1877.3	2140.7	1782.7	2115.6
	2528.0	2544.0	2401.6	2411.1	2574.4	2590.6	1730.8	1808.4
	1234.0	1766.8	1100.1	1626.0	1044.7	1536.8	1053.8	1499.7
Average	2260.4	2676.5	2066.5	2405.4	1924.0	2204.0	1730.3	1849.9
StDev	730.0	730.2	646.8	706.2	587.4	578.7	385.9	539.8
Max	3674.0	4205.6	3490.3	3925.0	3060.3	3491.5	2522.5	3058.3
Min	965.0	1766.8	912.0	1325.8	864.5	1426.5	1053.8	868.5

**Table 11: Current snow depths and projected changes in seasonal snow (in mm) between 2000-2019 and 2030 (warming of 0.5°C) and 2040 (warming of 1.0 and 1.5°C) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for the high (95 percentile) precipitation projections.**

Seasonal Snow Depths (mm)		Warming + 0.5 deg C		Warming + 1.0 degC		Warming + 1.5 deg C		
	Current	High +14%		High + 33%		High + 33%		
	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone	Cardrona	Treble Cone
	3014.0	3429.2	3331.1	4060.7	3641.5	3882.5	3242.5	2463.7
	1786.0	1991.2	1883.3	2171.9	2146.6	2084.9	2098.7	1903.0
	3282.0	4205.6	3723.2	4710.0	4107.0	5102.9	3391.5	4050.6
	2395.0	3412.4	2611.7	3770.7	3004.5	4151.7	2773.1	3925.6
	2802.0	3638.8	3178.3	4148.2	3672.1	4685.3	3686.8	4469.9
	965.0	1861.2	1094.4	1866.0	1263.5	2299.8	2114.7	2065.2
	2439.0	2375.2	2653.9	2394.0	2699.9	2800.4	2799.7	2512.6
	2108.0	2219.6	1993.9	1591.0	2277.0	2307.3	2116.0	1576.8
	2538.0	2178.0	2891.0	2258.1	3428.7	2889.3	2625.4	1269.4
	1815.0	2762.0	1926.6	2726.4	2175.9	3172.3	2108.1	2751.5
	2868.0	2799.2	3089.4	3029.7	3603.0	3427.7	3061.7	3227.1
	1697.0	1906.4	1581.2	1855.5	1864.7	2153.5	1844.7	2141.3
	2577.0	2732.4	2734.9	2962.6	2963.2	2648.3	2572.2	2356.2
	3674.0	3294.8	4188.4	3756.1	4472.8	4026.2	3263.8	2627.0
	1811.0	2219.2	2055.4	2333.8	2368.7	2624.9	2068.2	2522.7
	1849.0	3062.8	2097.6	3491.6	2242.4	3728.3	2011.0	3124.4
	1737.0	2550.0	1980.2	2905.2	2275.6	3279.2	2125.3	3159.0
	2088.0	2582.0	2380.3	2853.2	2743.8	3128.7	2605.5	3092.0
	2528.0	2544.0	2881.9	2893.3	3762.6	3786.2	2529.7	2643.0
	1234.0	1766.8	1320.1	1951.2	1526.8	2246.1	1540.1	2191.8
Average	2260.4	2676.5	2479.8	2886.5	2812.0	3221.3	2528.9	2703.7
StDev	730.1	730.5	776.2	847.5	858.5	845.8	564.0	789.0
Max	3674.0	4205.6	4188.4	4710.0	4472.8	5102.9	3686.8	4469.9
Min	965.0	1766.8	1094.4	1591.0	1263.5	2084.9	1540.1	1269.4

**Table 12: Projected changes in seasonal snow (in mm) for 2090 for a warming of 2.0°C (rcp 6.0) and as a warming of 3.0°C (rcp 6.0) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for no change in precipitation.**

<b>Seasonal Snow Depths (mm)</b>				
	Warming+2 deg C		Warming +3 deg C	
	Cardrona	Treble Cone	Cardrona	Treble Cone
	2398.0	2438.4	2328.0	2061.6
	1394.0	1082.0	900.0	598.8
	2342.0	2824.0	1810.0	1847.2
	1933.0	3014.4	1628.0	2641.6
	2749.0	3318.8	2728.0	3216.4
	916.0	1653.2	739.0	984.0
	2095.0	1880.4	2003.0	1718.0
	1479.0	1239.2	978.0	974.0
	2250.0	1793.6	1984.0	1628.8
	1418.0	1979.6	1384.0	1732.0
	1897.0	1620.4	1709.0	1606.0
	1152.0	1435.2	1137.0	1398.8
	1424.0	1531.2	1224.0	1233.6
	2422.0	1906.4	1573.0	1379.2
	1441.0	1486.4	1437.0	1448.8
	1526.0	2478.8	1473.0	2048.0
	1478.0	2160.8	1417.0	1970.8
	1879.0	2344.0	1487.0	1788.4
	1872.0	1976.0	1742.0	1383.2
	847.0	1316.8	814.0	1157.2
Average	1745.6	1974.0	1524.8	1640.8
St Dev	508.9	592.5	490.1	574.8
High	2749.0	3318.8	2728.0	3216.4
Low	847.0	1082.0	739.0	598.8

**Table 13: Projected changes in seasonal snow (in mm) for 2090 for a warming of 2.0°C (rcp 6.0) and as a warming of 3.0°C (rcp 6.0) for Cardrona and Treble Cone ski areas as derived from the SnowSim seasonal snow model for mid-range change in precipitation projections.**

<b>Seasonal Snow Depths (mm)</b>				
	Warming + 2.0 degC		Warming + 3.0 deg C	
	Mid-range + 14%		Mid-range + 17%	
	Cardrona	Treble Cone	Cardrona	Treble Cone
	2733.7	2779.8	2723.8	2412.1
	1589.2	1233.5	1053.0	700.6
	2669.9	3219.4	2117.7	2161.2
	2203.6	3436.4	1904.8	3090.7
	3133.9	3783.4	3191.8	3763.2
	1044.2	1884.6	864.6	1151.3
	2388.3	2143.7	2343.5	2010.1
	1686.1	1412.7	1144.3	1139.6
	2565.0	2044.7	2321.3	1905.7
	1616.5	2256.7	1619.3	2026.4
	2162.6	1847.3	1999.5	1879.0
	1313.3	1636.1	1330.3	1636.6
	1623.4	1745.6	1432.1	1443.3
	2761.1	2173.3	1840.4	1613.7
	1642.7	1694.5	1681.3	1695.1
	1739.6	2825.8	1723.4	2396.2
	1684.9	2463.3	1657.9	2305.8
	2142.1	2672.2	1739.8	2092.4
	2134.1	2252.6	2038.1	1618.3
	965.6	1501.2	952.4	1353.9
Average	1990.0	2250.3	1784.0	1919.8
St Dev	580.2	675.5	573.4	672.5
High	3133.9	3783.4	3191.8	3763.2
Low	965.6	1233.5	864.6	700.6



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