NZ Glacier Ice Volume calculated using Willsman (2017) method

Updated for Environment Aotearoa 2022

Prepared for Ministry for the Environment

November 2021

Climate, Freshwater & Ocean Science

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NIWA CLIENT REPORT No: 2021343WN
Report date: November 2021
NIWA Project: MFE21302

Quality Assurance Statement		
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Executive summary

The Ministry for the Environment (MfE) and Stats NZ Tatauranga Aotearoa (StatsNZ) are required to report on the state of the environment under a 3-yearly cycle, and a new synthesis report, *Environment Aotearoa 2022* (EA22), is due for publication in April 2022. MfE will include New Zealand glacier ice volume data in EA22, and have requested the National Institute of Water and Atmospheric Research (NIWA) to provide these data. Specifically, annual glacier ice volume (km^3) for the period 1978-2020 are required.

NIWA provided MfE with 1978-2020 annual glacier ice volume data calculated using a new methodology (Lorrey and Macara, 2021). However, this methodology wasn't published in international peer-reviewed literature in time to meet MfE's requirements. As a result, NIWA agreed to supply MfE with glacier ice volume data calculated using the Willsman (2017) methodology which was previously used to generate the data for MfE and StatsNZ.

MfE have requested a brief summary report that highlights the updated glacier ice volume data obtained using the Willsman (2017) methodology. As this methodology has been described in detail in previous client reports (Willsman, 2017), only a short overview will be provided here to help interpret the calculations and formulate MfE/StatsNZ's description for the indicator web page.

Data are delivered to MfE as .csv files along with this report.

Key findings presented in this report:

- From a starting ice volume of 53.29 km^3 (Chinn, 2001), New Zealand's estimated ice volume in 2020 has reduced to 34.60 km^3.
- New Zealand's glacier ice volume at 2020, is 65% of the 1978 volume.
- The cumulative ice volume loss has accelerated in recent years along with an apparent acceleration in the pace of snowline rise seen for Southern Alps index glaciers.
- The results presented in this report are similar to those of Lorrey and Macara (2021). Specifically, Lorrey and Macara (2021) estimated New Zealand's 2020 ice volume as 34.53 km^3, which is 0.07 km^3 less than estimated in this report.

1 Introduction

The National Institute of Water and Atmospheric Research (NIWA) has been commissioned by the Ministry for the Environment (MfE) to update the glacier ice volume change in New Zealand from the previous accounts ending in 2016. To do this we have re-run the ice volume change calculation from 1978 to 2020 using the modified version of the Chinn et al. (2012) model (Willsman, 2017). This information is intended for use by the Ministry for the Environment for environmental reporting and climate change analysis.

2 Methodology

The following is a short overview of the methodology to help MfE and StatsNZ interpret the calculations and formulate a description for the indicator web page.

2.1 Derivation of ice volume estimates using Willsman (2017)

The method for estimating ice volume change was developed by Trevor Chinn and others in 2007, and subsequently published in 2012 (Chinn et al., 2012). It utilises end of summer snowline (EOSS) measurements from New Zealand's index glaciers from 1977-2020. Details about the index glaciers can be found in the report by Lorrey and Macara (2021) that was supplied to MfE.

Ice volumes are representative of glacier years (1 April – 31 March), such that the 2020 ice volume value represents the situation as at 31 March 2020. The EOSS used for the 2020 calculation represents the elevation (above sea level; asl) of the snowline remaining after the 1 April 2019 – 31 March 2020 year of snow accumulation and melt.

Steps taken to calculate ice volume:

- Annual EOSS, average EOSS and mass balance gradient are used to calculate annual ice volume change for each index glacier;
- Annual volume change is divided by the respective index glacier area to derive an annual net balance. These annual net balances are averaged to derive an average annual net balance;
- Average annual net balance is applied to areas of the remaining glaciers (excluding 12 large debris-covered glaciers) to derive an annual volume change;
- Annual volume change applied to initial ice volume (53.29 km^3) taken from 1978 New Zealand Glacier Inventory (Chinn, 2001).
- Willsman (2017) differs from earlier reports (e.g. Willsman, 2011), by applying a longer and more recent mass balance gradient dataset obtained from Brewster Glacier (2000-2015; Cullen et al., 2017), i.e. accumulation rate 7.4 mm/m, ablation rate 14.5 mm/m.
- Willsman (2017) presents total Glacier Ice Volume for New Zealand, as opposed to regional breakdowns of some earlier reports (e.g. Willsman, 2011) due to the difficulty applying the model/methodology to very small ice areas/volumes in some regional areas.

- Changes to the 12 largest debris covered valley glaciers in the Southern Alps are calculated using a geodetic method based on topographic and pro-glacial lake changes determined from repeated surveys. Two processes are considered:
  - The first is "down-wasting" defined here as the net lowering of the surface profile by normal ablation and ice flow. The down-wasting rates were determined for the period 1977 to 2008 (Chinn et al., 2012) and these rates are assumed to have remained constant for this calculation to extend volumes to 2020.
  - The second incorporates the development since the 1970s of pro-glacial lakes and the combined ice volumes lost to ice calving into the lakes. The pro-glacial lake growth for the recent period 2016 to 2020 was reassessed and any changes measured from relevant satellite images.
- Note, the EOSS was not obtained during an official flight in 1990 and 1991. As such, observations of Tasman Glacier for these years are used to inform the calculations. Lorrey and Macara (2021) outline the caveats associated with this approach.

3 Results

From a starting ice volume of 53.29 km^3 (Chinn, 2001), New Zealand's estimated ice volume in 2020 has reduced to 34.60 km^3. New Zealand's glacier ice volume at 2020, is 65% of the 1978 volume. Figure 3-1 illustrates the interannual variability of New Zealand's estimated glacier ice volume for the period 1978-2020. Note, tabular data are presented in Appendix A.

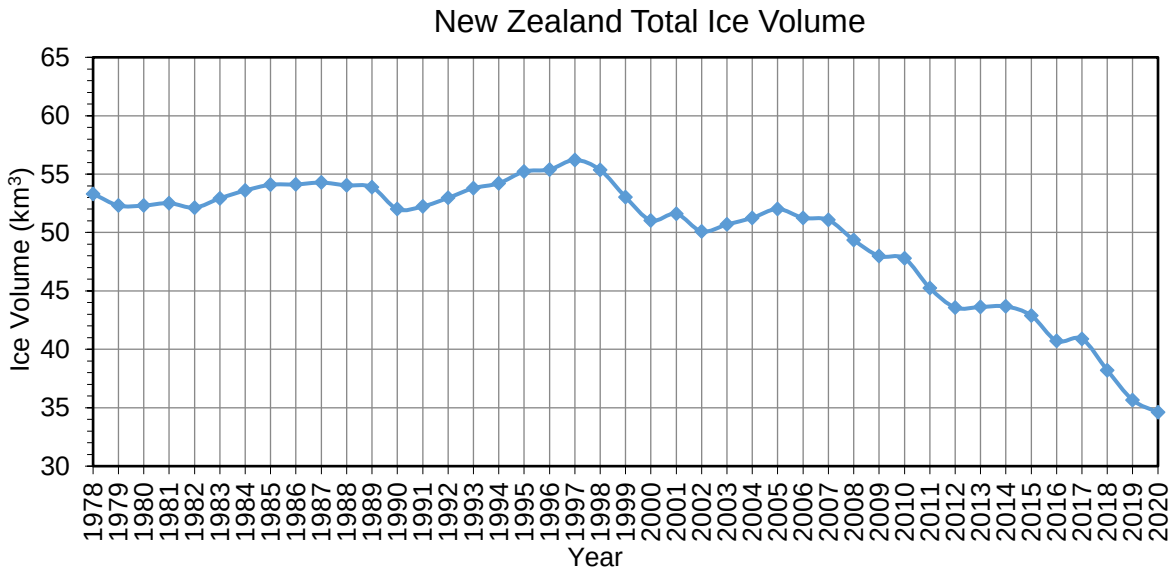

Figure 3-1: New Zealand total ice volume (km^3), 1978-2020.

As noted in Section 2, changes to the 12 debris covered valley glaciers are calculated separately. Figure 3-2 illustrates the interannual variability of estimated glacier ice volume for the 12 debris covered valley glaciers, and the remaining index glaciers.

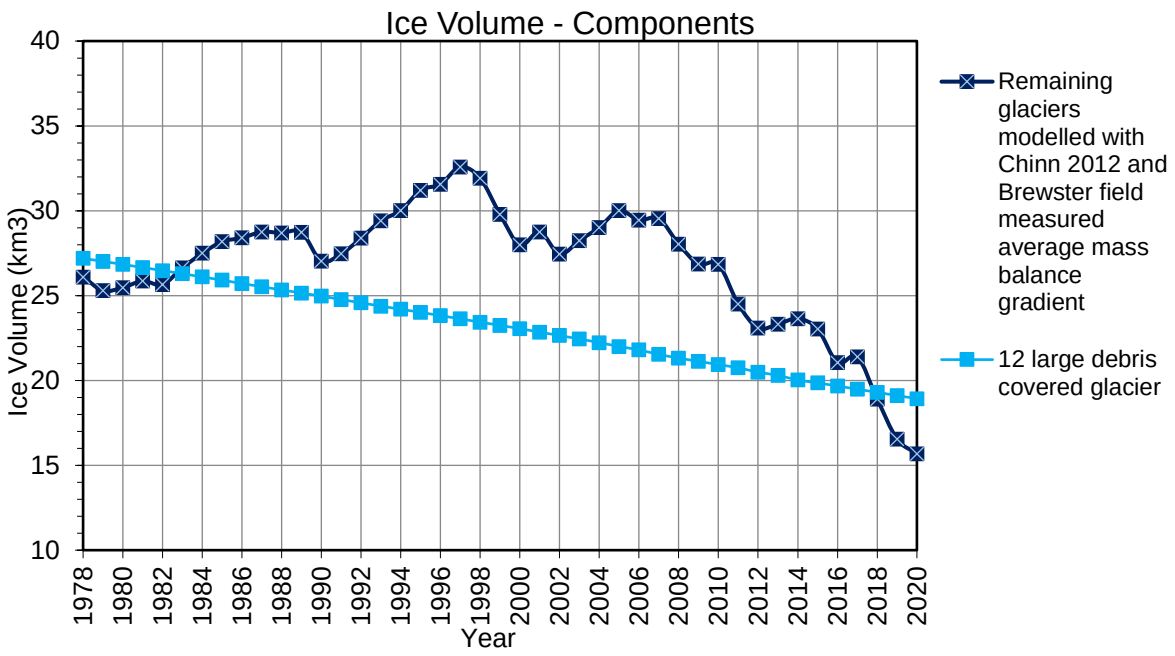

Figure 3-2: Annual changes to the components of New Zealand's total ice volume (km^3), 1978-2020. Ice volume change for the 12 large debris covered glaciers is shown in light blue, with change for the remaining index glaciers shown in dark blue.

4 Conclusion

This report presents an update to New Zealand's annual glacier ice volumes using the Willsman (2017) methodology. These volumes were last calculated through to 2016, with the present report calculating data for the period 1978-2020. New Zealand's estimated ice volume in 2020 has reduced to 34.60 km^3, which is 65% of the 1978 volume.

The 2020 estimate represents an ice loss of 6.12 km^3 since the 2016 estimate presented by Willsman (2017). This ice loss is equivalent to 11% of the 1978 volume. The highest annual ice loss in the 1978-2020 record occurred in 2018, with 2.68 km^3 of ice loss. This is followed by 2019 and 2011, with 2.54 km^3 of ice loss, respectively.

5 Glossary of abbreviations and terms

Ablation	Glacier loss through melting, sublimation or calving of snow and ice
Accumulation	Glacier gain from input and retention of snow and ice
asl	above sea level
Cryosphere	The frozen water part of the Earth system, including land and water (terrestrial and marine) areas where ice and the processes related to freezing or subzero conditions dominate the climate and physical geography
ELA	Equilibrium Line Altitude. A line of demarcation where loss of ice and gain of snow and ice is equal
EOSS	End of Summer Snowline
Geodetic method	A method of measuring glacier mass balance by subtracting the glacier surface elevation and glacier extent at two different times. This may be achieved using topographic maps, digital elevation models, and satellite imagery for example
Glacier inventory	A survey of ice that accounts for the total number of glaciers in a given region, and includes details about their shapes (length, width, thickness), aspect (the direction they face), their slope, and altitudes (highest ice, lowest ice, etc.)
Glaciological method	A method of measuring glacier mass balance based on in-situ measurements, such as stakes drilled into the glacier
Index glacier	A glacier that is regularly monitored and studied to provide details about variability and change of the cryosphere
m w.e.	metres water equivalent, i.e. in the context of this report, the meltwater equivalent of glacier ablation
Mass balance	The calculation of ice loss or ice gain for a glacier over a specified interval of time
Mass balance gradient	The change in mass balance that exists from the accumulation zone to the ablation zone on a glacier (typically this gradient increases with a decrease in elevation along a transect from the highest part of a glacier to its terminus
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research
NZGI	New Zealand Glacier Inventory
Snowline	Synonymous with ELA, but a seasonally-varying line of demarcation across the landscape (including glaciers) where the lowest altitude of snow on the ground can be observed

6 References

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Appendix A Ice volume data

Table A-1: Estimated national glacier ice volume (km^3), 1978-2020.

Year	Ice volume	Year	Ice volume
1978	53.29	**2001**	51.61
1979	52.31	**2002**	50.10
1980	52.31	**2003**	50.69
1981	52.52	**2004**	51.25
1982	52.13	**2005**	52.02
1983	52.93	**2006**	51.25
1984	53.60	**2007**	51.07
1985	54.09	**2008**	49.35
1986	54.12	**2009**	47.98
1987	54.28	**2010**	47.78
1988	54.03	**2011**	45.24
1989	53.88	**2012**	43.57
1990	52.01	**2013**	43.61
1991	52.23	**2014**	43.66
1992	52.96	**2015**	42.88
1993	53.80	**2016**	40.71
1994	54.21	**2017**	40.88
1995	55.22	**2018**	38.20
1996	55.39	**2019**	35.66
1997	56.21	**2020**	34.60
1998	55.36		
1999	53.04		
2000	51.04		