Environment and Climate Change Canada
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SNOW COVER

CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

Canada

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CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

SNOW COVER

March 2024

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Snow cover

Terrestrial snow is an important component of Canada's climate, water resources, and ecosystems. The quantity, coverage, and duration of terrestrial snow varies with temperature, precipitation and climate cycles (e.g. El Niño), which influence long term trends. Information on all 3 aspects of terrestrial snow is important for assessing long-term changes in climate in Canada.

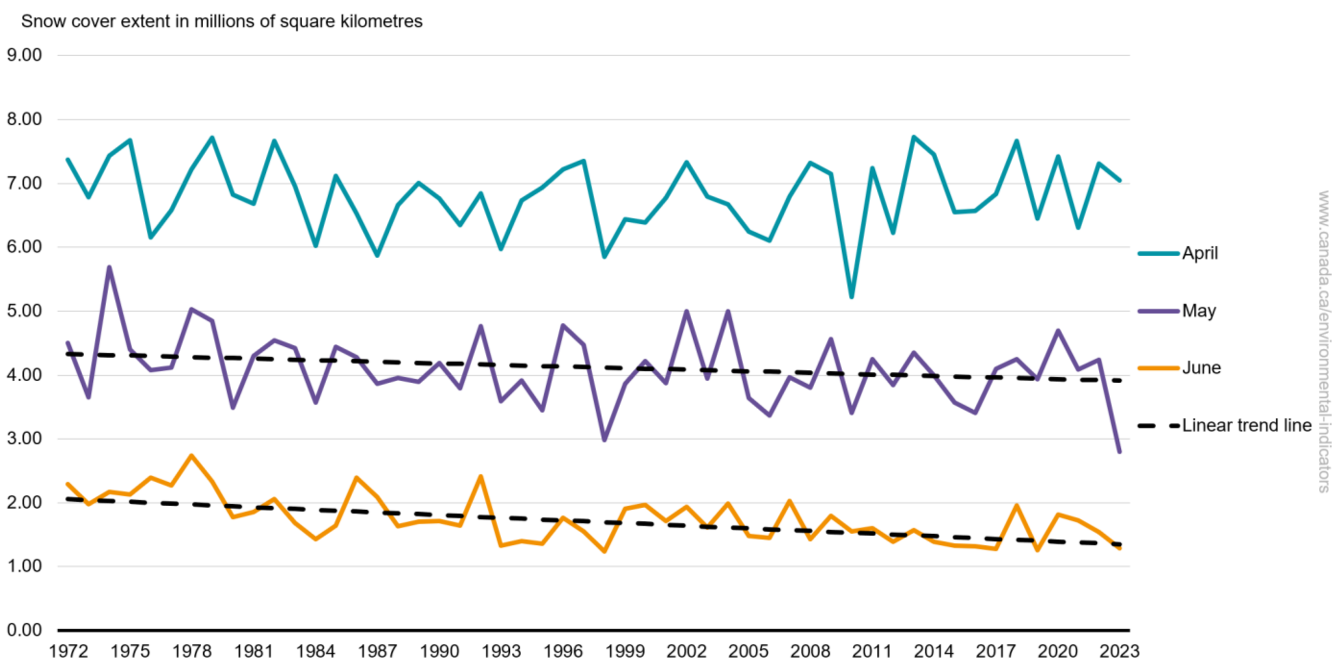
Snow cover extent

Snow cover extent is the area of land with snow on the ground. Snow cover extent is closely linked to air temperature, which means it changes significantly according to the seasonal cycle and varies from year-to-year. Spring snow cover trends are of particular interest because of the wide range of impacts (for example, hydrology, ecosystems and wildfire risk) and because decreases in snow cover result in a positive albedo feedback in the climate system that is especially strong during this season.

Key results

- Since the early 1970s, snow cover extent has decreased significantly in Canada during the months of May and June

Figure 1. Annual variations in spring (April, May and June) snow cover extent, Canada, 1972 to 2023



Data for Figure 1

Note: The dashed line indicates a statistically significant trend based on the Mann-Kendall and Sen methods at the 95% confidence level. Note that the trend over time for the month of April is not statistically significant.
Source: Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

While no statistical trend was detected for Canadian snow cover extent in April over the 1972 to 2023 period, decreasing trends of 1.9% and 6.7% per decade were detected in May and June, respectively.

The extent of snow cover in May 2023 was at the lowest level since 1972. Snow cover extent in June 2023 was at the 4th lowest level since 1972. However, snow cover extent in April 2023 was at its 19th highest since 1972.

Recent decreases in snow cover extent, especially in the spring period, are linked to warming air temperatures over the Northern Hemisphere and Canada during the same time period. The more pronounced warming in the Canadian Arctic is a contributor to the greater reductions observed in June since snow is mostly present in that region. More rapid warming of the Arctic relative to lower latitudes is explained by a phenomenon known as

"Arctic amplification"[1] and is projected to continue. Reductions in high latitude spring snow cover extent across Canada are consistent with similar observed decreases in the Eurasian Arctic.[2]

Snow cover duration

The duration of snow cover influences climate through the insulating and reflecting properties of snow. Snow cover duration is controlled by the timing of the onset of snow cover in fall/winter and subsequent melt in the spring, as well as any thaw periods in between. The indicators express the snow cover duration departures for the 2023 snow year[3] and the trends over the period from 1999 to 2023. Departures correspond to the difference between the numbers of days with snow on the ground for a given year and the average duration for a reference period (1999 to 2018).

Snow cover duration departures

Key results

Each year, snow cover duration departures are regionally variable across Canada. For the 2023 snow year:

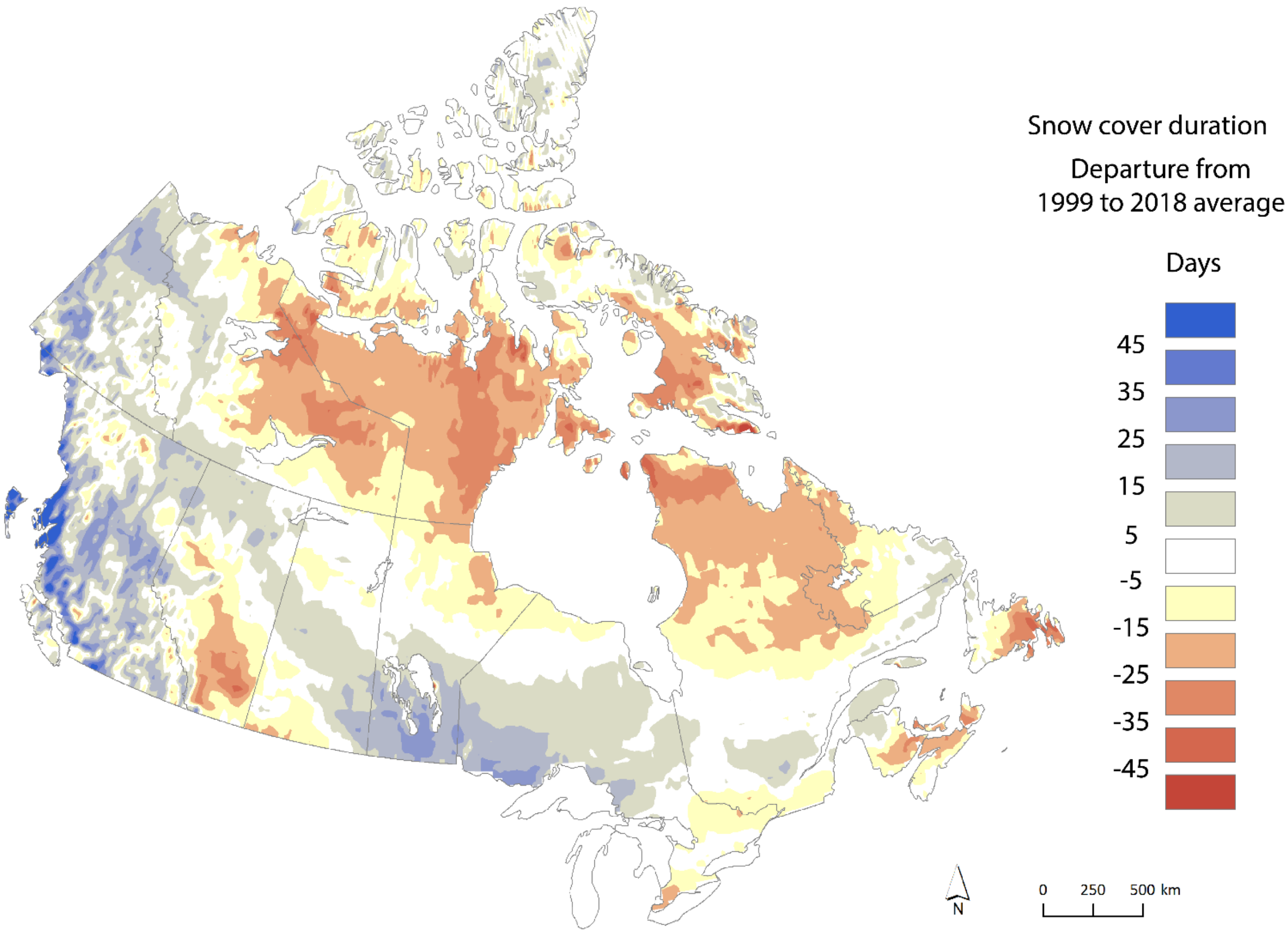
- The number of days with snow cover were above average in western Canada, southern parts of Manitoba and southeast Ontario
- Below-average snow cover durations were observed in a substantial part of the Canadian Arctic, as well as southern Alberta

Figure 2. Snow cover duration departures relative to the 1999 to 2018 reference period, Canada, 2023

[1] Bush E et al. (2019) Understanding Observed Global Climate Change - Chapter 2 in Canada's Changing Climate Report.

[2] Mudryk L et al. (2023) Terrestrial Snow Cover. Arctic Report Card: Update for 2023.

[3] The snow season is defined as the period starting from July 1 of the previous year to June 30 of that year. The snow season is assigned to the year corresponding to the end of the snow season. For example, 2023 corresponds to the July 2022 to June 2023 snow season.



Note: The 2023 snow year is the period beginning on July 1, 2022, and ending on June 30, 2023. Departures are obtained by subtracting the 1999 to 2018 average value from the number of days with snow on the ground during the snow season (July to June). Warm colours (yellow to red) indicate shorter snow cover duration; cool colours (blue) indicate longer duration.
Source: United States National Ice Center (2024) Interactive Multisensor Snow and Ice Mapping System (IMS). Departures calculated by Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

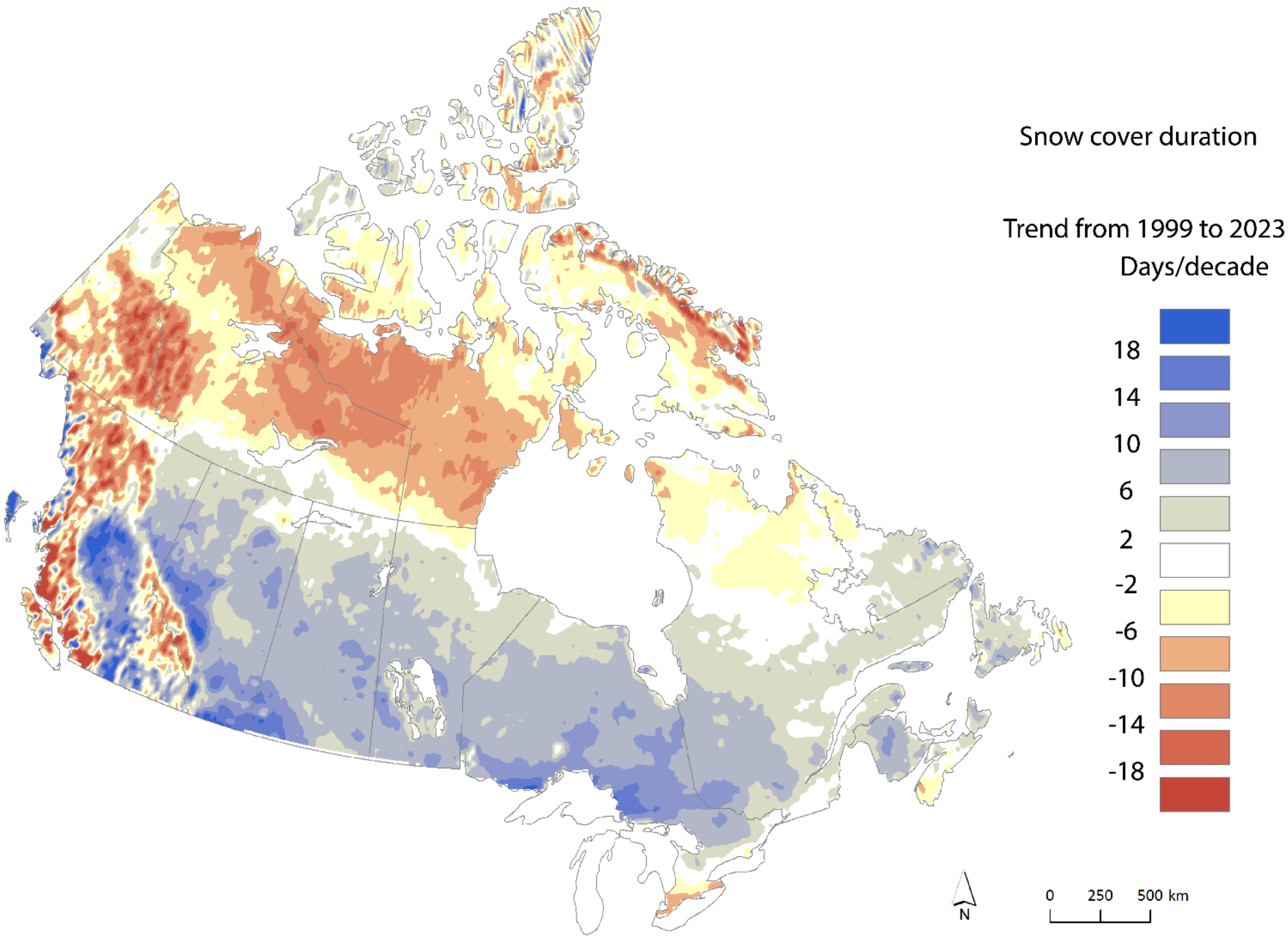
Snow cover duration trend

Key results

Over the analyzed period from the 1999 to 2023 snow years,

- the number of days with snow cover are decreasing along the Pacific coast of Canada, most of the Canadian Arctic, and along the Rocky Mountains
- The number of days with snow cover are increasing along southern Canada and central British Columbia

Figure 3. Snow cover duration trend, Canada, 1999 to 2023



Note: Snow cover duration trends indicate general increasing or decreasing of number of snow days in Canada over time from 1999 to 2023 due to a combination of climate change and natural variability. Warm colours (yellow to red) indicate shorter snow cover duration; cool colours (blue) indicate longer duration.
Source: United States National Ice Center (2024) Interactive Multisensor Snow and Ice Mapping System (IMS). Trends calculated by Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

Snow cover duration is variable from year to year, with long term trends resulting from a combination of changes related to climate warming and natural variability (year-to-year differences in regional weather patterns). Because statistical significance of the trends has not yet been evaluated, it is not possible to establish where trends represent a climate response and where they predominately reflect natural variability.

Changes in the number of days with snow cover can affect both ecosystems and human systems. For example, a shorter snow cover duration can affect seasonal cycles for plants, migratory birds and crops. Meanwhile, a longer snow cover duration can affect the length of the growing season and habitat availability in the spring. Additionally, changing snow cover duration may affect the mental wellbeing and identity of many northern communities, including Inuit, Métis, and Indigenous communities. During the 2022-2023 season in particular (Figure 2), most of western Canada experienced higher than average number of snow cover days in the 2023 snow year. However, over the past two and a half decades, the number of days with snow cover has declined by over 43 days in many regions of western Canada.[4] Much of the central Canadian Arctic (including northern Quebec and Labrador), the Maritimes, and southern Ontario experienced fewer than average snow days in 2023, which is in line with the trend since 1999.

[4] Trend values drop to below -18 days per decade (Figure 3), which represents a total difference of 45 days over the 25-year analysis period.

Snow water equivalent

Water from melted snow is an important resource across Canada. Snow water equivalent is a way to measure the amount of water contained in snowpack. Regions of Canada that remain below freezing in the winter season will tend to accumulate snow throughout the season so that snow water equivalent increases before reaching a seasonal peak value just before spring temperatures warm enough to begin melting the snow. While the seasonal timing of when this peak occurs will vary across the country, March is a reasonable estimate for much of Canada. Changes in peak snow water equivalent can in turn affect water availability, which in turn affects aspects such as drinking water and flooding. The indicators below express snow water equivalent departures in March 2023 from the average value for the reference period (1991 to 2020) and March snow water equivalent trends calculated over the period from 1981 to 2023. Like snow cover duration, the influence of both climate warming and natural variability will affect the departures for an individual year and long-term trends in snow water equivalent.

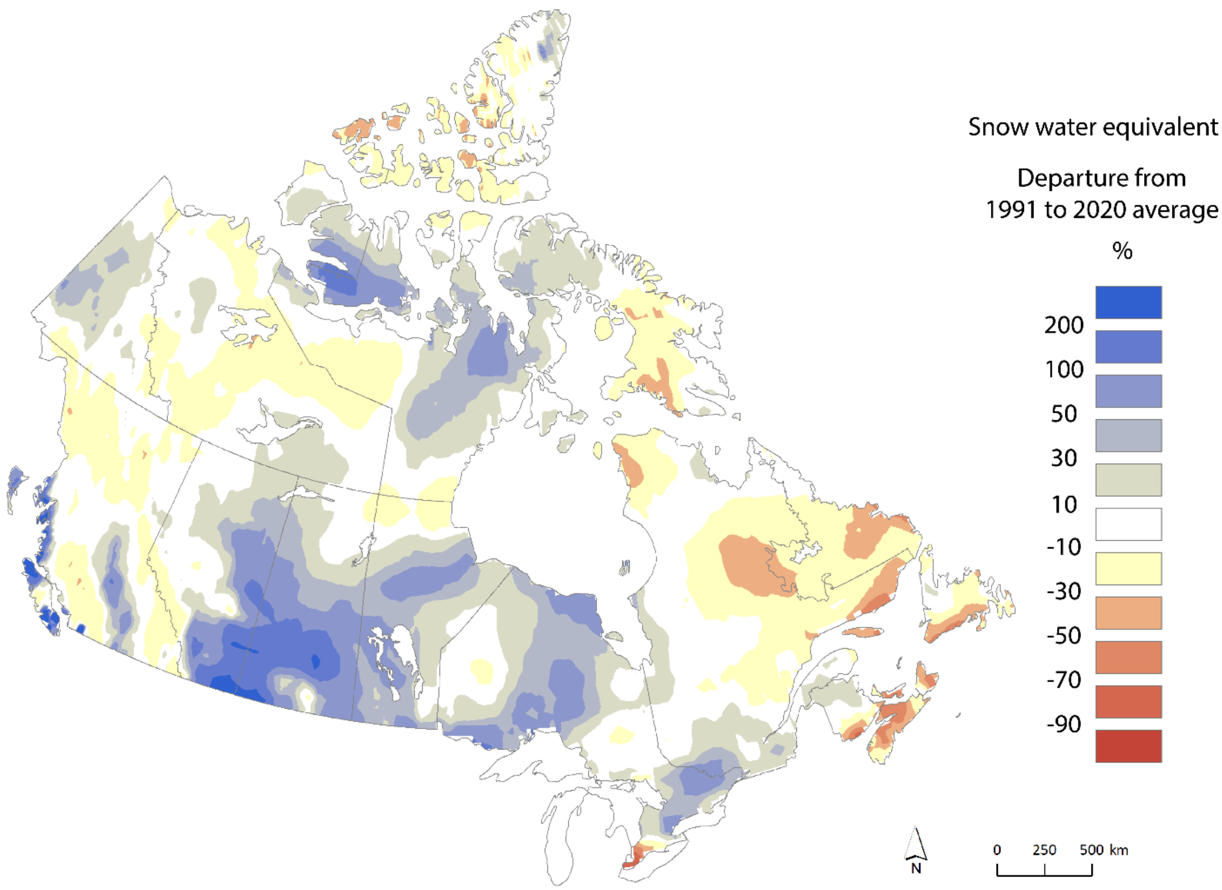
March snow water equivalent

Key results

For the 2023 snow year compared to the 1991 to 2020 reference period,

- the snow water equivalent was above average along the southern part of the Pacific coast, in central Nunavut, in the Prairies, in Ontario and in southern Quebec
- the snow water equivalent was below average in northern Nunavut, Northwest Territories, northern Quebec, and the Maritimes

Figure 4. March snow water equivalent departures relative to 1991 to 2020 reference period, Canada, 2023



Note: The indicator considers the snow water equivalent value for the month of March. Departures are obtained by subtracting the 1991 to 2020 average from the 2023 value. Warm colours (yellow to red) indicate less snow water equivalent; cool colours (blue) indicate more snow water equivalent.
Source: Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

Because the density of snow can vary from location to location and over the course of a season, it is not always easy to determine how much water will result from a layer of snow of a particular depth. Snow water equivalent accounts for both the height/depth of the snowpack as well as its density.

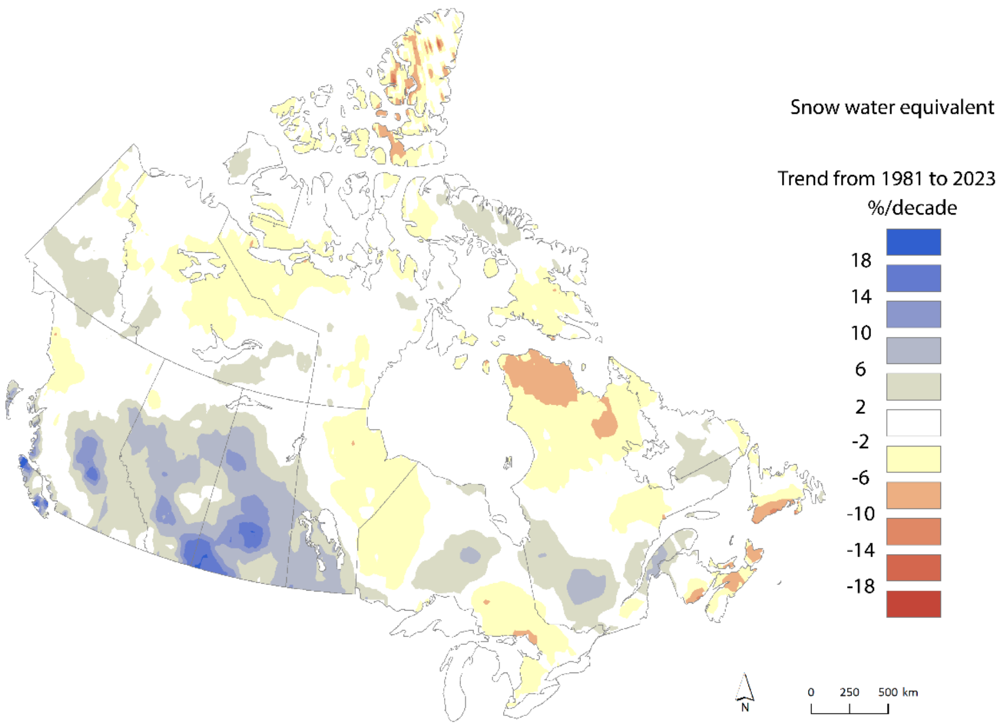
Snow water equivalent trend

Key results

From 1981 to 2023,

- snow water equivalent generally increased in central British Columbia and the Prairies
- snow water equivalent generally decreased in northern Canada, the Maritimes, and around the Great Lakes

Figure 5. Snow water equivalent trends, Canada, 1981 to 2023



Note: Snow equivalent trends indicate general increasing or decreasing snow water equivalent in Canada over time from 1981 to 2023 due to a combination of climate change and natural variability. Warm colours (yellow to red) indicate decreasing snow water equivalent; cool colours (blue) indicate increasing snow water equivalent.
Source: Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

Snow water equivalent is variable from year to year, with long term trends resulting from a combination of changes related to climate warming and natural variability (year-to-year differences in regional weather patterns). Because statistical significance of the trends has not yet been evaluated, it is not possible to establish where trends represent a climate response and where they predominately reflect natural variability.

About the indicators

What the indicators measure

The indicators illustrate independent elements of terrestrial snow over Canada and how it is changing over time. The indicators reported include spring snow cover extent, annual snow cover duration and March snow water equivalent.

Snow cover extent is expressed in millions of square kilometres and is presented for the spring months of April, May and June. The Snow cover duration indicator shows the spatial pattern of annual (July to June) snow cover duration departure relative to the 1999 to 2018 average, as well as the trend from 1999 to 2023. Snow water equivalent is expressed in the percent departure from the 1991 to 2020 average, as well as the trend from 1981 to 2023.

Why these indicators are important

Canada is a snowy country. Sixty-five (65) percent of Canada's land mass has annual snow cover for more than 6 months of the year. Changes in snow cover have important and far-reaching consequences for ecological and human systems. For example, the melting of ice and snow stored in mountain snowpacks is critical for a multitude of sectors including aquatic ecosystems, agriculture, hydro-electric power generation, and recreational activities.

Changing snow cover duration, extent, and snow water equivalent have a disproportionate effect on Northern communities, including Inuit, Métis, and Indigenous peoples. Snow and ice are critically important in the traditional ways of life for many of these communities: connection to place and land, transmission of traditional knowledge and land skills, access to food and water, and mental health aspects are all subject to change with changing weather patterns.

Because of its white colour, snow reflects a high proportion of incoming sunlight. Snow cover is therefore an important factor influencing the Earth's surface temperature because it determines how much of the energy from the sun is absorbed by the Earth's surface. A decrease in snow cover contributes to positive feedback because the highly reflective snow surface is replaced by bare soil or vegetation which absorbs more incoming sunlight. This increased absorption of sunlight warms the surface and contributes to additional snow melt in the surrounding area. This effect is called the "snow-albedo feedback."

Snow also insulates the soil beneath the snowpack and protects plants and animals from cold winter temperatures. The amount of winter snow and the frequency of winter thaw events have important consequences for Arctic animals such as muskox and caribou that must travel over snow and forage through the snow to graze. Human-related activities, such as outdoor recreation, snow clearing and reservoir management, are all highly sensitive to how much snow is on the ground and when/how fast it melts.

The Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change uses snow cover, among several variables, to assess long-term changes in climate. Snow cover is considered an Essential Climate Variable by the World Meteorological Organization–Global Climate Observing System.

Related initiatives

These indicators support the measurement of progress towards the following 2022 to 2026 Federal Sustainable Development Strategy long-term goal: Take action on climate change and its impacts.

Related indicators

The Sea ice in Canada indicators provide information on variability and trends in sea ice in Canada during the summer season.

The Temperature change in Canada indicator measures yearly and seasonal surface air temperature departures in Canada.

The Precipitation change in Canada indicator measures annual and seasonal precipitation departures.

Data sources and methods

Data sources

There are 3 indicators for Snow cover in Canada: Snow cover extent, Snow cover duration and Snow water equivalent. The data used for the indicators is current up to 2023.

The snow cover extent indicator was calculated using an ensemble of 6 different products derived from a variety of sources: optical satellite imagery, snow models driven by atmospheric reanalysis, and satellite remote sensing combined with in-situ snow depth measurements. Four of these datasets were also used to calculate the Snow water equivalent indicators. This multi-dataset approach was developed in the Climate Research Division of Environment and Climate Change Canada.

Data for computing annual snow duration were retrieved from the Interactive Multisensor Snow and Ice Mapping System (IMS) daily snow chart product, which is derived by analysts primarily from optical satellite imagery.

More information

Snow cover extent indicator (1972 to 2023) and Snow water equivalent indicator (1981 to 2023)

The time series used for the Snow cover extent indicator are based on input from the 6 datasets described in Table 1, while the Snow water equivalent indicator used only the last 4.

Table 1. Snow datasets used to produce the Snow cover extent and Snow water equivalent indicators

Dataset	Time period	Variable	Method	Indicator
National Oceanic and Atmospheric Administration (NOAA) Snow Chart Climate Data Record (CDR)	1967 to 2023	Snow cover fraction	Manual analysis of primarily optical satellite imagery	Snow cover extent
Rutgers 24km Product	1981 to 2023	Snow cover fraction	Enhanced analysis similar to NOAA CDR but available at 24km resolution	Snow cover extent
Crocus-ERA5	1950 to 2023	Snow water equivalent	Crocus physical snow model driven by ERA5 reanalysis	Snow cover extent, Snow water equivalent
MERRA-2	1979 to 2023	Snow water equivalent	Modeled snow water equivalent from MERRA2 reanalysis	Snow cover extent, Snow water equivalent
Snow CCI CRDPv2	1981 to 2020	Snow water equivalent	Satellite passive microwave data and surface snow depth observations	Snow cover extent, Snow water equivalent
ERA5-Land	1981 to 2023	Snow water equivalent	Modeled snow water equivalent from ERA5 reanalysis	Snow cover extent, Snow water equivalent

The multi-dataset analysis provides monthly mean snow extent values from September 1967 to August 2023. The period from 1972 was used for the indicator because the dataset has some missing data between 1966 and 1971. For datasets providing snow water equivalent, a threshold of 5 mm was used to indicate the presence of snow on the ground.

Snow cover duration indicator (1999 to 2023)

The Snow cover duration indicator is based on 24-km daily binary (presence/absence) snow cover maps generated by the United States National Ice Center's Interactive Multisensor Snow and Ice Mapping System (IMS). These maps are derived from the interpretation of mainly visible satellite data but also make use of other satellite products and surface observations.

Methods

The Snow cover extent indicator shows the area of Canada covered by snow during the months of April, May and June for the years 1972 to 2023. The total area of Canada's land mass covered by snow is estimated from a multi-dataset approach developed in the Climate Research Division of Environment and Climate Change Canada.

The Snow cover duration indicator shows the difference (or departure) between the numbers of days with snow on the ground for the latest year available relative to the 1999 to 2018 reference period. It also shows the snow cover duration trend in Canada from 1999 to 2023.

The Snow water equivalent indicator shows the percent difference (or departure) between the amount of snow water equivalent on the ground for the latest year available relative to the 1999 to 2020 reference period. It also shows the snow water equivalent trend in Canada from 1981 to 2023.

More information

Snow cover extent

The Snow cover extent indicator is based on the monthly mean snow extent values derived from 6 datasets: NOAA Snow Chart Climate Data Record, Rutgers 24km Product, Crocus-ERA5, MERRA-2, Snow CCI CRDP and ERA5-Land.

In order to merge all snow extent datasets, the climatology and standard deviation of each dataset are adjusted based on the methodology used in Mudryk et al (2020). As part of this process, each dataset's climatology is replaced by the climatology of the Rutgers 24km data, and each dataset's variability is adjusted to that of the ensemble mean standard deviation. The NOAA product is not used to construct the ensemble mean standard deviation. Specifically:

1. The standardized anomalies are calculated using each dataset's own climatology and standard deviation (sampled over 1991 to 2020).
2. These standardized anomalies are then converted back into raw values using the ensemble mean standard deviation and the climatology of the Rutgers 24km data.
3. The adjusted Rutgers 24km time series and the 4 adjusted time series derived from snow water equivalent are averaged over the 1981 to 2023 period.
4. This average time series is merged with the adjusted NOAA time series over the 1967 to 1980 period in order to extend the record back to 1967.

As the NOAA data record is the only one covering the period from 1967 to 1980, this methodology ensures that the transition between the pre- and post-1981 periods (where the number of available data sets changes from 1 to 5) does not contain any discontinuities due to changes in climatology (for example, were the full time series simply averaged together) or variability (for example, were unadjusted anomalies averaged together). The adjustment of the variability of the individual time series is particularly important during June, July and August when NOAA's variability is higher compared to the other data sets. The NOAA climatology was used as no additional verification data are available and, as such, it is assumed to have the best estimate of the historical snow extent.

Canada's land mass is defined by a shape file provided by Statistics Canada. Snow-covered area was computed in the Climate Research Division at Environment and Climate Change Canada using grid cell areas from subroutine MSCALE in the RMNLIB software library package of Environment and Climate Change Canada.

Snow extent - Trend calculation

Non-parametric statistical tests were carried out on temporal snow cover extent data to detect the presence of a linear trend and, if present, to determine the orientation (positive or negative) and magnitude of the rate of change (slope). The standard Mann-Kendall trend test was used to detect trend presence and orientation, while the Sen's pairwise slope method was used to estimate the slope. A trend was reported when the Mann-Kendall test indicated the presence of a trend at the 95% confidence level.

Snow cover duration

Higher resolution information showing annual variations in snow cover duration across Canada for the 2001 to 2023 period was obtained from the 24-km Interactive Multisensor Snow and Ice Mapping System (IMS) daily snow cover product.

Daily maps of snow cover from the United States National Ice Center's IMS were converted by the Climate Research Division at Environment and Climate Change Canada into monthly snow cover duration.

The number of days with snow cover per year (from July 1 to June 30 of the following year) was obtained by adding up the monthly number of days with snow on the ground for each land grid cell in Canada (identified with the land/sea mask supplied with the 24-km IMS dataset). Annual snow cover duration departures were then computed by subtracting the 1999 to 2018 reference period average to generate a rasterized departure map. This reference period is used to be consistent with snow cover duration departures derived in the Climate Research Division as part of previous assessments.

Snow water equivalent

Snow water equivalent products were merged using the same method used for snow cover extent, but applied on a pixel by pixel basis. Monthly snow water equivalent was calculated for each of the 4 snow water equivalent datasets, and the monthly fields were regridded to a common output grid. Then for each pixel on the common grid, each dataset's climatology was replaced by the four-product mean and each dataset's variability was adjusted to that of the ensemble mean standard deviation. Trends and departures calculated from the resulting merged product tend to be more accurate than those from individual datasets.[5] The snow water equivalent indicator is calculated based on results from the month of March, as for much of Canada this is a reasonable estimate of peak snow water equivalent. All trends and departures (differences) were then presented as percent differences relative to the 1991 to 2020 baseline period.

Recent changes

Snow water equivalent anomalies and trends were added to the indicators. Trends were also added to the Snow cover duration indicator.

Caveats and limitations

The identification of terrestrial snow cover from visible satellite data is heavily influenced by anything that obscures the surface, such as darkness, cloud cover or dense forest. Increased frequency of visible satellite coverage over time, as well as all-weather snow cover information from passive microwave satellites, means that our ability to detect and map snow is now much better than in the early part of the data record. Therefore, some care is required when interpreting snow cover trends that extend back to the 1970s. Fall period snow cover data (October and November) are not included in the Snow cover extent indicator, because these months are known to be affected by spurious increasing trends. The spring period is less affected by this problem.[6]

The more recent IMS-24 snow cover extent data (2000 to 2023) do not have any documented homogeneity issues, so the snow cover duration departures are not affected by any fall season uncertainties.

Resources

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Annex A. Data tables for the figures presented in this document

Table A.1. Data for Figure 1. Annual variations in spring (April, May and June) snow cover extent, Canada, 1972 to 2023

Year	April snow cover extent (millions of km^2)	May snow cover extent (millions of km^2)	June snow cover extent (millions of km^2)
1972	7.37	4.51	2.29
1973	6.78	3.65	1.98
1974	7.43	5.68	2.17
1975	7.68	4.40	2.13
1976	6.15	4.08	2.40
1977	6.58	4.12	2.27
1978	7.22	5.03	2.73
1979	7.72	4.85	2.33
1980	6.82	3.49	1.77
1981	6.68	4.30	1.85
1982	7.66	4.54	2.06
1983	6.96	4.42	1.68
1984	6.02	3.57	1.43
1985	7.12	4.44	1.65
1986	6.53	4.28	2.40
1987	5.87	3.87	2.09
1988	6.66	3.96	1.63
1989	7.01	3.89	1.70
1990	6.76	4.19	1.72
1991	6.35	3.79	1.64
1992	6.84	4.76	2.41
1993	5.98	3.59	1.33
1994	6.73	3.91	1.40
1995	6.93	3.45	1.36
1996	7.22	4.78	1.76
1997	7.35	4.47	1.55
1998	5.85	2.99	1.24
1999	6.44	3.87	1.91
2000	6.39	4.21	1.96
2001	6.77	3.87	1.72
2002	7.33	5.00	1.94
2003	6.79	3.94	1.61
2004	6.67	5.00	1.99
2005	6.24	3.64	1.48
2006	6.11	3.36	1.45
2007	6.80	3.97	2.03
2008	7.32	3.81	1.43
2009	7.15	4.56	1.80
2010	5.23	3.41	1.55
2011	7.24	4.25	1.60
2012	6.22	3.85	1.39
2013	7.73	4.35	1.58

Year	April snow cover extent (millions of km²)	May snow cover extent (millions of km²)	June snow cover extent (millions of km²)
2014	7.45	3.99	1.39
2015	6.55	3.56	1.33
2016	6.57	3.40	1.32
2017	6.84	4.10	1.28
2018	7.67	4.25	1.95
2019	6.44	3.93	1.26
2020	7.42	4.69	1.81
2021	6.30	4.08	1.72
2022	7.31	4.24	1.55
2023	7.05	2.80	1.29

Source: Environment and Climate Change Canada (2024) Climate Research Division, Climate Processes Section.

Additional information can be obtained at:

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