Environment and Climate Change Canada
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SNOW COVER

CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

Canada

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SNOW COVER

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Table of contents

List of Figures

List of Tables

Snow cover

Snow cover is an important factor in Canada's climate, water flows and ecosystems. Snow cover varies with temperature, precipitation and climate cycles (e.g. El Niño), which influence long term trends. Information on snow cover extent and snow cover duration is important for assessing long-term changes in climate in Canada.

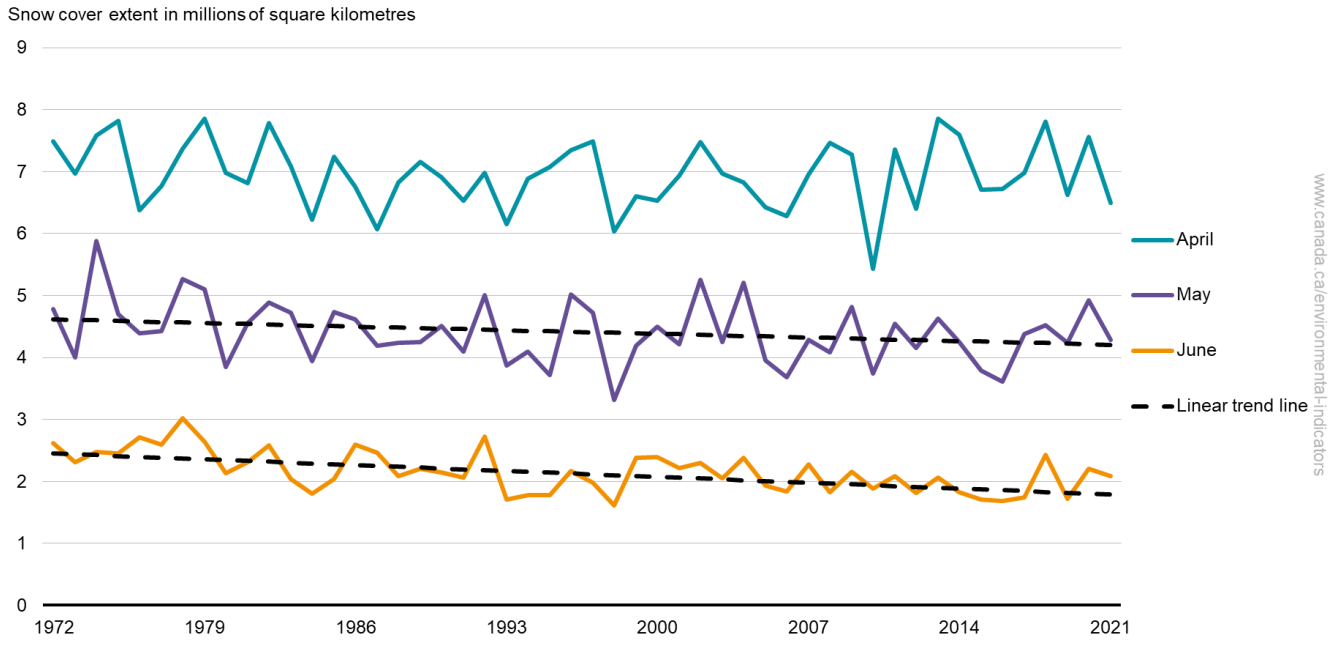
Snow cover extent

Snow cover extent is the area of land with snow on the ground.[1] Snow cover extent is closely linked to air temperature, which means it changes significantly according to the seasonal cycle and also 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 positive feedbacks in the climate system are strongest 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 2021



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 (2022) Climate Research Division, Climate Processes Section.

While no statistical trend was detected for Canadian snow cover extent in April over the 1972 to 2021 period, decreasing trends of 1.7% and 5.2% per decade were detected in May and June, respectively. In 2021, snow cover in April was at its 10th lowest since 1972 (i.e., 10th lowest out of 49 years of available data). In comparison, snow cover extent in May and June was at its 24th and 22nd lowest since 1972.

[1] Snow cover extent is defined as the area of grid cells having 50% or more snow cover for the gridded data sets used for the indicator.

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 reductions are greater in June because at that time of year, most of the snow is located in the Canadian Arctic, where warming has been the most pronounced over recent decades. More rapid warming of the Arctic relative to lower latitudes is explained by a phenomenon known as "Arctic amplification"[2] 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.[3]

Snow cover duration

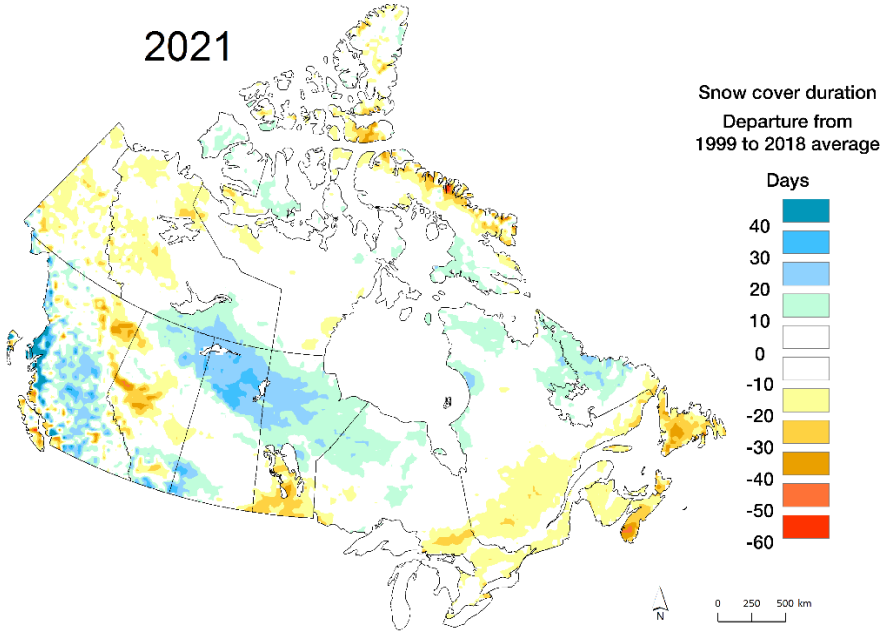
The duration of snow cover influences climate through the insulating and reflecting properties of snow. Snow cover duration is controlled by the timing of the onset of snow cover in fall/winter and subsequent melt in the spring, as well as any thaw periods in between. The indicator expresses the snow cover duration in terms of departures corresponding 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 (being the period from 1999 to 2018).

Key results

Each year, snow cover duration departures are regionally variable across Canada. For the 2021 snow year[4]:

- The number of days with snow were above average in northern parts of Manitoba and Saskatchewan, and along the Pacific coast
- Below-average snow cover durations were observed in a substantial part of the Maritimes, southern Manitoba, central Alberta and Nunavut's north-eastern coastline experienced

Figure 2. Snow cover duration departures relative to the 1999 to 2018 reference period, Canada, 2021



Note: The 2021 snow year is the period beginning on July 1, 2020, and ending on June 30, 2021. 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 orange) indicate shorter snow cover duration; cool colours (blue) indicate longer duration.
Source: United States National Ice Center (2022) Interactive Multisensor Snow and Ice Mapping System (IMS). Departures calculated by Environment and Climate Change Canada (2022) Climate Research Division, Climate Processes Section.

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

[3] Mudryk L et al. (2021) Terrestrial Snow Cover. Arctic Report Card: Update for 2021.

[4] 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, 2021 corresponds to the July 2020 to June 2021 snow season.

About the indicators

What the indicators measure

The indicators show how Canada's snow cover is changing from year-to-year and over time. The indicators report spring snow cover extent and annual snow cover duration.

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.

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.

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 therefore contributes to a positive feedback, because the highly reflective snow surface is replaced by more absorptive bare soil or vegetation. This 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 have to 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.

Effective action on climate change

These indicators support the measurement of progress towards the following 2019 to 2022 Federal Sustainable Development Strategy long-term goal: A low-carbon economy contributes to limiting global average temperature rise to well below 2 degrees Celsius and supports efforts to limit the increase to 1.5 degrees Celsius.

These indicators are currently included as part of the draft 2022 to 2026 Federal Sustainable Development Strategy.

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, while the Precipitation change in Canada indicator measures annual and seasonal precipitation departures.

Data sources and methods

Data sources

There are 2 indicators for Snow cover in Canada: Snow cover extent and Snow cover duration.

Data for the Snow cover extent indicator were obtained from an ensemble of 6 different products derived from snow models driven by atmospheric reanalysis, and satellite remote sensing. 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 2021)

The time series used for the Snow cover extent indicator are based on input from the 6 datasets described in Table 1.

Table 1. Snow datasets used to produce the Snow cover extent indicator

Dataset	Time period	Variable	Method
National Oceanic and Atmospheric Administration (NOAA) Snow Chart Climate Data Record (CDR)	1967 to 2021	Snow cover fraction	Manual analysis of primarily optical satellite imagery
Rutgers 24km Product	1981 to 2021	Snow cover fraction	Enhanced analysis similar to NOAA CDR but available at 24km resolution
Crocus-ERA5	1950 to 2021	Snow water equivalent	Crocus physical snow model driven by ERA5 reanalysis
MERRA-2	1979 to 2021	Snow water equivalent	Modeled snow water equivalent from MERRA2 reanalysis
Snow CCI CRDPv2	1981 to 2020	Snow water equivalent	Satellite passive microwave data and surface snow depth observations
ERA5-Land	1981 to 2021	Snow water equivalent	Modeled snow water equivalent from ERA5 reanalysis

The multi-dataset analysis provides monthly mean snow extent values from September 1967 to August 2021. 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 4 mm was used to indicate the presence of snow on the ground.

Snow cover duration indicator (2001 to 2021)

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.

The snow cover duration departures are calculated for each year from 2001 to 2021. In the context of this indicator, a year is defined as the period from July 1 of the previous year to June 30 of that year. For example, the year 2021 is the period beginning on July 1, 2020, and ending on June 30, 2021.

The data used for the Snow cover extent and Snow cover duration indicators is current up to 2021.

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 2021. 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 departures) between the numbers of days with snow on the ground for a given year relative to the 1999 to 2018 reference period.

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).

1. 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.
2. The standardized anomalies are calculated using each dataset's own climatology and standard deviation (sampled over 1981 to 2014).
3. These standardized anomalies are then converted back into raw values using the ensemble mean standard deviation and the climatology of the Rutgers 24km data.
4. The adjusted Rutgers 24km time series and the 4 adjusted time series derived from snow water equivalent are averaged over the 1981 to 2021 period.
5. This average time serie 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.

Over the 1981 to 2021 period, 95% uncertainty bounds were determined from the standard error (se):

$$\mathrm{se} = \mathrm{s}/\sqrt{\mathrm{n}-1}$$

which depends on the standard deviation, *s*, of the *n* datasets included.

Over the 1967 to 1980 period, 95% uncertainty bounds were determined from the standard error of forecast (se_f):

$$\mathrm{se_f(x)} = \mathrm{se_{res}(x)}\sqrt{1+\frac{1}{\mathrm{n}}(1+\mathrm{x_i}^2)}$$

where $se_{res}(x)$ is the standard error of the residuals from a best-fit line, *x* is the standardized anomaly of the independent variable in year *i* of the analysis period, and *n* is the number of years of the analysis period.

Only the spring months are shown because the multi-dataset approach for the snow cover onset period (October, November) is still under development due to an artificial increasing trend in one of the datasets.[5] Winter months, when Canada is almost completely snow-covered, are not shown.

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.

[5] Mudryk LR et al. (2017) Snow cover response to temperature in observational and climate model ensembles.

Snow cover duration

Higher resolution information showing annual variations in snow cover duration across Canada for the 2001 to 2021 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.

Recent changes

Previously, the Snow cover extent indicator was obtained from an ensemble of 5 different datasets. For this release, the multi-dataset approach was kept but it was based on 6 different products, summarized in Table 1.

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.

The more recent IMS-24 snow cover extent data (2000 to 2021) 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

Annex A. Data table for the figure 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 2021

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	7.48	4.78	2.61
1973	6.97	4.00	2.31
1974	7.58	5.88	2.48
1975	7.82	4.69	2.45
1976	6.37	4.39	2.71
1977	6.77	4.42	2.59
1978	7.37	5.26	3.02
1979	7.85	5.10	2.64
1980	6.98	3.85	2.14
1981	6.81	4.56	2.31
1982	7.78	4.89	2.58
1983	7.09	4.72	2.04
1984	6.23	3.94	1.80
1985	7.24	4.73	2.04
1986	6.75	4.62	2.60
1987	6.07	4.19	2.46
1988	6.82	4.24	2.09
1989	7.16	4.25	2.20
1990	6.91	4.50	2.15
1991	6.54	4.10	2.06
1992	6.98	5.00	2.72
1993	6.15	3.87	1.70
1994	6.89	4.10	1.78
1995	7.07	3.72	1.78
1996	7.35	5.01	2.17
1997	7.49	4.72	1.98
1998	6.03	3.31	1.62
1999	6.60	4.19	2.38
2000	6.53	4.50	2.39
2001	6.93	4.21	2.21
2002	7.48	5.25	2.30
2003	6.96	4.24	2.05
2004	6.82	5.21	2.38
2005	6.42	3.95	1.93
2006	6.29	3.69	1.84
2007	6.95	4.29	2.27
2008	7.46	4.09	1.83
2009	7.27	4.82	2.16
2010	5.43	3.74	1.88

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)
2011	7.35	4.54	2.09
2012	6.40	4.16	1.81
2013	7.85	4.63	2.06
2014	7.59	4.25	1.82
2015	6.71	3.78	1.71
2016	6.72	3.61	1.69
2017	6.98	4.38	1.74
2018	7.80	4.52	2.43
2019	6.63	4.24	1.72
2020	7.56	4.92	2.20
2021	6.50	4.28	2.08

Source: Environment and Climate Change Canada (2022) Climate Research Division, Climate Processes Section.

Additional information can be obtained at:

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