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SNOW COVER

CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

Canada

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SNOW COVER

July 2020

Table of contents

List of Figures

List of Tables

Snow cover

Canada is a snowy country, which affects our climate, water flows and ecosystems. Snow cover naturally varies with temperature, precipitation and climate cycles, such as El Niño. Over the long term, trends are primarily controlled by changes in temperature and precipitation. Information on snow quantities like snow cover extent and snow cover duration is important for understanding how climate change is influencing snow cover in Canada.

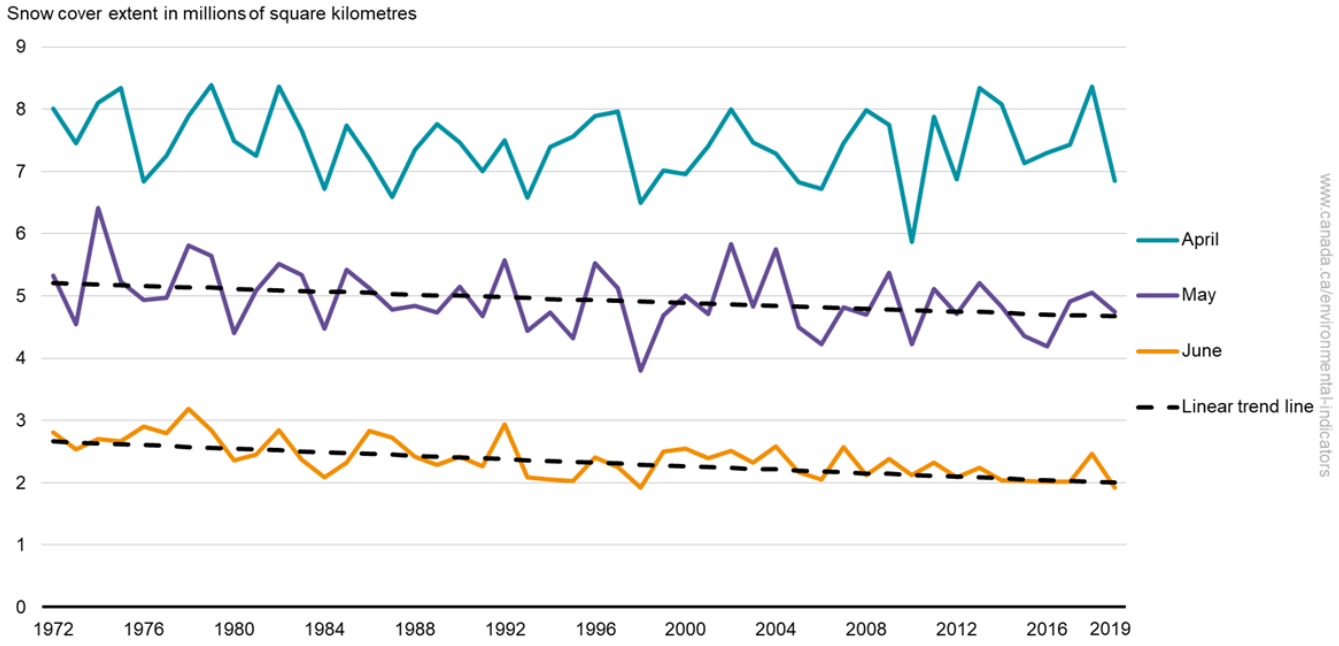
Snow cover extent

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 has a strong seasonal cycle, and varies from year-to-year.

Key results

- Since the early 1970s, snow cover extent has decreased significantly in Canada during the months of May and June
- In 2019, snow cover extent for April, May and June was, respectively, at its 9th lowest, 19th lowest and 2nd lowest since 1972

Figure 1. Annual variations in spring (April, May and June) snow cover extent, Canada, 1972 to 2019



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.
Source: Environment and Climate Change Canada (2020) Climate Research Division, Climate Processes section.

While no statistical trend was detected for Canadian snow cover extent in April over the 1972 to 2019 period, decreasing trends of 2.2% and 5.2% per decade were detected in May and June, respectively. Recent decreasing snow cover extent, especially in the spring period, is 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 strongest over recent decades. More rapid warming of the Arctic relative to lower latitudes is explained by a phenomenon known as

[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.

"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 Alaska and northern Eurasia.[3]

Spring snow cover trends are of significant 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.

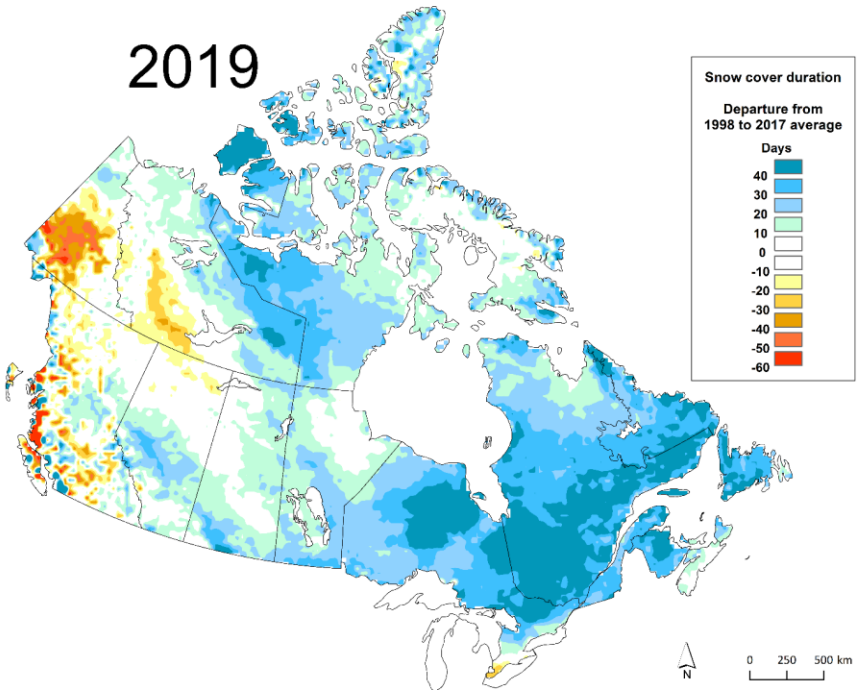
Snow cover duration

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 melt in the spring, as well as thaw periods in between.

Key results

- The number of days with snow for the year 2019[4] were above average for most of Eastern Canada, the Prairies and Nunavut
- A substantial part of Yukon and smaller areas of the Northwest Territories and along the Pacific coast experienced below-average snow cover duration

Figure 2. Snow cover duration departures relative to the 1998 to 2017 reference period, Canada, 2019



Note: Departures are obtained by subtracting the 1998 to 2017 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. Departures in snow cover duration, compared to the 1998 to 2017 reference average, are from the National Ice Centre Interactive Multisensor Snow and Ice Mapping System (IMS) 24-kilometre daily snow cover product.
Source: Environment and Climate Change Canada (2019) Climate Research Division, Climate Processes Section and National Ice Centre (2019) Interactive Multisensor Snow and Ice Mapping System (IMS).

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

[3] Mudryk L et al. (2019) Terrestrial Snow Cover. Arctic Report Card: Update for 2019.

[4] In the context of this indicator, a 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, 2019 corresponds to the July 2018 to June 2019 snow season.

The duration of snow cover fluctuates substantially across Canada, reflecting year-to-year variations in temperature and snowfall. 2010 was notable for extensive below-average snow cover across the country in response to record warm temperatures. The year 2010 is Canada's warmest year in the historical temperature record.

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 1998 to 2017 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 river aquatic systems, 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.

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 5 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 2019)

The time series used for the Snow cover extent indicator are based on input from the 5 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	1967 to 2019	Snow cover extent	Manual analysis of primarily optical satellite imagery
Crocus	1981 to 2018	Snow water equivalent	Crocus physical snow model driven by ERA-interim reanalysis
MERRA-2	1981 to 2019	Snow water equivalent	Reanalysis (Catchment land surface model)
GlobSnow-3	1981 to 2019	Snow water equivalent	Satellite passive microwave data and surface snow depth observations
Brown	1981 to 2019	Snow water equivalent	Simple snow model driven by ERA-interim reanalysis

The multi-dataset analysis provides monthly mean snow extent values from September 1967 to August 2019. 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 (1999 to 2019)

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 data used for the Snow cover extent and Snow cover duration indicators is current up to 2019.

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 2019. 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 1998 to 2017 reference period.

More information

Snow cover extent

The Snow cover extent indicator is based on the monthly mean snow extent values derived from 5 datasets: NOAA Snow Chart Climate Data Record, Crocus, MERRA-2, GlobSnow-3 and Brown.

In order to merge all 5 snow extent datasets, the climatology and standard deviation of each data set are adjusted as follow based in part on the methodology used in Brown et al. (2010) and Brown and Robinson (2011).

1. Each data set's climatology is replaced by the climatology of the NOAA data record, and each data set's variability is adjusted to that of the ensemble mean standard deviation.
2. The standardized anomalies are calculated using each data set'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 NOAA data record.
4. These 5 adjusted time series are averaged over the 1981 to 2019 period.
5. This average time series is merged with the adjusted NOAA time series over the 1967 to 1980 period.

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 2019 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):

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

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.

Snow cover duration

Higher resolution information showing annual variations in snow cover duration across Canada for the 1999 to 2019 period was obtained from the 24-km Interactive Multisensor Snow and Ice Mapping System (IMS) daily snow cover product. The snow cover duration departures are calculated for each year from 1999 to 2019. 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 1999 is the period beginning on July 1, 1998, and ending on June 30, 1999.

Daily maps of snow cover from the 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 1998 to 2017 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 based on a single dataset, the National Ocean and Atmospheric Administration (NOAA) Northern Hemisphere Snow Cover Extent Climate Data Record (NOAA-CDR). For this release, the snow cover extent is based on a new approach that provides monthly mean extent values derived from an ensemble of 5 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.[6] The spring period is less affected by this problem.

The more recent IMS-24 snow cover extent data (1999 to 2019) do not have any documented homogeneity issues, so the snow cover duration departures are not affected by any fall season uncertainties.

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

[6] Brown RD and Derksen C (2013) Is Eurasian October snow cover extent increasing?

Resources

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Annex

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 2019

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	8.00	5.33	2.80
1973	7.45	4.55	2.53
1974	8.10	6.41	2.70
1975	8.34	5.23	2.66
1976	6.83	4.94	2.90
1977	7.26	4.97	2.79
1978	7.89	5.81	3.19
1979	8.38	5.64	2.84
1980	7.49	4.40	2.35
1981	7.26	5.09	2.46
1982	8.36	5.51	2.84
1983	7.66	5.34	2.37
1984	6.71	4.47	2.09
1985	7.73	5.41	2.33
1986	7.20	5.12	2.83
1987	6.59	4.78	2.72
1988	7.34	4.84	2.42
1989	7.75	4.73	2.29
1990	7.47	5.14	2.41
1991	7.00	4.67	2.26
1992	7.49	5.58	2.94
1993	6.58	4.43	2.09
1994	7.39	4.73	2.04
1995	7.56	4.32	2.03
1996	7.88	5.52	2.41
1997	7.96	5.13	2.25
1998	6.50	3.80	1.92
1999	7.01	4.69	2.50
2000	6.96	5.00	2.55
2001	7.41	4.72	2.40
2002	8.00	5.84	2.51
2003	7.47	4.83	2.32
2004	7.29	5.75	2.58
2005	6.82	4.50	2.17
2006	6.72	4.22	2.05
2007	7.45	4.82	2.57
2008	7.99	4.70	2.13
2009	7.75	5.37	2.39
2010	5.87	4.22	2.12

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	7.88	5.11	2.32
2012	6.87	4.71	2.08
2013	8.34	5.21	2.24
2014	8.08	4.83	2.04
2015	7.13	4.36	2.03
2016	7.30	4.19	2.01
2017	7.43	4.91	2.01
2018	8.36	5.05	2.47
2019	6.85	4.75	1.92

Source: Environment and Climate Change Canada (2020) Climate Research Division, Climate Processes section.

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