5.2: Snow cover

Key Message

The portion of the year with snow cover decreased across most of Canada (*very high confidence*) as did the seasonal snow accumulation (*medium confidence*). Snow cover fraction decreased between 5% and 10% per decade since 1981 due to later snow onset and earlier spring melt. Seasonal snow accumulation decreased by 5% to 10% per decade since 1981 with the exception of southern Saskatchewan, and parts of Alberta and British Columbia (increases of 2% to 5% per decade).

Key Message

It is *very likely* that snow cover duration will decline to mid-century across Canada due to increases in surface air temperature under all emissions scenarios. Scenario-based differences in projected spring snow cover emerge by the end of the century, with stabilized snow loss for a medium emission scenario but continued snow loss under a high emission scenario (*high confidence*). A reduction of 5% to 10% per decade in seasonal snow accumulation is projected through to mid-century for much of southern Canada; only small changes in snow accumulation are projected for northern regions of Canada (*medium confidence*).

Snow cover is a defining characteristic of the Canadian landscape for a few months each winter along the southern margins of the country and for up to nine or 10 months each year in the high Arctic. Snow is responsible for a cascade of interactions and feedbacks that affect the climate system, freshwater availability, vegetation, biogeochemical activity including exchanges of carbon dioxide and trace gases, and ecosystem services (Brown et al., 2017). To understand changes in snow, it is necessary to consider multiple variables, including snow cover fraction (SCF), which is affected by the timing of snow onset and snow melt, and the maximum seasonal snow water equivalent (SWE_{max}), the amount of water stored by snow and available for melt in spring. These variables affect the exchange of energy between the surface and the atmosphere (with important feedbacks to the global climate system) and freshwater availability, as nearly all Canadian watersheds are snow-dominated in the winter. Snow is critical to winter travel and tourism in many regions of the country and is a key requirement for the construction of winter roads that connect remote communities and mines, particularly in the Northwest Territories, northern Manitoba, and northern Ontario.

Surface observations of snow depth from climate monitoring stations (such observations are referred to as "in situ data") are not well suited for detecting trends and variability in snow cover because they measure snow only at individual points (Brown and Braaten, 1998). Snow depth can vary significantly at the local scale because of interactions with vegetation and topography (typically driven by winds), which means single point measurements may not capture the mean snow depth on the landscape (Neumann et al., 2003). In addition, climate stations are exceptionally sparse above 55º north latitude in Canada and are biased to lower elevations in mountainous areas and in coastal areas in the sub-Arctic and Arctic. It is, therefore, challenging to use the conventional Canadian climate observing network for a national-scale assessment of snow. Satellite observations and land surface models are available that provide daily, spatially continuous data across all of Canada, extending back for decades. These products have a coarse spatial resolution (25–50 km), which presents problems for alpine areas and regions with mixed land cover. Researchers have made significant efforts to determine the agreement among datasets to ensure robust analysis of trends (Mudryk et al., 2018).

5.2.1: Observed changes in snow cover

Based on an analysis of multiple datasets covering 1981–2015, SCF (characterized as the proportion of days within each month that snow was present on the ground) decreased by 5% to 10% across most of Canada during most seasons (Mudryk et al., 2018; see Figure 5.2), notably, for eastern Canada in spring (April/May/June) and most of the Canadian land area in the fall (October/November/December). This loss of snow cover is consistent with previous studies using in situ datasets covering a longer time period (Brown and Braaten, 1998; Vincent et al., 2015), but the 1981–2015 period is characterized by stronger reductions in snow cover during the snow onset period for eastern Canada in response to enhanced fall warming (consistent with Brown et al., 2018). Decreasing SCF trends over high latitudes of Canada are consistent with documented reductions in annual snow cover duration (SCD; the number of days with snow cover) across circumpolar Arctic land areas of two to four days per decade (approximately 1% to 2% per decade, assuming 250 days mean snow cover) (Brown et al., 2017). Some studies (Derksen and Brown, 2012; Derksen et al., 2016; Brutel-Vuilmet et al., 2013; Hernández-Henríquez et al., 2015; Mudryk et al., 2017) identified spring snow cover losses slightly stronger than those in Figure 5.2, because different datasets and time periods were considered. Despite these differences, all studies consistently show reductions in spring SCF.

Analysis of surface temperature from a blend of six atmospheric reanalysis datasets showed that warming trends over the 1981–2015 period are found in all Canadian land areas with SCF reductions (Mudryk et al., 2018). Cooling trends in winter and spring are associated with the regions of increasing SCF (see Figure 5.2). Observations from climate stations in the regions where SCF trends increased over 1981–2015 also show decreased maximum snow depth and SCD over the longer 1950–2012 period (Vincent et al., 2015), so the positive trends over 1981–2015 reflect nature variability in regional surface temperatures and precipitation.

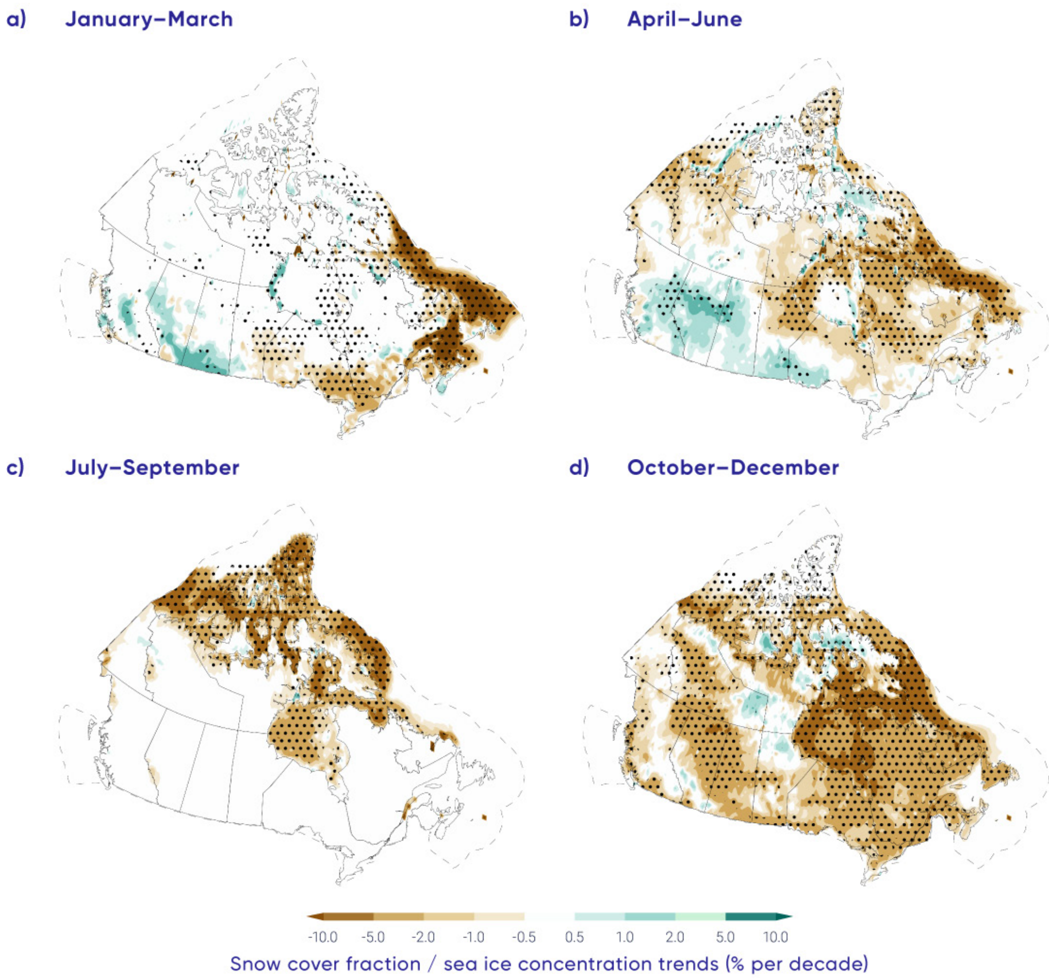


Figure 5.2: Snow cover fraction and sea ice concentration trends, 1981–2015

Figure caption: Terrestrial snow cover fraction and sea ice concentration seasonal trends for 1981–2015. Stippling indicates statistical significance (there is only a 10% possibility that such changes are due to chance). Dashed line denotes limit of Canadian marine territory. Changes in sea ice are discussed in Section 5.3.

FIGURE SOURCE: MUDRYK ET AL. (2018)

While SCF information is important for identifying changes in where snow covers the ground, from a water-resources perspective, it is important to understand how much water is stored in the form of snow. This is determined from the pre-melt SWE_{max}. SWE_{max} declined by 5% to 10% across much of Canada during the period 1981–2015, according to the multi-dataset analysis shown in Figure 5.3 (Mudryk et al., 2018). This is consistent with snow depth trends from surface measurements (Brown and Braaten, 1998; Vincent at al., 2015) and other observational studies (for example, Mudryk et al., 2015). Increases in SWE_{max} are evident across parts of British Columbia, Alberta, and southern Saskatchewan. The influences of temperature and precipitation changes need to be separated to understand the driving mechanisms behind trends in SWE_{max} (Raisanen, 2008; Brown and Mote, 2009; Mankin and Diffenbaugh, 2014; Sospedra-Alfonso and Merryfield, 2017).

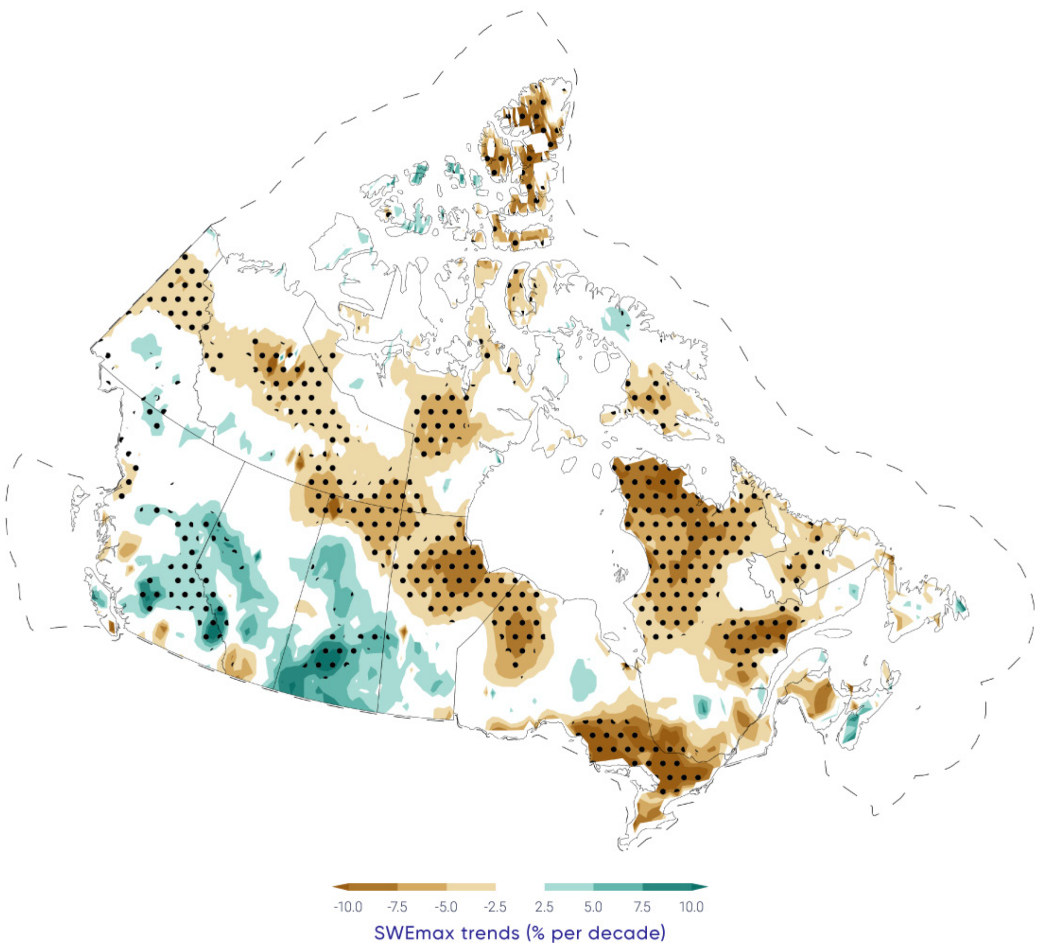


Figure 5.3: Trends in maximum snow water equivalent, 1981–2015

Figure caption: Trends in maximum snow water equivalent (SWE_{max}) (% per decade) for 1981–2015. Stippling indicates statistical significance (there is only a 10% possibility that such changes are due to chance).

FIGURE SOURCE: MUDRYK ET AL. (2018).

5.2.2: Projected changes in snow cover

Projections of surface temperatures across Canada for the near-term under a high emission scenario (RCP8.5) show warming in all seasons in the multi-model average (see Chapter 4, Section 4.2.1.3), with concurrent decreases in projected SCF across all of Canada during all seasons (Figure 5.4; Mudryk et al., 2018). During winter, projected snow cover reductions will be greatest across southern Canada, where temperature increases result in less snowfall as a proportion of the total precipitation. Temperatures will remain sufficiently cold at higher latitudes that winter (January/February/March) SCF in this region is not projected to change in response to warming. During spring, the region of snow sensitivity to temperature forcing is projected to shift north, as snow cover retreats across the boreal forest, sub-Arctic, and high Arctic. This leads to projected negative SCF trends (loss of snow) across these regions during the April through June period. Important differences in spring snow cover projections between emissions scenarios emerge by the end of the century, with stabilized snow loss under a medium emission scenario (RCP4.5) but continued loss under a high emission scenario (RCP8.5) (Brown et al., 2017).

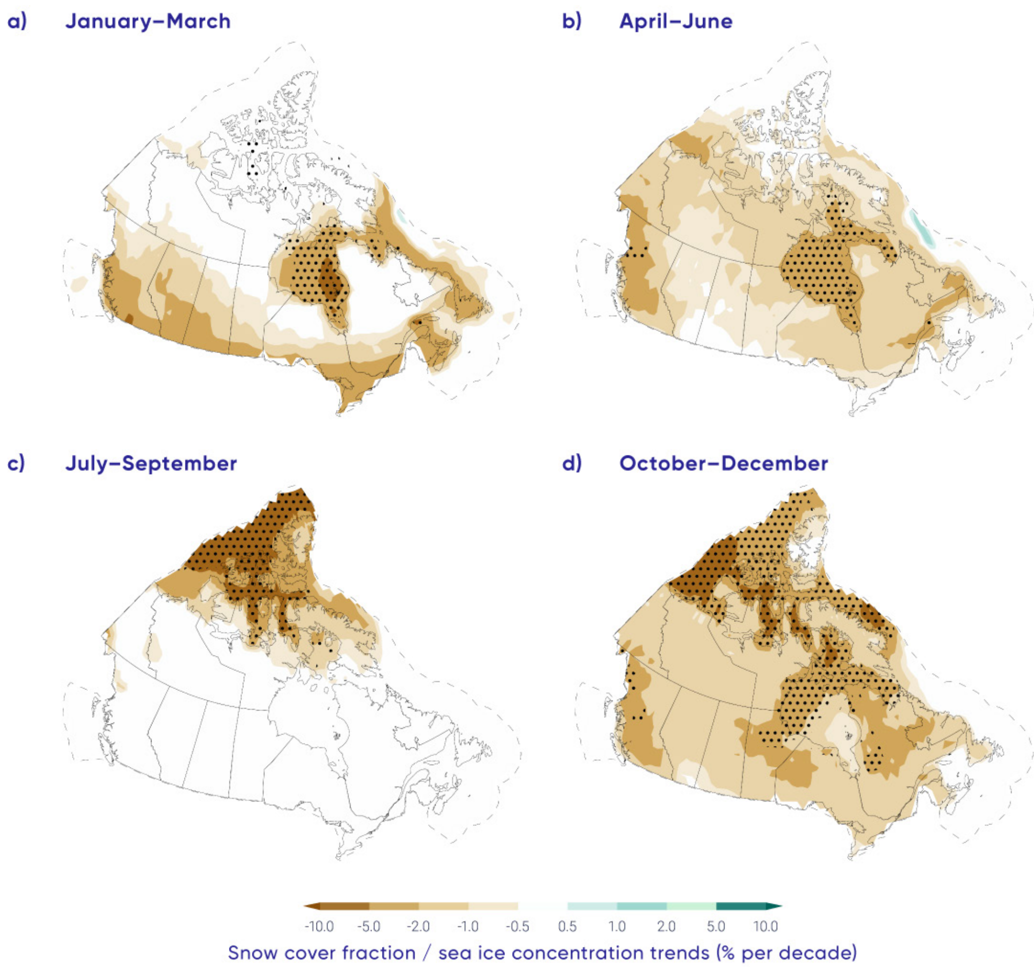


Figure 5.4: Projected snow cover fraction and sea ice concentration trends, 2020–2050

Figure caption: Projected terrestrial snow cover fraction and sea ice concentration seasonal trends (% per decade) for the 2020–2050 period for Canadian land and marine areas. Trends are calculated from the multi-model mean of an ensemble of climate models (Coupled Model Intercomparison Project - CMIP5), using a high emission scenario (RCP8.5). Stippling indicates statistical significance (there is only a 10% possibility that such changes are due to chance).

FIGURE SOURCE: MUDRYK ET AL. (2018)

Projected changes in SWE_{max} indicate that reductions will be extensive (5% to 10% per decade through 2050, or a cumulative loss of 15% to 30% over the entire 2020–2050 period) over much of southern Canada, with the greatest changes in the Maritimes and British Columbia (see Figure 5.5). The decreases across the prairies, Ontario, Quebec, and the Maritimes are attributable to increasing temperatures that will shift the proportion of total precipitation that currently falls as snow toward rain (Sospedra-Alfonso and Merryfield, 2017). (Note that the greatest near-term reductions in SWE_{max}, according to the climate model projections, will be just south of the Canadian border.) Projected changes in British Columbia are consistent with projected SWE_{max} reductions in the Western Cordillera (Fyfe et al., 2017). While SWE_{max} is projected to increase by mid-century in the Eurasian Arctic (Brown et al., 2017), minimal change is projected across high-latitude land areas of Canada because increased snowfall is expected to be offset by increasing temperatures that shorten the snow accumulation season.

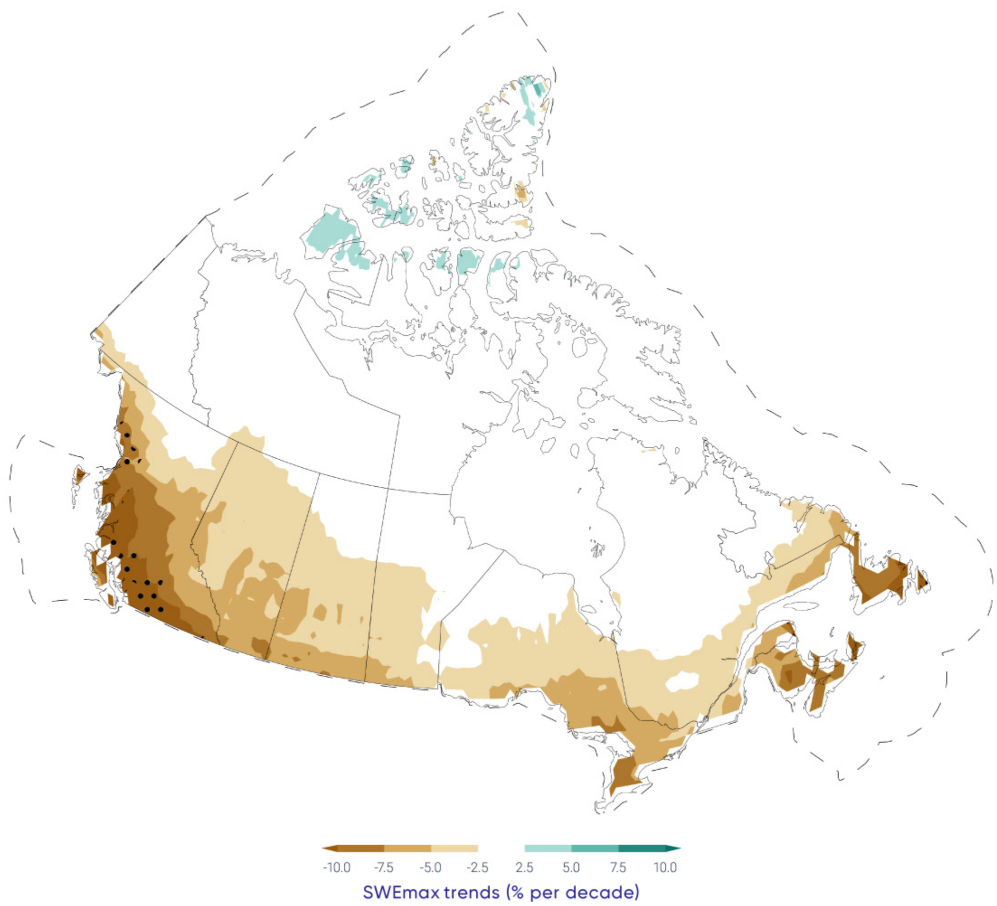
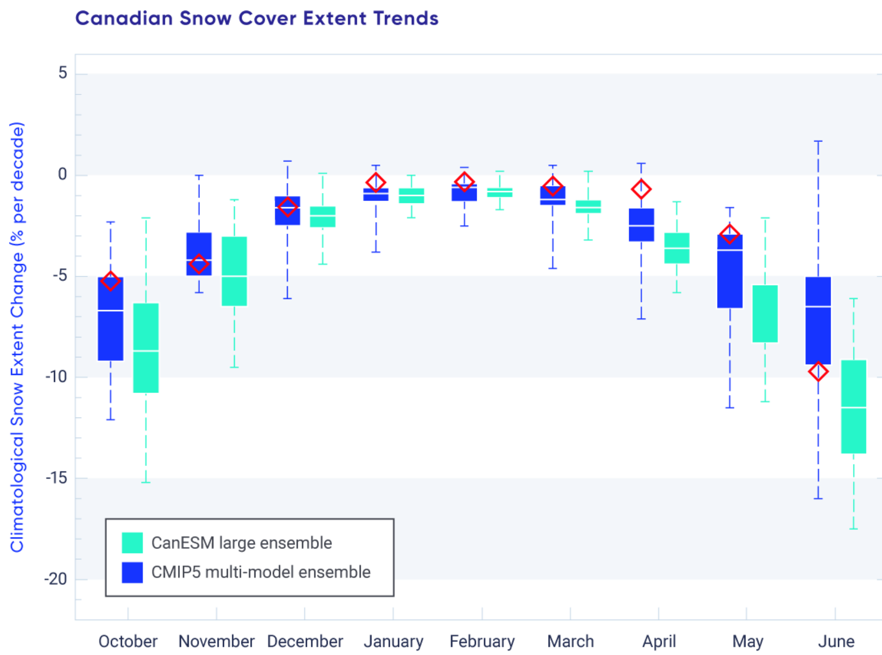


Figure 5.5: Projected trends in maximum snow water equivalent, 2020–2050

Figure caption: Projected trends in maximum snow water equivalent (SWE_{max}, % per decade) for 2020–2050 for Canadian land areas. Trends are calculated from the multi-model mean of an ensemble climate models (Coupled Model Intercomparison Project - CMIP5), using a high emission scenario (RCP8.5). Stippling indicates statistical significance (there is only a 10% possibility that such changes are due to chance).

FIGURE SOURCE: MUDRYK ET AL., 2018

The greatest snow loss across Canada during the 2020–2050 period is projected to occur in the shoulder seasons (October–November and May–June; Thackeray et al., 2016) (see Figure 5.6). During mid-winter, there is minimal percentage change in projected snow cover extent because winter temperatures across northern regions of Canada will remain cold enough to sustain snow cover and there is greater climatological snow extent in winter, which results in smaller percentage changes (see Figure 5.5). The projected trends are similar to the rate of change already observed during the historical period (see Section 5.2.1). Trends from a large ensemble of simulations from the Canadian Earth System Model (CanESM2) are slightly stronger than the CMIP5 multi-model mean because projected warming is greater in CanESM2 than in the CMIP5 multi-model mean (Thackeray et al., 2016).



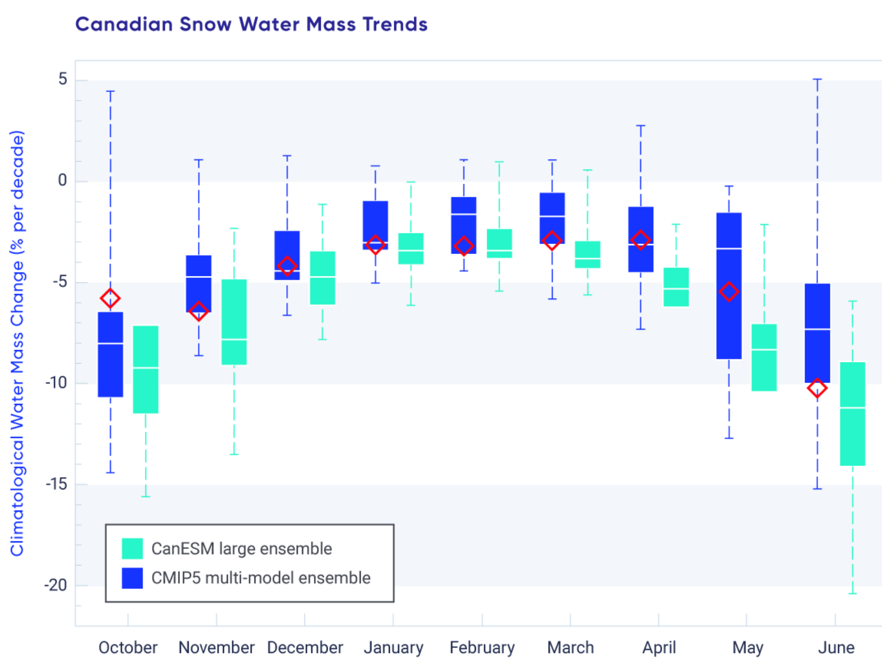


Figure 5.6: Observed (1981–2015) and projected trends in Canadian snow cover extent and snow water mass, 2020–2050

Figure caption: Monthly projected trends in Canadian snow cover extent (upper) and snow water mass (lower) from the Coupled Model Intercomparison Project (CMIP5) multi-model ensemble (blue) and from the Canadian Earth System Model (CanESM) large ensemble (aqua), under a high emission scenario (RCP8.5). Monthly mean observational trends (1981–2015) from the snow dataset used in Section 5.1.1 are shown in red. Boxes show the 25th–75th percentile range, the horizontal line shows the median, and the dashed whiskers illustrate the minimum and maximum.

FIGURE SOURCE: MUDRYK ET AL. (2018)

Section summary

In summary, analysis of multiple sources of SCF data from satellite remote sensing and land surface models over the 1981–2015 period show the portion of the year with snow cover decreased across Canada at a rate of 5% to 10% per decade. There is *very high confidence* in these trends based on consistency among multiple datasets and quantitative relationships with surface temperature trends in which there is also *high confidence* (see Chapter 4). Seasonal snow accumulation decreased by a rate of 5% to 10% per decade across most of Canada (1981–2015), with the exception of southern Saskatchewan, Alberta, and British Columbia (increases of 2% to 5% per decade), driven by both temperature and precipitation changes. Because of greater uncertainty in sources of data on snow accumulation (compared to those on SCF), we have *medium confidence* in these trends. It is *very likely* that snow cover duration will decline to mid-century across Canada as a result of increases in surface air temperature under all emission scenarios. This likelihood assessment is based on the strongly established sensitivity of snow cover to surface temperature in both observations and climate models. Scenario-based differences in projected spring snow cover emerge by the end of the century, with stabilized snow loss for low and medium emission scenarios (RCP2.6 and 4.5) but continued snow loss under a high emission scenario (RCP8.5). A reduction of 5% to 10% per decade in seasonal snow accumulation (through 2050) is projected across much of southern Canada; only small changes in snow accumulation are projected across northern regions of Canada because increases in winter precipitation are expected to offset a shorter snow accumulation period. There is greater uncertainty in SWE projections (compared to SCD) because of greater spread in climate model responses due to the competing effects of temperature and precipitation, so there is *medium confidence* in these results.