Canadian Meteorological Centre (CMC) Daily Snow Depth Analysis Data, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Brown, R. D. and B. Brasnett. 2010, updated annually. *Canadian Meteorological Centre (CMC) Daily Snow Depth Analysis Data, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/W9FOYWH0EQZ3. [Date Accessed].

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FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0447

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

This data set contains daily analyzed snow depths and monthly mean snow depth (in cm) and estimated snow water equivalent (SWE; in mm) from 1998 through 2020. It also includes climatologies of monthly mean snow depth and estimated SWE for the original period of 1998–2012 and the updated period of 1998–2017, which takes into account several changes in the analysis since 2012. The snow depth analysis is performed using real-time, in situ daily snow depth observations, and optimal interpolation with a first-guess field generated from a simple snow accumulation and melt model, which is driven with analyzed temperatures and forecast precipitation from the Canadian forecast model (see Brasnett, 1999). In situ observations include snow depths from surface synoptic (synop) observations, meteorological aviation (metar) reports, and special aviation (SA) reports from the World Meteorological Organization (WMO) information system.

Note: This data set is NOT homogeneous. It is derived from operational data that are subject to frequent changes. See the Warnings and Notices section for details.

1.1 Format

All data files are provided in compressed (`.zip`), ASCII tab-delimited format (`.txt`). In addition, daily snow depth files for each calendar year are also provided in GeoTIFF (`.tif`) format. A comma-separated value data mask is available for continental-scale studies (see See the Warnings and Notices section for details.)

1.2 File and Directory Structure

Data are available via HTTPS from the following directory:

https://daacdata.apps.nsidc.org/pub/DATASETS/nsidc0447_CMC_snow_depth_v01/

The directory structure and existing files are described in Table 1. To check which years are available, refer to the Temporal Coverage section.

Table 1. Directories and Contents

Top-Level Directory	Contents
/nsidc0447_CMC_snow_depth_v01/	Along with the directories Snow_Depth/ and SWE/, the top-level directory contains the following files: cmc_analysis_lsmask_binary_nogl_v01.2.txt: Land/sea mask defining ocean points for the data set. Also masks out Greenland (_nogl_). cmc_analysis_ps_lat_lon_v01.2.zip: Unpacks a .txt file with the same name, containing the position of grid points (latitude/longitude) for the polar stereographic grid centered on the North Pole. Note that the grid point locations in this file correspond to the upper right corner of each pixel. cmc_homog_mask_points_v01.2.csv: Mask to maintain homogeneity in continental-scale studies (see the Warnings and Notices section for details).

Sub-Directory	Contents
Snow_Depth/ (contains three sub-directories)	Snow_Depth_Daily_Values/ (contains two sub-directories) ASCII/ cmc_sdepth_dly_YYYY_v01.2.zip: Unpacks a .txt file with the same name, containing daily snow depth for the given calendar year. Contains one file per year. GeoTIFF/ cmc_sdepth_dly_YYYY_v01.2[4].tif: Daily snow depth for the given calendar year in GeoTIFF format. Each yearly file contains one band per day, so files can have either 365 or 366 bands. cmc_sdepth_dly_YYYY_v01.2.tif.aux.xml: Associated XML metadata files for the same years.
	Snow_Depth_Monthly_Averages/ cmc_sdepth_mly_YYYY_v01.2.zip: Unpacks a .txt file with the same name, containing monthly average snow depth for the given calendar year. Contains one file per year.

	Snow_Depth_Monthly_Climatologies/ cmc_sdepth_mly_clim_1998to2012_v01.2.zip[1]: Unpacks a .txt file with the same name, containing the monthly snow depth climatology for snow seasons (Aug–July) 1998–2012. Snow seasons span two calendar years; e.g., August 1998 to July 1999. cmc_sdepth_mly_clim_1998to2017_v01.2.zip[2]: Unpacks a .txt file with the same name, containing the monthly snow depth climatology for snow seasons (Aug–July) 1998–2017. Snow seasons span two calendar years; e.g., August 1998 to July 1999. cmc_sdepth_mly_mean_animation_1999to2006_v01.2.avi: snow depth animation cmc_sdepth_legend_v01.2.gif: snow depth legend
SWE/ (contains two sub-directories)	SWE_Monthly_Averages/ cmc_swe_mly_1998to20YY_v01.2.zip: Unpacks a .txt file with the same name, containing monthly mean SWE from October to June[3] of each calendar year from 1998 through the latest complete year.
	SWE_Monthly_Climatologies/ cmc_swe_mly_clim_1998to2012_v01.2.zip[1]: Unpacks a .txt file with the same name, containing the monthly SWE climatology for snow seasons (Oct–Jun) 1998–2012. Snow seasons span two calendar years; e.g., October 1998 to June 1999. cmc_swe_mly_clim_1998to2017_v01.2.zip[2]: Unpacks a .txt file with the same name, containing the monthly SWE climatology for snow seasons (Oct–Jun) 1998–2017. Snow seasons span two calendar years; e.g., October 1998 to June 1999.

[1]Original climatologies for monthly mean snow depth and monthly estimated SWE for the period 1998–2012 are provided as a fixed reference period for anomaly tracking.

[2]Updated climatologies for monthly mean snow depth and monthly estimated SWE for the period 1998–2017 are provided to take into account several changes in the analysis since 2012 (See the Warnings and Notices section for details).

[3]The July through September time period was not processed due to a lack of observed snow density information.

[4]See version history for details regarding 2019 GeoTIFF

1.3 Spatial Coverage

Southernmost Latitude: 0° N
Northernmost Latitude: 90° N
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

1.3.1 Spatial Resolution

The analysis has a resolution of 1/3° Gaussian. The error correlations used by the analysis have an e-folding distance of approximately 120 km horizontally and 800 m vertically.

1.3.2 Projection and Grid Description

A Northern Hemisphere subset of the Canadian Meteorological Centre (CMC) daily global analysis was interpolated to a standard 24 km polar stereographic grid that closely approximates the grid used by NOAA for the 24 km daily IMS snow product. At 706 pixels, the grid covers a slightly smaller area than the full 1024-pixel IMS grid. The land/sea mask should be used to remove snow over sea ice and over Greenland.

Grid Specification:

North Polar Stereographic

ni (# rows) = 706, nj (# cols) = 706, bottom left grid point = (1,1)

Grid rotation -10°

Pole position = (353, 353)

Grid resolution at 60°N = 23812.5 m

Geocoordinates:

Latitude and longitude coordinates corresponding to the center of each grid cell are stored in `cmc_analysis_ps_lat_lon_v01.2.txt` (compressed as `cmc_analysis_ps_lat_lon_v01.2.zip`). This file lists each cell and its geographic coordinates as a row, column (i, j) ordered pair starting with (1,1), the cell in the lower left corner of the polar stereographic grid. Note that the grid point locations provided correspond to the upper right corner of each pixel. Cell locations then increment across each column of the first row, each column of the second row, and so on, until reaching the upper right corner at (706,706).

Refer to Figure 1 to see the first 10 entries from `cmc_analysis_ps_lat_lon_v01.2.txt`.

I	J	Lat	Long
1	1	1.665461E-01	-125.000000
1	2	2.479315E-01	-125.081500
1	3	3.293158E-01	-125.163200
1	4	4.106980E-01	-125.245200
1	5	4.920774E-01	-125.327400
1	6	5.734532E-01	-125.409800
1	7	6.548244E-01	-125.492500
1	8	7.361903E-01	-125.575400
1	9	8.175499E-01	-125.658500
1	10	8.989025E-01	-125.741900

Figure 1. Latitude and longitude coordinates for cells (1, 1) through (1, 10) from cmc_analysis_ps_lat_lon_v01.2.txt

proj4 string:

'+proj=stere +lat_0=90 +lat_ts=60 +lon_0=10 +x_0=0 +y_0=0 +R=6371200 +units=m +no_defs=True'

1.4 Temporal Coverage

Data include daily observations from 01 August 1998 to 31 December 2020.

Note: the daily analysis for 08 December 2014 was missing, so the investigators replaced it with the previous day's data.

1.4.1 Temporal Resolution

The analysis is updated every six hours, but only the 00-hour analysis is archived in this data set. For more information, refer to the Processing Steps.

1.5 Parameters

The parameters contained in this data set are snow depth (in cm) and SWE (in mm). In the following, the individual parameters are explained in more detail.

1.5.1 Daily Snow Depth

Each daily snow depth ASCII file contains one year of data with the following FORTRAN statements:

```
do 1001 iday=1,ndays ! 365 or 366 depending on # days in year
         write(60,*) idate ! date in format YYYYMMDDHH where HH is always 00
               do 1002 i=1,NI
                write(60,100) (sdep(i,j),j=1,706) !cm
100         format(706(1x,f5.1)) !values exceeding 1000 set to 999.9
1002       continue
1001     continue
```

Note: In 1998, the data start on 01 August, listed as `1998080100` in the data file.

For the daily snow depth TIFF files, note that a file-level attribute indicates a NoData value of -1.7e+308. However, the algorithm that generated the data used -999.9 as an undefined snow depth value, thus the latter should be used as the actual NoData value.

1.5.2 Land/Sea Mask

The CMC analysis includes snow on sea ice. A custom binary (0,1) land/sea mask is provided to mask out ocean areas and Greenland. Land (mask=1) was assigned for grid land cover fractions greater than or equal to fifty percent. The array should be read in as follows:

```
    open(50,file='cmc_analysis_lsmask_binary_nogl_v01.2.txt',status='old')
    do 5 i=1,706
      read(50,21) (lsmask(i,j),j=1,706)
21    format(706(i1))
5   continue
```

1.5.3 Monthly Mean Snow Depth

Monthly mean snow depth data are included with one year of data per file. An upper snow depth limit of 600 cm was applied to the recent analyses to maintain continuity. The land/sea mask should be used to remove snow over sea ice and over Greenland where the analysis is unreliable.

Each file contains one year of data with the following FORTRAN statements:

```
      do 1000 imon=1,12
      write(60,*) iyear,imon
      do 1001 i=1,ni
        write(60,100) (sd_avg(i,j),j=1,706) !cm
100     format(706(1x,f5.1))
1001  continue
1000  continue
```

Note: In 1998, the data start in August.

1.5.4 Snow Water Equivalent (SWE)

Monthly mean estimates of SWE are included in this data set. Monthly mean SWE for the October to June period of each year was estimated from monthly mean snow depth files by applying a look-up table (see Table 2) of monthly mean snow density values. Monthly mean snow density values were derived from Canadian snow course observations corresponding to snow-climate classes in the Sturm et al. (1995) classification.

Table 2 lists the monthly mean snow density look-up table used to estimate SWE based on Canadian snow course observations averaged over the snow-climate classes defined by Sturm et al. (1995) and (Brown and Mote, 2009). This assumes the Canadian density observations are representative of snow-climate classes in other regions of the Northern Hemisphere.

Table 2. Parameter Range and Description

Month	Tundra	Taiga	Maritime	Ephemeral	Prairie	Alpine
Oct	200.0	160.0	160.0	250.0	140.0	160.0
Nov	210.7	176.9	183.5	300.0	161.6	172.0
Dec	218.1	179.8	197.7	335.1	185.1	181.6
Jan	230.3	193.1	216.5	316.8	213.7	207.2
Feb	242.7	205.9	248.5	337.3	241.6	241.5
Mar	254.4	221.8	283.3	364.3	261.0	263.5
Apr	273.6	263.2	332.0	404.6	308.0	312.0
May	311.7	319.0	396.3	458.6	398.1	399.6
Jun	369.3	393.4	501.0	509.8	464.5	488.9

The Sturm et al. (1995) snow-climate classification was interpolated from the 0.5° by 0.5° gridded version (ARCSS045) at the University Corporation for Atmospheric Research (UCAR) (Liston & Sturm, 1998) to the 24 km polar stereographic grid of the monthly mean snow depth. This process resulted in land/sea confusion at a number of points, which were excluded from the analysis. The number of points affected by this problem (nconf) is indicated in the header record for each month. The SWE estimates are contained in a single file (`cmc_swe_mly_1998to2019_v01.2.txt`) with -999.0 values at all grid points where SWE could not be calculated (such as ocean or Sturm snow-class undefined). Greenland was excluded from the analysis, as the analysis is considered unreliable in this area. Values were written as tab-delimited with the following FORTRAN statements:

```
write(60,*)iyear,imonth,nconf
         do 1002 i=1,ni
              write(60,107) (swe(i,j),j=1,706) !mm
107         format(706(1x,f6.1))
1002 continue
```

Note: In 1998, values start in October.

1.5.5 Climatologies of Snow Depth and Estimated SWE

The snow depth climatologies include values from January to December, while the SWE climatologies include values from October to June. Both files are written in comma-delimited latitude-longitude tagged format with a single header record containing the variable names. Along with the climatologies, an animation of monthly mean snow depth, averaged over the 1999-2006 period (`cmc_sdepth_mly_mean_animation_1999to2006_v01.2.avi`), and a legend for the snow depth animation as a separate GIF image file (`cmc_sdepth_legend_v01.2.gif`) are included. The land/sea mask was applied to these outputs. The original climatologies for the period 1998–2012 are provided as a fixed reference period for anomaly tracking. The updated climatologies for the period 1998–2017 are provided to take into account several changes in the analysis since 2012 (See the Warnings and Notices section for details).

Note: Starting in 2013/2014, processing was migrated from a UNIX platform to a PC. As such, zero values in some files after this date are written as .0 instead of 0.0.

1.5.6 Sample Analysis Image

Figure 2 displays an example of the CMC analysis data used for evaluating Global Climate Model (GCM) output from Brown and Mote (2009).

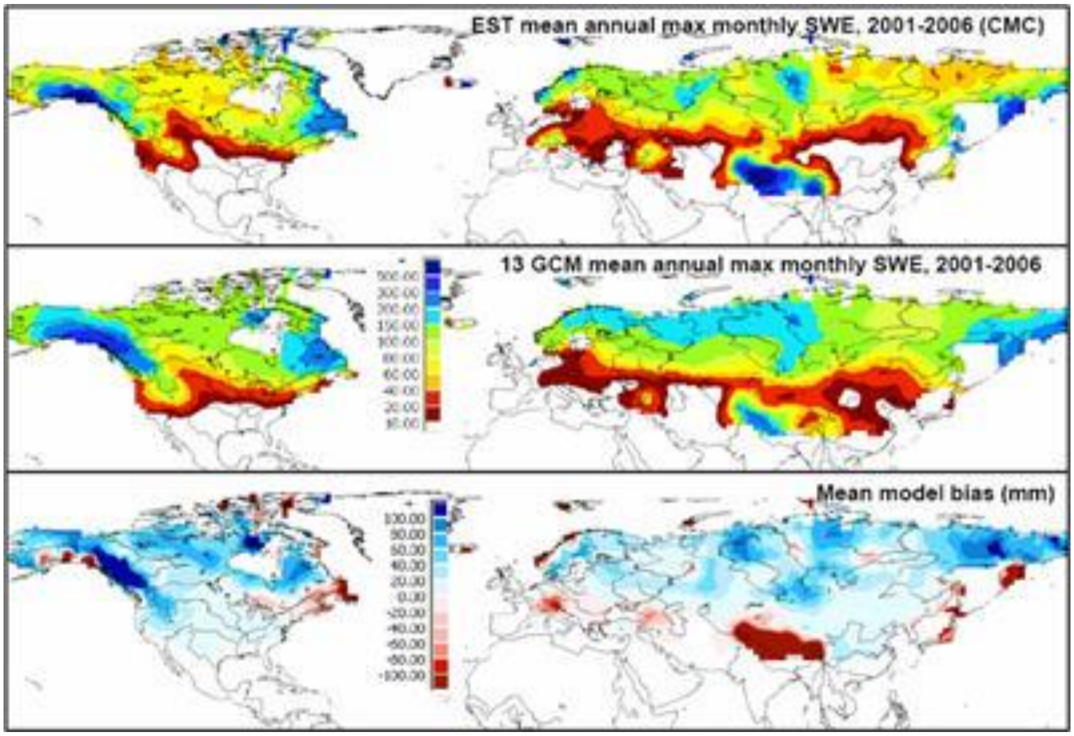

Figure 2. Sample of CMC Analysis Data Used for Evaluating Model Output. Comparison of (middle) 13 GCM mean SWEmax (mm), with (top) estimated SWEmax from CMC daily snow depth analyses for 2001–06 and (bottom) mean model bias (mm). Image from Brown & Mote (2009).

2 SOFTWARE AND TOOLS

The ASCII files are readable by any text editor. The GeoTIFF files are readable by a variety of software such as ArcGIS, ENVI, QGIS, etc.

2.1 Quality Assessment

A complete description of the analysis methodology and validation is published in Brasnett (1999). The methodology was applied to carry out a reanalysis of snow depths over North America for the Atmospheric Model Intercomparison Project - 2 (AMIP-2) project from 1979-1997 using a more elaborate snow model for the first guess field, Brown et al., (2003). The scheme makes use of an analysis of screen-level temperature produced with vertical correlations taken into account.

Over most of the Arctic region, there are no observations, so the analysis is based on estimated snow depths from the first guess field. In addition, snow depth observations over northern Canada tend to be biased to coastal locations with observing sites at open areas near airports. The snow at these sites tends to be shallower and to melt out earlier than snow in surrounding terrain.

In cold, high precipitation environments, such as Greenland, the snow accumulation is capped at 600 cm to avoid excessive amounts of snow accumulating. The analysis is not considered reliable in these regions. This limit was changed to 1200 cm in October 2008 when a Limited Area Model (LAM) version of the analysis was implemented over British Columbia. Verification of that product showed it had insufficient residual snow during the summer months due to the 600 cm limit, so the limit was also changed in the global analysis. This limit is not unreasonable; mean annual snowfall in some locations in British Columbia exceeds 1000 cm, as illustrated by the mean annual snowfall levels for the 1951 through 1980 normal climate period listed in Table 3.

Table 3. Mean Annual Snowfall Levels (1951–1980)

Location	Snowfall
Allison Pass	1431.5 cm
Rogers Pass	1106.7 cm
Pine Pass	1075.5 cm
Tahtsa Lake	1041.2 cm
Mt. Fidelity	1974.8 cm

Values exceeding 1000 cm after 01 January 2007 were set to 999.9 to conform to the existing database format.

3 DATA ACQUISITION AND PROCESSING

Real-time snow depth data were originally acquired from the World Meteorological Organization (WMO) information system.

3.1 Processing Steps

The analysis is updated every six hours using the method of optimum interpolation with an initial guess field provided by a simple snow accumulation and melt model using analyzed temperatures and forecast (six hour) precipitation from the CMC Global Environmental Multiscale (GEM) forecast model. The precipitation is assumed to be snow if the analyzed screen-level temperature is less than 0 degrees Celsius. A degree-day melting algorithm removes mass from the snowpack at the rate of 0.15 mm h^{-1} K^{-1}.

In regions where there are no observations of snow depth, the snow depth shown in the analysis corresponds to the initial guess field simplified assumptions regarding snowfall, melt and aging.

Note: When there is an ice cover, the analysis will accumulate snow on it, so the snowfield can extend over water bodies. This can be masked out if desired.

3.1.1 Snowpack Density

The first-guess snow model assumes the density of new snow to be 100 kg/m^3 and the snowpack gradually increases in density as it ages. The increase in density with aging stops when the density reaches 300 kg/m^3 (except 210 kg/m^3 if the vegetation is needleleaf forest, since in these regions, the canopy shelters the snowpack from wind and sunlight and densities are less). New snow causes the density to decrease by an amount related to the mass of the new snow and the mass of the existing snowpack. During melting, the density is allowed to increase up to a maximum of 550 kg/m^3.

3.2 Error Sources

The analysis had been run essentially unchanged from 12 March 1998. An error was introduced into the operational implementation of the analysis in October 2006, but this has been corrected in offline runs and an offline version of the analysis is being run in parallel with the operational analysis to maintain data continuity.

3.2.1 Warnings and Notices

1. Prior to 04 January 2010, the analyses from October 2006 were inadvertently run with the vertical correlation component of the optimal interpolation switched off, which would have affected snow depths in mountainous areas. These files were corrected and replaced on 04 January 2010. The error resulted in slightly lower continental snow cover extent (less than 10 percent) from October to June, but 10 to 20 percent underestimates of snow cover extent from July to September.
2. The snow depth analysis is NOT homogeneous in data-sparse regions! A change of resolutions from 100 km to 33 km on 31 October 2006 (and the removal of an upper limit cap on snow accumulation) to the Global Environmental Multiscale (GEM) model generating the forecast precipitation fields has resulted in increased SWE values. A preliminary evaluation over Arctic land areas suggests maximum SWE values are about 20 mm higher after the implementation of the higher resolution version of GEM. The impact is even more noticeable in high SWE regions such as mountains, which exhibit an increasing trend in annual maximum SWE since 2007. In continental-scale studies, the increasing trend is reduced if regions with mean annual maximum accumulations exceeding 300 mm are masked out (see Figure 3). A more aggressive mask (`cmc_homog_mask_points_v01.2.csv`) with the location of points to exclude is needed to maintain homogeneity in continental-scale studies in recent years, due to a further increase in the resolution of GEM forecast precipitation to 25 km in 2013.

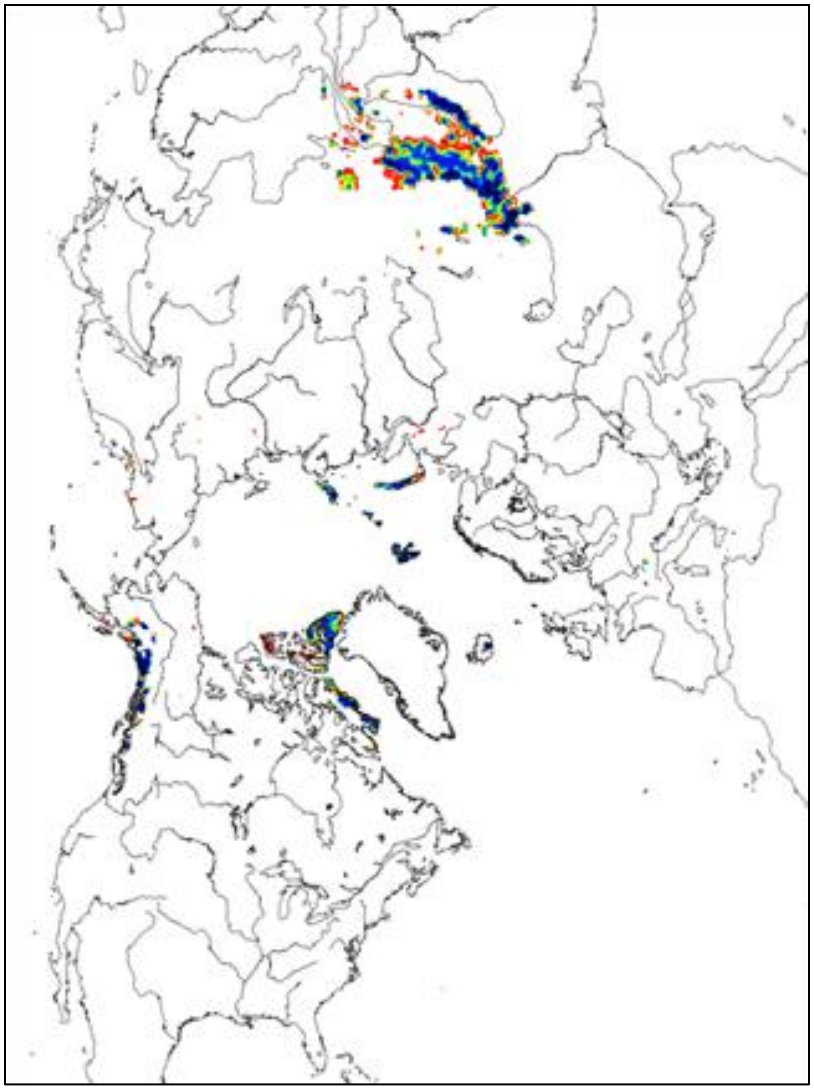

Figure 3. Land areas with mean annual maximum accumulations exceeding 300 mm. These areas need to be masked out with cmc_homog_mask_points.csv to maintain homogeneity in continental-scale studies in recent years.

3. Over most of the Arctic and mountain regions, there are no observations, so the analysis is based essentially on estimated snow depths from the first guess field. In addition, snow depth observations over northern Canada tend to be biased to coastal locations with observing sites at open areas near airports. The snow at these sites tends to be shallower and to melt out earlier than snow in surrounding terrain.
4. Data prior to August 1998 have been removed from the data archive, as the snowpack model used in the analysis was unable to be properly initialized for the 1997/98 snow season. The snow depths have been determined to be anomalously high in consequence.
5. An improved land/sea mask has been generated for use with the analysis.
6. Snow depth and SWE values over Arctic land areas in March, April, and May 2002 are anomalously low compared to other data sets. There is evidence from Canadian in situ observations that spring 2002 snow depths were the shallowest observed since 1951. Nevertheless, the striking discrepancy between CMC and other data sets in these particular months suggests that it may be prudent to exclude them from any analysis.

7. The daily analysis for 08 December 2014 was missing. To fill this gap, the investigators replaced it with the previous day's data.
8. Starting in 2013/2014, processing was migrated from a UNIX platform to a PC. As such, zero values in some files after this date are written as .0 instead of 0.0.
9. The current product is scheduled for phase-out in 2018–2019 when the new Canadian Land Data Assimilation System (CaLDAS) becomes operational. See Carrera et al. (2015).
10. Harry Stern at the Polar Science Center (University of Washington) documented an anomalously large decrease in snow depths around 10 December 2009, with a sharp increase on 01 January 2010 at several locations on Baffin Island. This problem was found to affect all mountain regions with high snow accumulation (areas in dark blue shown in Figure 4). The precise reasons for this dropout have not been identified.

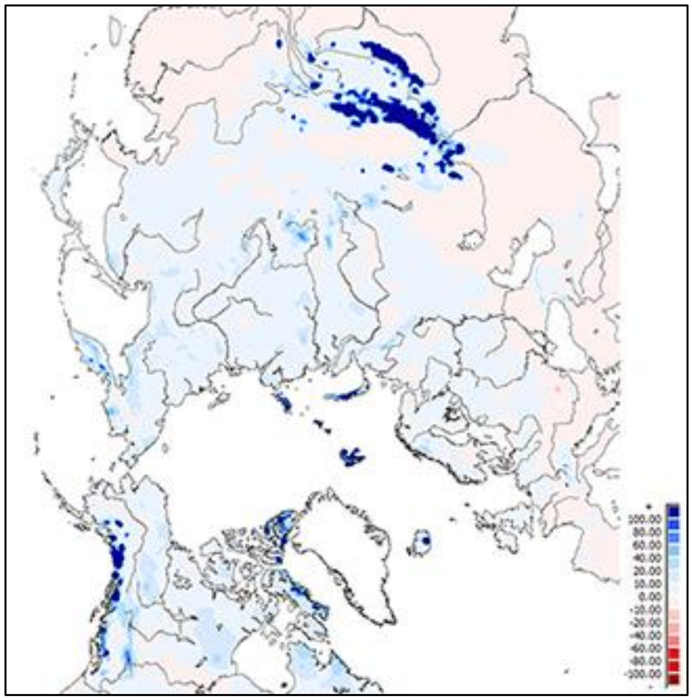

Figure 4. Difference in snow depth (cm) between 01 January 2010 and 31 December 2009. Areas in dark blue are affected by the anomalous December 10–31 drop-out.

11. Michael Notaro at the Nelson Institute for Environmental Studies' Center for Climatic Research (University of Wisconsin-Madison) documented instances where the CMC analysis substantially underestimates snow depths in areas bordering Lake Superior in northern Michigan. In this region, CMC annual maximum snow depths are about half the observed values. A lack of real-time snow depth observations and under-represented lake-effect snowfall in the CMC precipitation forecast contribute to this underestimate. In this area, snow depths from the Snow Data Assimilation System (SNODAS) are likely more realistic, as SNODAS has access to more real-time observations of snow depth than the CMC global analysis.
12. In October 2015 the output was switched from a frozen offline run of the analysis to the operational version of the analysis. A comparison of the two products for 31 March 2015 showed that differences were typically less than 5 cm between the two runs.

3.3 Conditions of Data Use

1. **Grant of License**: The Government of Canada (Environment Canada) is the owner of all intellectual property rights (including copyright) of this data product. You are granted a limited, non-exclusive, non-assignable, and non-transferable license to use this data product for research purposes only, subject to the terms below. This license is not a sale of any or all of the owner's rights. This product may only be used by you, and you may not rent, lease, lend, sell, sub-license, or transfer the data product or any of your rights under this agreement to anyone else.
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3.4 Version History

Version 1.2 was released in February 2020. Refer to Table 4 for the data set version history:

Table 4. Version History

Version	Description
V1 (Feb 2010)	Initial release
V1.1 (Feb. 2013)	Version 1.1 includes the following updates: - New and updated data files incorporating 2012 data - Updated data files for all 1998 data - Updated data file for 2009 daily snow depth data - Improved binary land/sea mask

Version	Description
V1.2 (Feb. 2020)	Version 1.2 includes the following updates: - New and updated data files incorporating 2019 data - New file naming convention and directory reorganization to more easily indicate file contents and temporal resolution.
V1.2, V1.3 (April 2021)	This update includes the following changes: - Temporal coverage expanded to 2020 - The 2019 files, cmc_sdepth_dly_2019_v01.2.tif and cmc_sdepth_dly_2019_v01.2.tif.aux.xml, were reprocessed and named with the suffix, v01.3, to make the NoData value consistent across all records; value now equals -1.7e+308

4 REFERENCES AND RELATED PUBLICATIONS

Brasnett, Bruce. 1999. A Global Analysis of Snow Depth for Numerical Weather Prediction. *Journal of Applied Meteorology* 38: 726–740.

Brown, Ross D. and Philip W. Mote. 2009. The Response of Northern Hemisphere Snow Cover to a Changing Climate. *Journal of Climate* 22: 2124–2145.

Brown, Ross D., Brasnett, Bruce, and David Robison. 2003. Gridded North American Monthly Snow Depth and Snow Water Equivalent for GCM Evaluation. *Atmosphere-Ocean* 41: 1–14.

Carrera, M. L., S. Bélair, and B. Bilodeau. 2015. The Canadian Land Data Assimilation System (CaLDAS): Description and Synthetic Evaluation Study. *J. Hydrometeor* 16: 1293–1314. DOI: https://doi.org/10.1175/JHM-D-14-0089.1

Liston, G. E., and M. Sturm. 1998. A Snow-Transport Model for Complex Terrain. *Journal of Glaciology* 44: 498–516.

Sturm, M., J. Holmgren, and G. E. Liston. 1995. A Seasonal Snow Cover Classification System for Local to Global Applications. *Journal of Climate* 8: 1261–1283.

5 CONTACTS AND ACKNOWLEDGMENTS

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Acknowledgments:

The PI wishes to thank Bruce Brasnett, Meteorological Service of Canada, for his unfailing help and support in providing this dataset to the scientific community.

6 DOCUMENT INFORMATION

6.1 Publication Date

January 2010

6.2 Date Last Updated

20 May 2021