Data Article

Cold region data accessibility portal for Québec (CRDAP-QC): An integrated, multi-variable and multi-scale data repository for studying cold-region hydrological processes in Québec

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A B S T R A C T

We present an integrated data portal and retrieval system for various variable related to hydrology and cryosphere of Québec, named Cold Region Data Accessibility Portal for Québec (CRDAP-QC). The raw data with which this integrated platform is built are pulled from various publicly available data sources. The platform integrates data variables related to climate (maximum, minimum and mean temperature along with total precipitation), snow accumulation (snow cover and depth) as well as Freeze-Thaw characteristics. The platform enables downloading, visualizing, and comparing these data across various temporal (monthly, seasonal and annual) and spatial scales (from 25 × 25 km\textsuperscript{2} grids, to sub-basin and basin, to the whole province). The platform also provides a Printable Document File with summary of the data, an additional set of information on elevation, land-use, and land-cover as well as the location of climate and hydrometric sta-
Specifications Table

| Subject | Hydrology; Climatology; Freeze-Thaw |
|---------|--------------------------------------|
| Specific subject area | Data of cold region hydro-limatic processes including freeze-thaw, snow cover and depth, minimum, mean and maximum temperature, and precipitation, along with physical characteristics, e.g., elevation, land cover, etc., across a range of temporal and spatial scales |
| Type of data | Various types of Tables, Images, Charts, Graphs, Figures, Maps, Reports, Animations produced by a website according to the user's command. |
| How data were acquired | Raw data are obtained from various public data repositories. |
| • Climate data | https://hydrology.princeton.edu/data.pgf.php |
| • Freeze-Thaw data | https://nsidc.org/data/nsidc-0477/versions/4 |
| • Snow depth | https://nsidc.org/data/NSIDC-0447 |
| • Snow cover (Terra): | https://nsidc.org/data/MOD10CM/versions/6 |
| • Snow cover (Aqua): | https://nsidc.org/data/MYD10CM/versions/6 |
| • Elevation data: | https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333 |
| • Landcover data: | https://open.canada.ca/data/en/dataset/c688b87f-e85f-4842-b0e1-a8f79ebf1133 |
| • Locations of in-situ weather stations: | https://climate.weather.gc.ca/ |
| • Locations of hydrometric stations: | https://collaboration.cmc.ec.gc.ca/cmc/hydrometrics/www/ |
| Data format | Raw, Analyzed, Processed, Regridded, Filtered |
| Parameters for data collection | Gridded data for various climatic and hydrologic variables are pulled together from multiple publicly variables sources and regridded using the nearest neighbour algorithm into a unified grid system and delineated across a range of temporal (from monthly to annual) and spatial (from the grid to the whole province of Québec) scales. |
| Description of data collection | Raw data were obtained from mentioned data repositories, regridded, and upscaled into coarser spatial and temporal scales. The data is integrated into a unified bilingual portal, including various functionalities for data visualization, downloading, animation, as well as comparison. |
| Data source location | Institution: Concordia University; City/Town/Region: Montreal, Québec; Country: Canada |
| Latitude and longitude for collected samples/data: | The province of Québec. The source of raw and primary data is provided above. |
| Data accessibility | https://doi.org/10.5281/zenodo.6546226 |
| (Direct link to) | http://wsc.cc.encs.concordia.ca/home.html |
| Related research article | Hatami, S., & Nazemi, A. (2021). A statistical framework for assessing temperature controls on landscape Freeze-Thaw: Application and implications in Québec, Canada (1979–2016). Journal of Hydrology, 603, 126891, https://doi.org/10.1016/j.jhydrol.2021.126891. |
Value of the Data

- Understanding the impact of climate on the form and dynamics of water above and below landscape has an enormous importance for various applications, relevant to human’s land, water and infrastructure management in cold regions. Our portal integrates the data support needed for historical analysis of these dynamics in Québec, one of the most ecologically diverse and water-rich areas within global cold regions.
- Researchers, local and provincial governments, urban and rural municipalities, farmers, water managers and miners, transportation officials, Indigenous communities, geoscientists and engineers, college and university students in Québec and beyond can benefit from these data. Due to being user-friendly, our portal has the potential to bring public awareness about the climate change and its impacts on the landscape in Québec.
- The data, figures, animations, and reports provided by this portal can be used for the analysis of climate variability and change along with its impact on snow depth and cover as well as freeze and thaw patterns across different time scales and regions of Québec.
- The report produced by the portal provides information on landcover and elevation, as well as distribution of in-situ climatic and hydrometric stations across any selected patch of land in Québec.
- The portal is inclusive and is available in both English and French.

1. Data Description

The Cold Region Data Accessibility Portal for Québec (CRDAP-QC; [1]) is a collection of public data query platforms to display, analyse, and compare climate variables along with Freeze-Thaw (FT) and snow cover and depth data (hereafter DATA) for the province of Québec across different temporal and spatial scales. CRDAP-QC includes three standalone tools, namely Data Tool, Comparison Tool, and Animation Tool. These applications are designed to be user-friendly and available in both English and French to maximize the accessibility of the portal for the local and global users. Below each application is described in more detail.

Data Tool (http://wscc.encs.concordia.ca/FTPROJ.html): The Data Tool in an application embedded in CRDAP-QC to download and plot different variables from DATA at monthly, seasonal and annual scales and across multiple land patches in Québec. The application also provides an opportunity to create a standardized report that includes a summary of the DATA variable chosen, along with relevant geographic information as well as metadata of climate and hydrometric stations across the chosen land patch. To download, plot, and/or get the summary file, three simple steps should be followed by the user.

The first step includes choosing the variable of interest among the array of DATA. The DATA array is composed of (a) climate data, including Maximum, Minimum, and Mean Temperature (°C) and Total Precipitation (mm); (b) snow data, including Snow Depth (cm/month) as well as the percentage of snow cover retrieved from two satellite products, i.e. Terra and Aqua; and (c) satellite-based FT data, including Number of Frozen Days, Number of Thawed Days and Number of Transitional Days. These variables include the data support for a series of recent publications about Freeze-Thaw characteristics and their dependence with climate and snow variables [2–5]. The sources of raw data for each of these DATA variables are indicated in the Specification Table. The second step consists of choosing the territory from which the chosen DATA variable should be retrieved. The territory can be as fine as a grid of 25×25 km² and can go as coarse as the whole province. The selection can be according to geographic regions (whole province, ecozones), hydrologic regions (drainage basins, watersheds, sub-watersheds), and a custom region or grid. There are eight ecozones in Quebec that are geographically distinct with a particular ecosystem, vegetation, and hydroclimatology [6]. There are 7 drainage basins, 13 watersheds, and hundreds of sub-watersheds that cover Quebec’s area. The shapefiles for these hydrologic regions are obtained from the World Wildlife Federation Hydroshed repos-
itory (https://www.worldwildlife.org/pages/hydrosheds). Users can also plot any polygon using the drawing tool provided and/or select any grid either by a mouse click or by entering the latitude and longitude for the point of interest. After the right scale is chosen, it must be clicked so the chosen region is selected. Note that a selected region must be highlighted after the click. In fact, if the chosen region is not highlighted after the click, it means that it is not selected. After selecting the region of interest, the third step includes choosing the temporal resolution and extent of the selected DATA variable. The data can be chosen at monthly, seasonal and annual scales, either as continuous timeseries or as annual snapshots, i.e. DATA variables at a certain month/season, e.g., mean temperature in month January. Depending on the DATA variable chosen, the possible temporal extent can change. For FT and climate variables, the chosen period can be between 1979 to 2016. For snow-related variables, the data can go back to 1999. After the DATA variable along with spatial and temporal scales are identified, users can request the portal to either plot the data online, download the data or create a report. The plot provides a simple timeseries graph of the DATA variable. If the spatial extent goes beyond a single grid, then an envelope is plotted, which represents the minimum, maximum and expected values of the selected DATA variable within the considered temporal and spatial scale. Users can also download the DATA variable at the selected temporal and spatial scale as a spreadsheet file including the lower and upper bounds and expected values of the selected DATA variable within the considered temporal and spatial scale. The Data Portal also provides additional information such as the location of climate and hydrometric stations in the selected region as well as elevation profile along any linearly interpolated path. This information is provided as online graphs and can be relevant for developing hydrological models, determining flow paths and/or determining regional transects that are vulnerable to landslides due to having steep slopes. Here, we try to illustrate the step-by-step procedure of extracting the data for an example, which includes retrieving the annual number of Frozen Days in the Northern Arctic ecozone of Québec. Fig. 1 below shows this example. First the user should choose the type of data they are interested in (see Fig. 1a and the arrow #1). Second, the spatial extent of data should be identified (see Fig. 1b and arrow #2) and the region of interest should be selected by clicking on the area (see arrow #3). Third, the temporal scale and period should be selected (see Fig. 1c and arrows #4 and #5). After these selections are made, the user can go to the Action menu and choose Download Data (see Fig. 1d and arrow #6). Accordingly, the data will be downloaded in a CSV file, which includes the lower and upper bounds as well as the expected values for number of frozen days in a typical year in the Northern Arctic ecozone. Note that the grid-based data can be also downloaded through selecting all the grids within the region of interest.

Comparison Tool (http://wscc.encs.concordia.ca/FTPROJCOMP.html): The Comparison Tool is another application embedded in CRDAP-QC to compare and inspect dependencies among DATA at monthly, seasonal and annual scales and across multiple spatial scales in Québec. The results provided by Comparison Tool are generated online as 2D or 3D graphs. To use the Comparison Tool, three simple steps related to choosing (1) two or three variables of interest at a particular (2) spatial scale, as well as (3) time scale and period. The first step includes choosing the variable of interest among the array of DATA. The DATA array is composed of (a) climate data, including Maximum, Minimum and Mean Temperature (°C) and Total Precipitation (mm); (b) snow data, including Snow Depth (cm/month) as well as the percentage of snow cover retrieved from two satellite products, i.e. Terra and Aqua; (c) satellite-based FT data, including Number of Frozen Days, Number of Thawed Days and Number of Transitional Days; and (d) elevation. The sources of raw data for each of these DATA variables are indicated in the Specification Table. The second step includes choosing the territory from which the chosen DATA variable should be retrieved. The territory can be as fine as a grid of 25×25 km² and can go as coarse as the whole province. The selection can correspond to geographic regions (whole province, ecozones), hydrologic regions (drainage basins, watersheds, sub-watersheds), and a custom region or grid. Spatial specifications are entirely similar to what mentioned for the Data Tool. Again, the region from which the DATA variables should be compared must be selected by clicking on the chosen region. If a region is selected, then it must be highlighted. The third step includes choosing the temporal resolution and the extent of the selected DATA variables. The data can be chosen
at monthly, seasonal and annual scales, either as continuous timeseries or as annual snapshots, i.e. DATA variables at a certain month/season, e.g. average snow cover in February. Depending on the DATA variable chosen, the possible temporal extent can change. See the description in the Data Tool for more information about the data period for each array of DATA. While in this setup, the data are compared across all the timesteps and grids within the chosen spatial scale, the user can also choose to compare the long-term mean values between the two or three variables from DATA across all grids. As soon as the variables of interest as well as the temporal and spatial scales of the comparison are identified, the user should select “4. Compare Data” and accordingly generate the figure. The figure is automatically displayed below the map as a new window when it is prepared.

In the example below we use Comparison Tool to visualize the dependence between annual number of frozen days and the annual mean temperature in the grids located in the Northern Arctic ecozone of Québec. We then need to select the variables of interest, in this case mean temperature (see Fig. 2a; arrow #1) and number of frozen days (see Fig. 2a; arrow #2). Accordingly, scale and region of interest should be selected as shown in Fig. 2b; arrows #3 and #4. Similar to the Data Tool and Visualization Tool, the region should be selected by clicking on the region of the interest on the map (Fig. 2b; arrow #4). Accordingly, the time scale and period of
data should be selected (see Fig. 3c; arrows #5 and #6) and the user should click on the “Generate Figure” bottom (see Fig. 2d; arrow #7). Fig. 2e shows the result of comparison, which shows the number of frozen days in a given year/grid vs. corresponding annual mean temperature.

Visualization Tool ([http://wscc.encs.concordia.ca/dynamicQC.html](http://wscc.encs.concordia.ca/dynamicQC.html)): The Visualization Tool is the third application embedded in CRDAP-QC and is designed to colormap, display, and animate a specific array of DATA or their long-term statistics and trend at monthly, seasonal and annual timescales across a range of Quebec’s regions. To use the Visualization Tool, the type of visualization along with the variables of interest, spatial resolution as well as the time scale and the time period should be identified. These selections can be easily made using drop down menus. The first step in utilizing the Visualization Tool is to select the type of visualization. There are four types of visualizations, including three types of visualizations for DATA variables along with elevation, i.e. animated maps (dynamic visualization) along with the snapshot maps of elevation as well as long-term averages and yearly trends of various variables in DATA (static visualization). For animation and long-term means, all variables in DATA can be animated across all spatial scales with multiple grids, i.e, single grid animation is not supported, and the data can
be plotted across all temporal scales noted in Data and Comparison Tools. For animation, the selected DATA variables can be also animated as the timeseries. For trends, DATA are reduced to FT and temperature related variables, and the yearly trends can be plotted during three data periods of 1980 to 1997 and 1999 to 2016 as well as 1980 to 2016. For elevation, only spatial resolution should be selected across all scales with multiple grids. After the appropriate settings are selected, the user can press the play button to visualize the variable selected in the given temporal and spatial scales. Here we illustrate using the Visualization Tool to monitor monthly number of frozen days in the Northern Arctic of Québec. To do so, we first choose the “Animation” as the visualization type (see Fig. 3a; arrow #1), choose the variable of interest (see Fig. 3a; arrow #2), and choose the scale of interest (see Fig. 3a; arrow #3).

Note that after the scale of interest is chosen, the region of interest should be selected by clicking on the map (see Fig. 3b; arrow #4). Then the time scale and the time period of the data visualization should be selected (see Fig. 2a; arrows #5 and #6) and the user should click on the play bottom (see Fig. 3b; arrow #7). After these settings are set, monthly number of frozen days are visualized over the map. Figs. 3c and 3d show two snapshots of this visualization related to March 1980 and September 1989, respectively.

2. Experimental Design, Materials and Methods

Through the use of a series of publicly available global datasets, CRDAP-QC provides an integrated look at the evolution of climate, snow and FT conditions in Québec, the largest province in Canada (total area of 1,542,056 km$^2$ from which 176,928 km$^2$ are waterbodies). With elevation varying from 0 to 1652 meters Québec includes eight distinct terrestrial ecozones [6], including Northern Arctic (∼35,500 km$^2$), Southern Arctic (∼160,375 km$^2$), Arctic Cordillera (∼12,336 km$^2$), Taiga Shield (∼536,635 km$^2$), Hudson Plains (∼37,000 km$^2$), Boreal Shield (∼658,500 km$^2$),
Mixed-Wood Plains (~26,215 km²) and Atlantic Maritime (~66,309 km²). While other gridded climate data support (e.g. ERA-Interim [7]), and/or other data variables (e.g. snow water equivalent) could have been included in the portal, the backbone data of CRDAP-QC are limited to the data support used in a number of recent contributions on the FT characteristics in Québec and their variations under changing climate conditions ([2–5]; see the information about the related data article in the specification table above).

The climate data within CRDAP-QC include precipitation data from the Global Meteorological Forcing Dataset (GMFD: https://hydrology.princeton.edu/data.pgf.php). GMFD includes an array of global near-surface meteorological variables with various spatial resolutions. These data are obtained by fusing reanalysis products of the National Centres for Environmental Prediction and National Centre for Atmospheric Research, with a group of global observation datasets. It has been shown that GMFD results in a higher global accuracy as well as a better temporal and spatial consistency compared to conventional reanalysis products [8]; and accordingly, it has been used widely to support large-scale hydrologic and land-surface studies [9–11]. We extract daily minimum and maximum temperature at 0.25°×0.25° from 1979 to 2016 from which daily mean temperature is estimated. We then upscale the daily minimum, mean and maximum temperature estimates to monthly, seasonal, and annual scales.

We obtain monthly snow depth data from the Canadian Meteorological Centre (CMC; https://doi.org/10.5067/W9FOYWH0EQQ3), which are constructed by blending the data from in-situ snow depth measurements with interpolated results of a simple physical snow dynamic model [12]. The data is provided for the period of 1998-2020 with the grid resolution of 24×24 km² across the northern hemisphere. In parallel, monthly snow cover data are obtained from MODIS Terra and Aqua satellites. These data are available respectively at https://nsidc.org/data/MOD10CM/versions/6 for Terra, and https://nsidc.org/data/MYD10CM/versions/6 for Aqua; see [13]. These data cover the period of 2002 to present and at the 0.05°×0.05° scale, which are further upsampled to 0.25°×0.25°.

The FT characteristics are obtained from FT Earth System Data Record (FT-ESDR) of National Snow and Ice Data Centre (NSIDC; https://doi.org/10.5067/MEASURES/CYROSHERE/nsidc-0477.004). The dataset includes global coverage of daily landscape FT states with the spatial resolution of 25×25 km² over the period of 1979-2017 [14]. Within the framework of FT-ESDR, daily FT states are categorized into four classes of (1) AM and PM frozen, (2) AM and PM non-frozen, (3) AM frozen and PM thawed, and (4) AM thawed and PM frozen. By having the grided daily FT states, three specific FT characteristics are extracted across multiple temporal and spatial scales. These three FT variables include the Number of Frozen Days, the Number of Thawed Days, and the Number of Transitional Days that include both type of days with AM frozen/PM thawed and AM thawed/PM frozen.

Prior to any further analysis, we homogenize the data both temporally and spatially. As climate data end on 2016, we filter out the FT and snow data beyond year 2016 to make that matchable with temperature and precipitation records. In addition, we map the DATA variables into a unique grid system to make them homogenized spatially. As the data related to FT states include discrete data, regridding FT data to a new grid system would be difficult; therefore, by considering the grids of FT-ESDR as the reference, we use the k-nearest neighbor interpolation [15] to regrid climate and snow data to the same grid system as the FT data. As a non-parametric gapfilling algorithm, the k-nearest neighbor method uses the known information about the quantity of a variable from an ensemble of neighboring points to estimate the unknown quantity of a variable at any given point [16, 17], here grid centers of FT-ESDR data. To identify neighboring points, a distance measure should be implemented. Given the centers of FT-ESDR grids as origins, we use the Euclidean distance of climate as well as snow depth and snow cover grids from the origin to identify neighboring points. Consequently, the value of climate and snow variables can be estimated at the grids of FT-ESDR through weighted averaging. Through numerical experimentation, we find that using the four nearest neighbors can provide the highest accuracy in modeling the mean and standard deviation of the daily temperature and monthly snow depth dataset over different ecozones as well as the Québec as a whole [2]. The
regridded estimations are then used to extract the DATA variables as well as their corresponding long-term means and trends. Long-term means are simply extracted for each DATA variable using the mean of data at a chosen temporal scale and during a chosen data period. The analysis of trend involves detecting monotonic changes in a particular DATA variable and includes quantifying the direction (positive vs. negative) and magnitude of the slope of change [18]. Here we apply Sen’s slope, which is a robust estimation of the linear trend [19], and is frequently used in the context of the Mann-Kendall trend test [20–21]. The advantage of using Sen’s slope estimator is in its insensitivity to extreme values that can dampen or exaggerate the true trend.

The data provided through CRDAP-QC have already supported a number of scientific studies. Based on the analyses of trends, there is a consistent signal of warming in Québec, manifested in all temperature variables over almost all landmass of the province. These trends are coincided with increasing number of thawed days and decreasing number of frozen days in a year over the majority of the Québec’s landmass. This demonstrates the strong dependency between temperature and FT characteristics that is discussed in details in [4]. Having said that, although temperature is the most influential variable on FT characteristics, it is not the sole driver of change. Using the Comparison Tool, the influence of snow depth on FT characteristics can be revealed. Compound impacts on temperature and snow depth in FT characteristics are discussed in details in [5]. By integrating climate, snow and FT data over various spatial scales along with other relevant data such as elevation, as well as location of climate and hydrometric stations, CRDAP-QC can be used for land and water managers in Québec for supporting design, assessment and operational studies. Also as the portal is bilingual, it can be used as a knowledge platform for informing general public in Québec about the extent and impact of global warming in the province.

**CRediT Author Statement**

**Ali Nazemi:** Idea creation; co-conceptualization; Supervision; Funding acquisition; Writing, revising & editing. **Shakil Jiwa:** Co-conceptualization; Platform design, development, launch, and maintenance; editing. **Shadi Hatami:** Data curation, processing and filtering; editing.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

**Data Availability**

Cold Region Data Accessibility Portal for Quebec (CRDAP - QC) (Reference data) (Zenodo).

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