

Computerized Tool for the Development of Intensity-Duration-Frequency-Curves Under a Changing Climate

www.idf-cc-uwo.ca

User's Manual

Version 6.5

March 2023

By

Andre Schardong

Abhishek Gaur

Slobodan P. Simonovic

and

Dan Sandink

Department of Civil and Environmental Engineering and

Institute for Catastrophic Loss Reduction

The University of Western Ontario

London, Ontario, Canada

Executive Summary

Municipal water management in Canada is heavily dependent on the use of IDF curves in planning, design, and operation of municipal water infrastructure. Many watershed management activities related to water supply, water quality management, flood control, and similar rely on the use of IDF curves. This manual documents version 6.5 of the web based tool for updating Intensity-Duration-Frequency (IDF) curves under a changing climate.

While there is a need in almost every Canadian municipality to adapt to changing climatic conditions, there is a lack of necessary expertise within municipalities for implementing current research related to the impact of climatic change on IDF curves. Thus, one of the primary objectives of the tool is to standardize the IDF updating process and make the results of current research on climate change impacts accessible to practitioners. The authors and supporting agencies believe that a freely available, computerized IDF updating tool aids in the selection of effective climate change adaptation options at the local level, advancing the decision-making capabilities of municipalities and watershed management authorities. The tool also provides a direct link between Canadian municipalities and the research community, creating opportunities for further research and innovation.

This manual describes the major functionalities of version 6.5 of the web-based IDF_CC tool. The tool is designed to assist users in developing and updating IDF curves using precipitation data from Environment Canada or user provided hydro-meteorological stations. Available precipitation data is integrated with projections obtained from Global Circulation Models to assess the impacts of climate change on IDF curves. The accompanying document, “*Computerized Tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate, Technical Manual Version 6.5*” referred to as *TechMan.*, presents the methodological background of the web-based IDF_CC tool version 6.5.

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1 Introduction

Changes in climate observed over recent decades are considered to be the cause of dramatic modifications of magnitude and frequency of extreme events. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013) has indicated a global surface temperature increase of 0.3 to 4.8 °C by the year 2100 compared to the reference period 1986-2005, with larger changes in the tropics and subtropics than in the mid-latitudes. It is expected that rising temperatures will have a major impact on the magnitude and frequency of extreme precipitation events in some regions (Barnett et al., 2006; Wilcox et al., 2007; Allan et al., 2008, Solaiman et al. 2011).

Assessment of climate change impacts and the implementation of the contemporary climate change research remains a challenge for many stakeholders and policymakers. The most likely reasons are: 1) complexity of the methods based on heavy analytical procedures and difficulties in their implementation; 2) a focus on publishing research findings under the rigorous peer review process with limited attention given to practical implementation; 3) political dimensions of climate change issues; and 4) a high level of uncertainty involved with future climate projections in presence of multiple climate models and emission scenarios. The implementation of a generic and simple web-based tool that allows users to easily consider the impacts of climate change in the form of updated IDF curves for storm water design and management is considered an effective strategy to increase climate change adaptation capacity in Canada (Sandink et al., 2016). To accomplish this task, the IDF_CC tool has been developed and has been in public use since March 2015 (Simonovic et al., 2016 and Schardong et al., 2020). This tool combines a friendly web-based user interface with a powerful database system, and applies an efficient, sophisticated methodology for the update of IDF curves.¹

Intensity duration frequency (IDFs) curves are typically developed by fitting a theoretical probability distribution to the annual maximum precipitation (AMP) time series. The AMP data is fitted using extreme value distributions including Gumbel, Generalized Extreme Value (GEV), Log Pearson, Log Normal, among other methods. IDF curves provide precipitation accumulation depths for various return periods (T) and different durations, typically, 5, 10, 15, 20 30 minutes, 1, 2, 6, 12, 18 and 24 hours. Longer durations may also be obtained, depending on the use of IDF curves.

¹ For more information on the methodology applied by the IDF_CC, see the accompanying document entitled “*Computerized Tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate, Technical Manual Version 6.5,*” referred to as *TechMan*.

Hydrologic design of storm sewers, culverts, detention basins and other elements of storm water management systems are typically performed based on specified design storms derived from IDF curves (Solaiman and Simonovic, 2010).

The web based IDF_CC tool version 6.5 developed for IDF update under changing climatic conditions is implemented in the form of a Decisions Support System (DSS) with three main components (Figure 1). The user interface is built as a GIS based component using Leaflet™, allowing clear geographical representation of hydro-meteorological stations. User information, station data, and Global Circulation Model (GCM) outputs are stored in the IDF_CC tool's database system. Mathematical models and algorithms populate the tool's model base.²

The major objectives of the IDF_CC tool version 6.5 are: (i) to automate; and (ii) facilitate the IDF update procedure using historical observed precipitation data and precipitation predictions from available GCM models. A repository of stations from Environment Canada is available through the user interface with complete records of historical yearly maximums. The tool also allows users to provide their own historical hydro-meteorological data, which can be used to generate locally relevant updated IDF curves. Version 6.5 of the tool also introduces a new dataset of gridded IDF curves for Canada. With the new module, users can obtain IDF curves for any location in the country, especially in regions where no observations are available.

The tool interface presents the IDF results in the form of tables and interactive graphs. Version 6.5 of the tool utilizes data from GCMs produced for Coupled Model Intercomparison Project Phase 6 – CMPI6 (Eyring et al., 2016) for Coupled Model Intercomparison Project Phase 5 - CMPI5 (IPCC, 2013) and statistically downscaled daily Canada-wide climate scenarios, at a gridded resolution of 300 arc-seconds (0.0833 degrees, or roughly 10 km) for the simulated period of 1950-2100 (PCIC, 2021) for three Representative Concentration Pathways (RCPs) (representative concentration pathways). For more information on GCMs and SSPs and RCPs used with the tool, see Section 3.2 and *TechMan* Sections 2.3 and 2.4.

² For more information, see *TechMan*

across the country. There are approximately 900 stations throughout the country and roughly 600 of these have at least 10 years of data, which is the minimum length of time series used by Environment Canada to develop IDF curves for a specific station.

- User provided stations and data: any registered user can create stations and provide data for them. The type of data and input options are discussed in section 2.5.5 of this manual. User-created stations can be shared among other users registered with the IDF_CC tool.
- CMIP5 GCMs and downscaled GCM output files: original and downscaled GCM outputs provided by IPCC (PCIC (2021 refer to *TechMan* section 2.4) are available in the netCDF format that is widely used for storing climate data. The direct use of netCDF with the web-based IDF_CC tool is not computationally efficient and would require huge storage space. Therefore, the netCDF files are converted into more efficient to use format. This converted climate data files are stored in the IDF_CC tool's database.
- CMIP6 GCMs are driven by a new set of Shared Socioeconomic Pathway (SSP) scenarios representing different socioeconomic assumptions. Specifically, a set of scenarios were chosen to provide a range of distinct end-of-century climate change outcomes. Earlier, the CMIP5 featured four Representative Concentration Pathways (RCPs) that examined different possible future greenhouse gas emissions. These scenario- RCP2.6, RCP4.5, RCP6.0, and RCP8.5 – have new versions in CMIP6. The updated scenarios are called SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, each of which result in similar 2100 radiative forcing levels as their predecessor in CMIP5 (Lawrence Livermore National Laboratory, 2021).
- Miscellaneous files: users can upload files that are related to a specific station. The files are also stored within the database and can be of type: text documents, spreadsheets and pdf files.

1.3 User Interface

The user interface (Figure 2) provides for management of user actions and inputs and link with the other two DSS components: Mathematical Models and Database. The major parts of the user interface are:

- Leaflet™: the GIS component responsible for map operations;

- Data manipulation: functionalities that allow users to manipulate stations and data;
- Results visualization: functionalities that present the results to the user (tables, equations, interactive graphs).

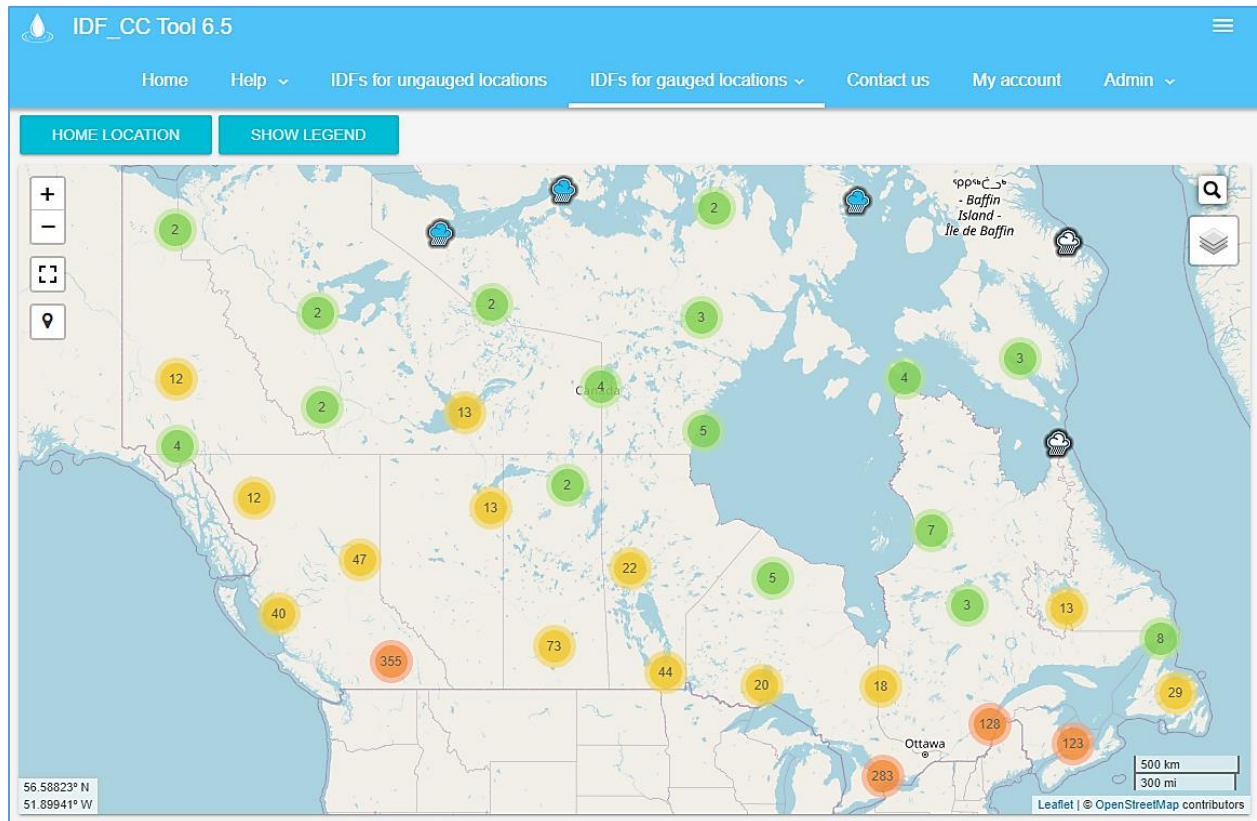


Figure 2. Screenshot of the IDF_CC tool version 6.5 user interface

1.4 Mathematical Models

The IDF_CC tool mathematical models are responsible for the calculations required to develop IDF curves based on historical data and incorporating GCM output data into IDF curves. Models listed below are used with the IDF_CC tool:

- Statistical analysis algorithms: statistical analysis is applied to fit the selected theoretical distribution to both historical and future precipitation data. The distribution applied by the tool for fitting historical data is Gumbel, which is fitted using method of moments. For future

IDFs and historical data the Generalized Extreme Value (GEV) distribution is used and parameters are fitted using L-moments method. Please refer to *TechMan* section 3.1 for detailed description of the Gumbel and GEV distributions.

- Optimization algorithm: an algorithm used to fit the analytical relationships (equations) to the IDF curves. For each return period (T) an equation is fitted using “Differential Evolution” optimization algorithm that is described in Storn and Price (1997) and Vasani (2008) (Appendix A). This algorithm is used to find the coefficients of the equation by minimizing the sum of the root square error of the IDF curve and calculated by the equation.
- IDF update algorithm: the Equidistant Quantile Matching (EQM) algorithm is applied to the IDF updating procedure. This algorithm combines historical observed precipitation data with data from the GCM models to develop the IDF for future periods. A detailed description of this algorithm is presented in the *TechMan* section 3.2.

2 The IDF_CC tool Use

This section describes in detail use of the IDF_CC tool version 6.5. Two case studies are presented to illustrate all functionalities of the tool. The first example uses one Environment Canada station. The second case study exemplifies use of the tool for locations where Environment Canada data are not available. In this case, the user creates a station and inputs their own hydro-meteorological data into the tool.

2.1 Creating an Account

The user must create an account before accessing all *IDF_CC* tool functionalities. The account is necessary in order to allow user to customize map locations, create stations and provide data, visualize and export IDF curves fitted by the *IDF_CC* tool using historical data and updated IDF curves developed using future climate data. The following information is required from the user to create an account (Figure 3): Full Name, Email address, Affiliation, Occupation, Intent of Use and Password.

Once information is provided an email will be sent to the user with the activation code and/or activation link as shown in Figure 4 (please be sure to check the spam folder for the email sent by the tool). By clicking on the link provided, the user will activate their account. If for some reason the link does not work, the user will be required to provide an activation code when they first access the tool (Figure 5 and Figure 6).

Login & Registration

Login Register Recovery

Name

Email

Password

Re-type Password

Affiliation

Occupation/Job

Intent of use

REGISTER NOW

Figure 3. Screenshot of the user account creation page

IDF CC Tool <webmaster@idf-cc-uwo.com>
to

Dear Test User.

You have created an account on IDF Update Tool. Your info provided is:
Name: Test User
Email: idftool@gmail.com
Password: 1234

To activate account click on: <http://localhost:53606/Activate.aspx?c=8c50526a7fde4521c384925617f68f7b>
If the above link doesn't work, please access <http://localhost:53606/Activate.aspx> and provide the following code: 8c50526a7fde4521c384925617f68f7b

Regards,
IDF Update Tool

Figure 4. An example of activation email message

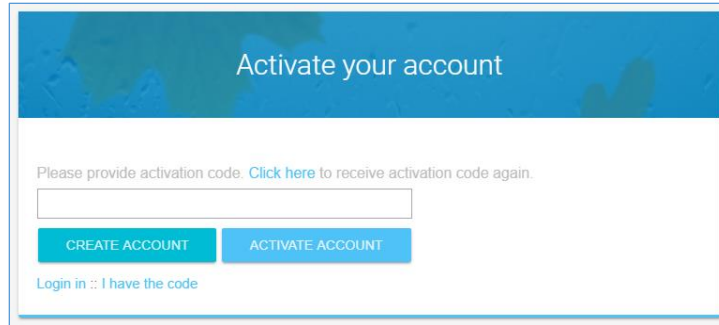


Figure 5. Activation page of the IDF_CC tool

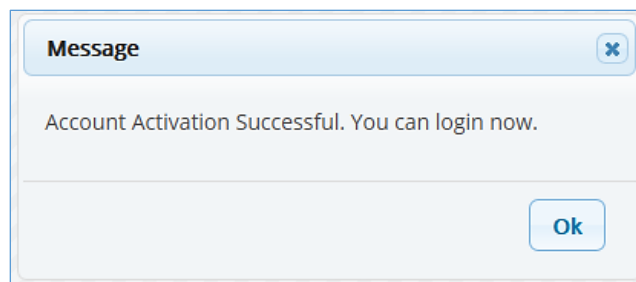


Figure 6. Message of account successfully activated and ready to use

2.2 Login and Password

After the account is created and activated, the user will be able to login using the email and password previously provided (Figure 7). The user can recover their password by using the “Recovery” option. A new password will be provided to the user by email as illustrated in Figure 8.

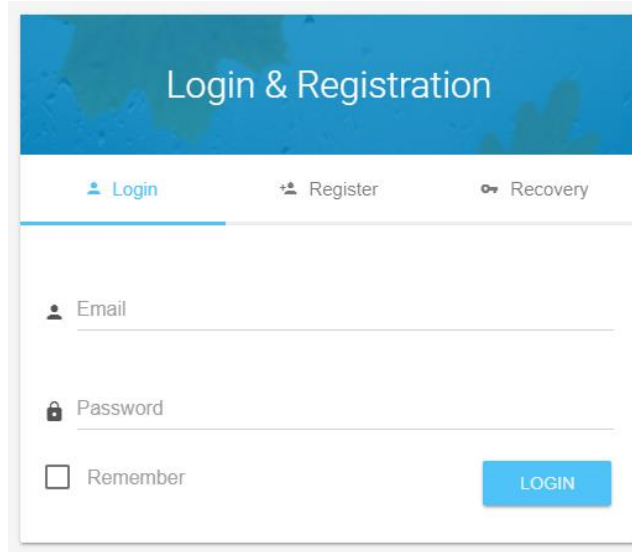


Figure 7. Login page

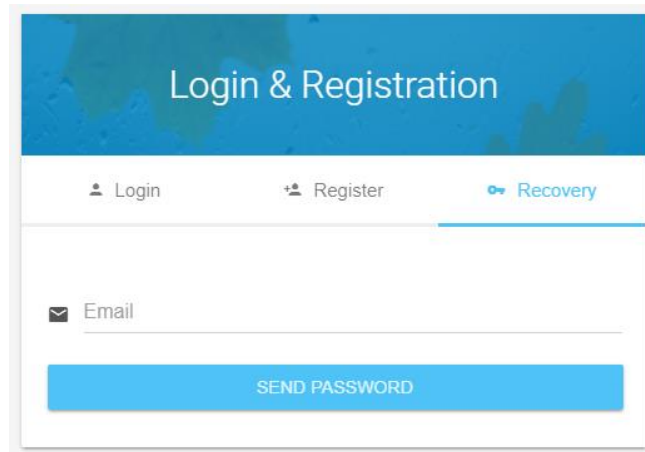


Figure 8. “Recover Password” screen

2.3 Main Page Description

After login, the main page is presented to the user (Figure 9). At the top portion, or header, a logo, the name of the tool, menu items, and user name are presented. The middle section is where information and maps are displayed. These functions will be described throughout this manual. The lower part, or footer, presents information and logo from the institutions involved in the development of the IDF_CC tool.

On the top left of the header, the name of the user is presented, as shown in Figure 10. By clicking on the user's name, the user is able to update account information as shown in Figure 11 and change password as shown in Figure 12.

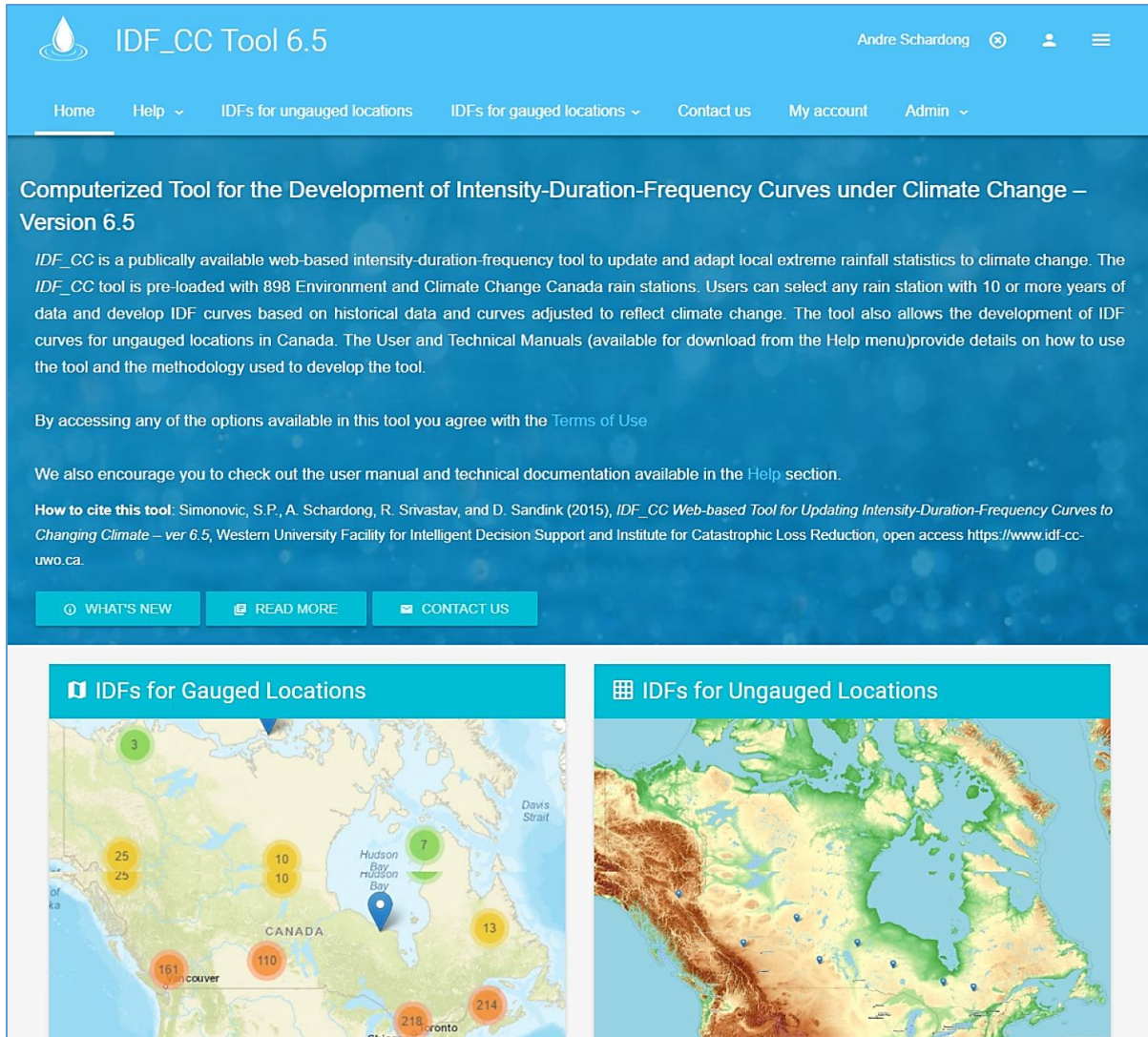


Figure 9. Main page screenshot



Figure 10. Logged user information

Update Password and Account

[Update password](#) [Update account](#)

Name
Andre Schardong -gmail

Affiliation
UWO

Occupation/Job
Student

Intent of use
Research

UPDATE ACCOUNT

Figure 11. Updating user information

Update Password and Account

Update password Update account

Current Password

New Password

Re-type New Password

UPDATE PASSWORD

Figure 12. Updating password

2.4 Menu Options

The menu options, as presented in Figure 13, are briefly described below:

- Home: description of the tool and home screen.
- Help: user manuals and additional resources.
- IDFs – ungauged locations: this option presents a map allowing the user to select any location (coordinates) in Canada to obtain the corresponding IDF.
- IDFs - gauged locations: this option presents the map and stations from Environment Canada and those created by the user.
- Stations and Data: this item opens a list of stations created by the user and allows them to select data, upload companion files, share with other users, delete and create stations. This page also allows users to see all stations from Environment Canada, as well as open the IDF screen.

- Help, FAQ and Terms of Use: provides access to help documents including the User Manual, *TechMan*, and other references, frequently ask question section – FAQ and terms of use of the IDF_CC tool.
- Contact us: contact form of the tool to send comments, report bugs and other issues.
- Admin Menu: this item is only available to IDF_CC tool’s administrator(s).



Figure 13. Main menu items

2.5 IDF curves for Gauged locations

2.5.1 Exploring Map Functionalities

The IDF_CC tool uses a GIS based map tool (Leaflet) to assist the user in locating stations and performing other map related operations (Figure 14). This map shows all stations available from Environment Canada and additional user-created stations. Regions with higher station coverage are grouped (depending on the zoom level) and shown as dots. The number inside the dot is the number of stations in that region. The colours indicate station density (green for lower density, to orange for high density). As users zoom in on a specific region of the map, stations are shown individually, as presented in Figure 15. Stations created by the user are presented with an icon in green while those from Environment Canada are shown in blue, and station with less than 10 years of data in grey (Figure 15).

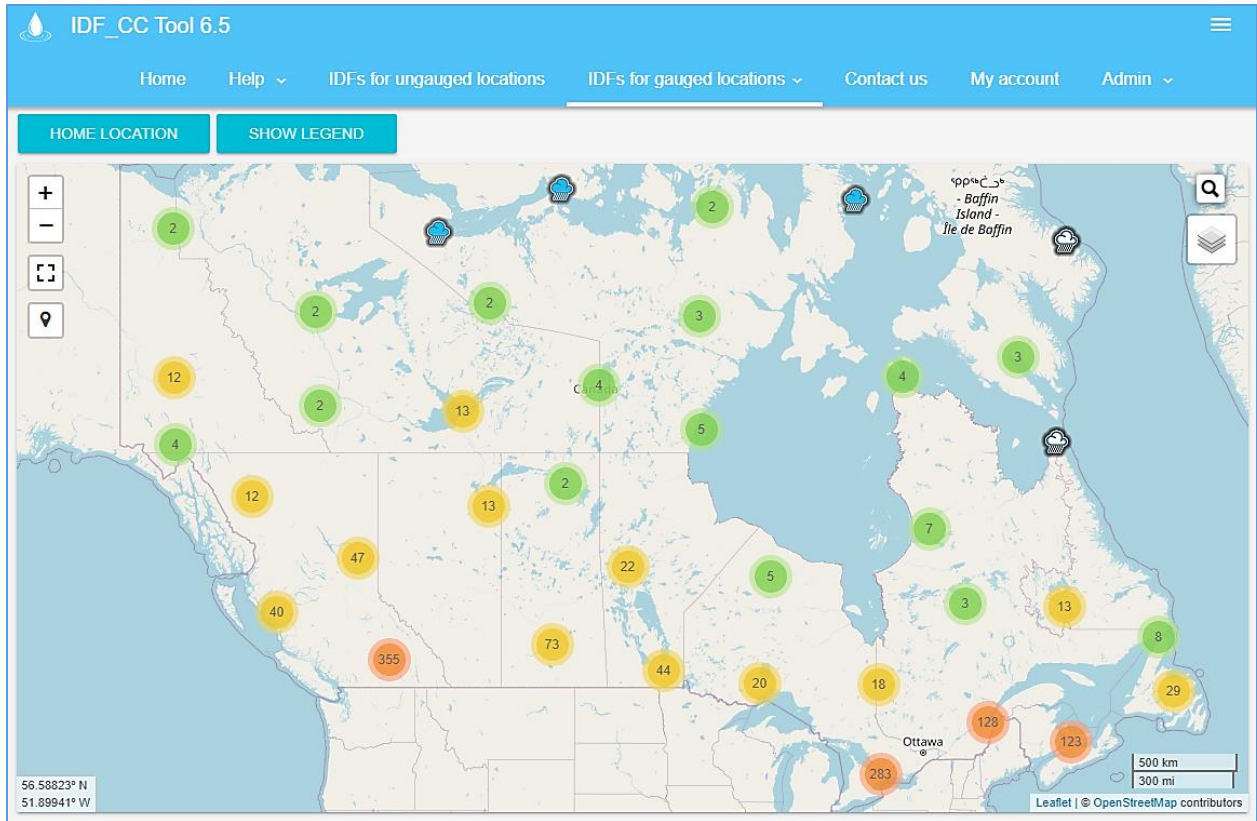


Figure 14. Screenshot with map of Canada showing stations from Environment Canada and/or user provided stations

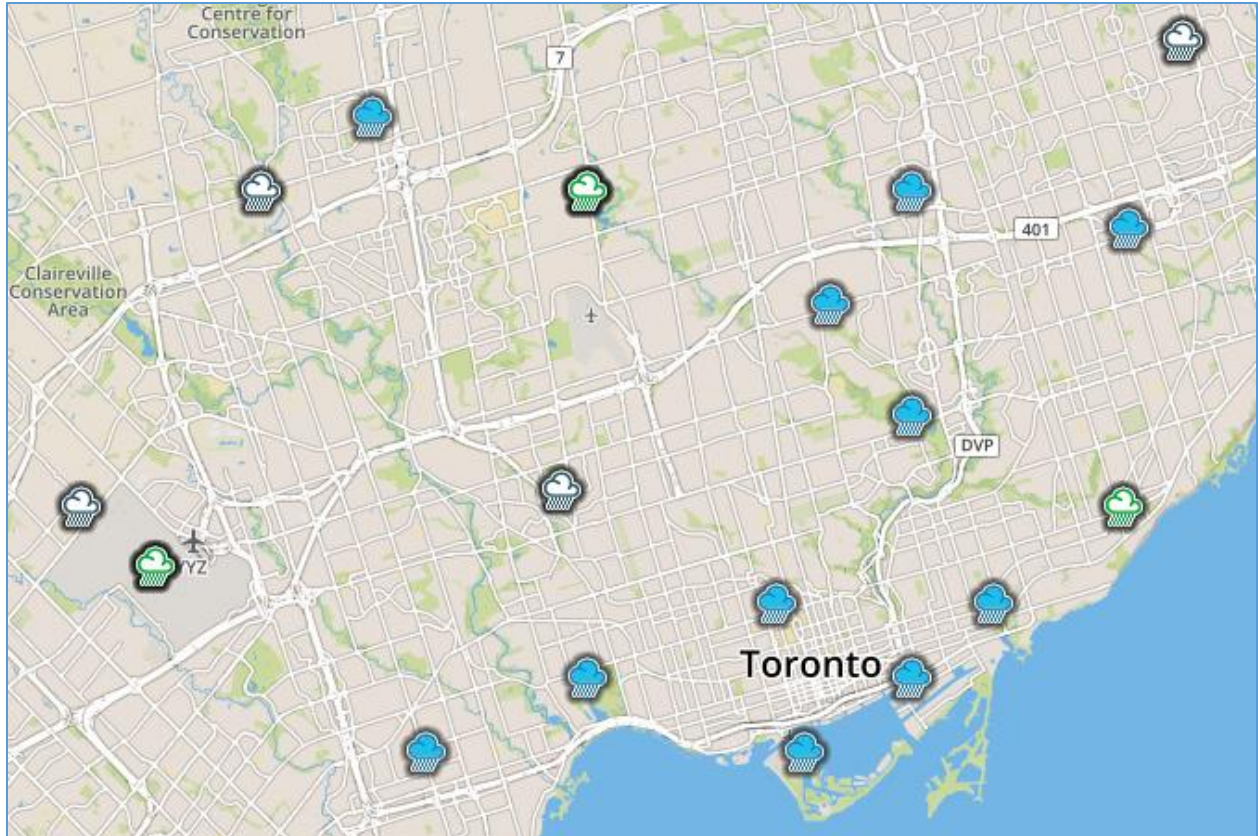


Figure 15. Stations map: Environment Canada (blue), user provided (green), and stations with less than 10 years of data (grey).

2.5.1.1 Locating an Existing Station on the Map

The stations can be visually located on the map or the user can search for stations using the search icon located in the top right corner of the map screen. As the user types in the box, the list of station names is searched and filtered based on the text provided, as in Figure 16. If one of the filtered stations is selected by the user, the map is zoomed-in and centered on the selected station (Figure 16).

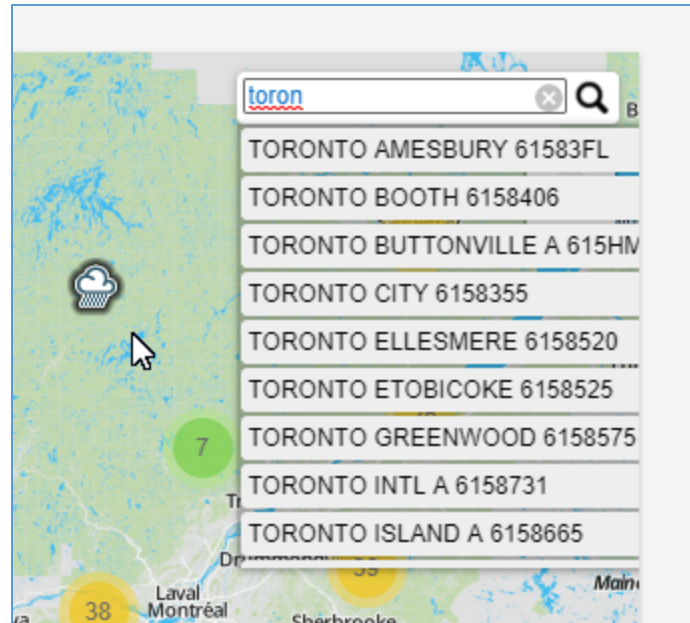




Figure 16. Additional options of the IDF_CC tool map

In the top right corner over the map screen, some additional functions are available, as shown in Figure 17 and Figure 18. These functions include:

- Show/Hide Legend
- Home Location: the IDF_CC tool allows user to set a home location by right clicking on a specific location on the map and selecting option “Set as Home Location” as shown in Figure 19. Home location is also where the map will open after login, once it is set.
- Current Location : the IDF_CC tool will try to obtain the user’s current location using “Geo Location.” A blue dot is placed on the location if found as in Figure 18. The user will also be asked to allow this operation (the web browser will present this request and the message may vary depending on the browser).
- Full Extent : shows the entire map of Canada as in Figure 18.

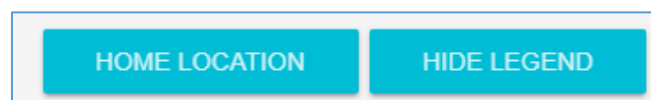


Figure 17. Additional options on the IDF_CC tool map

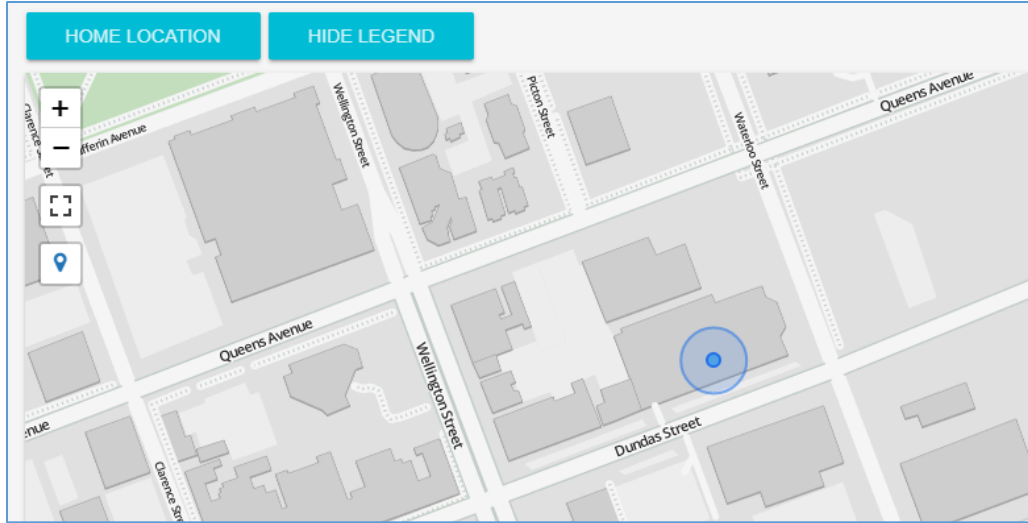


Figure 18. Current location

By right-clicking on the map a context menu will be presented as in Figure 19. One of the options is “set as home location” that will store this location as the “home location” for the logged user. “Center map here” centres the map on the selected location. “Show coordinates” will present the coordinates of the point on the map selected, “Create station here” will open the pop-up window for creating a new station. This option will be explained later in the manual. The advantage of creating a station from the map is that it will automatically provide the coordinates and location (city and province) of the station on the map.

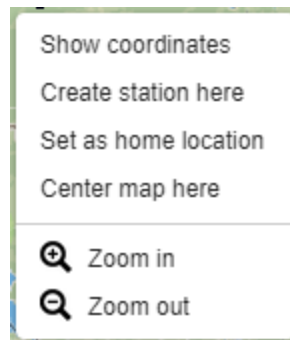


Figure 19. Context menu option on the map

2.5.1.2 Background Options for Maps

The tool provides eight different options for the map backgrounds that differ in the level of detail. The options are:

- No map: no background map is shown when this option is activated.
- OpenStreetMap: the tool's default base map. Presents details like street names and points of interest. The example map is presented in Figure 20.
- Clean: simplified map with only major points of interest and no labels are shown. The example map is presented in Figure 21.
- Simplified: simplified map with only major roads and major points of interest. The example map is presented in Figure 22.
- Image: satellite images (arterial view) from ESRI © (Figure 23).
- Water colour: simplified map, with minimal details - roads and points of interest. Water bodies are presented in blue and land as light brown (Figure 24).
- Grey: Light grey map with minimum details (Figure 25).
- OpenTopoMap: combines topology and OpenStreetMap (Figure 26).

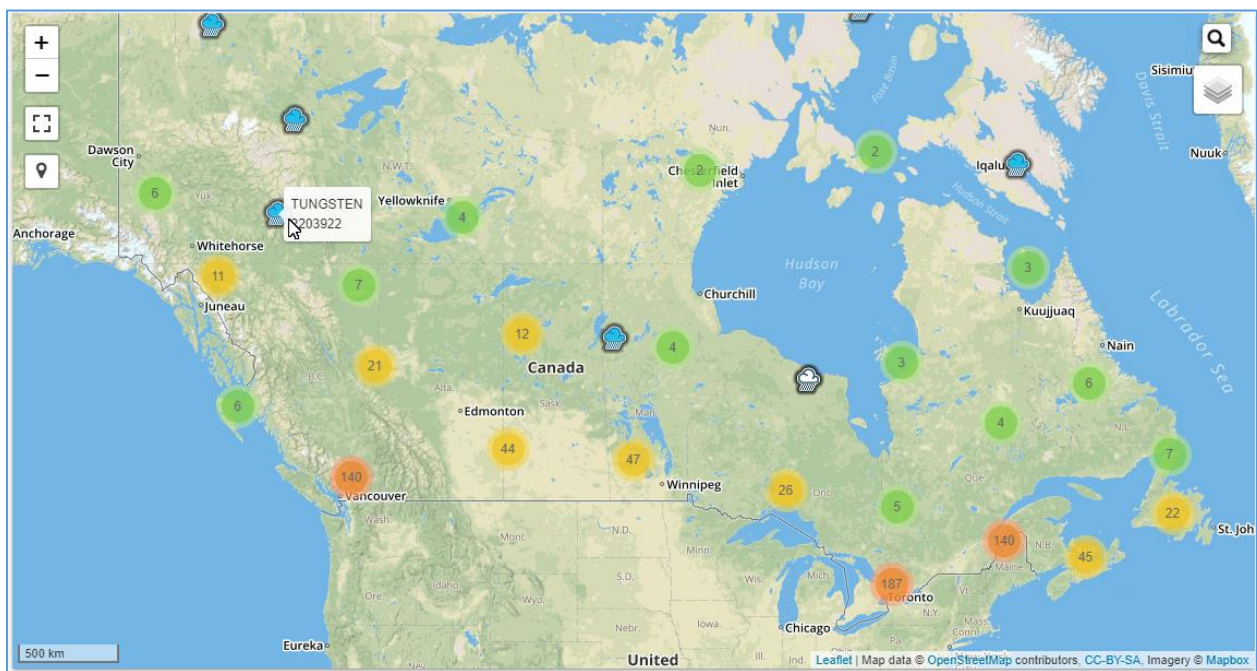


Figure 20. OpenStreetMap (IDF_CC tool's default)

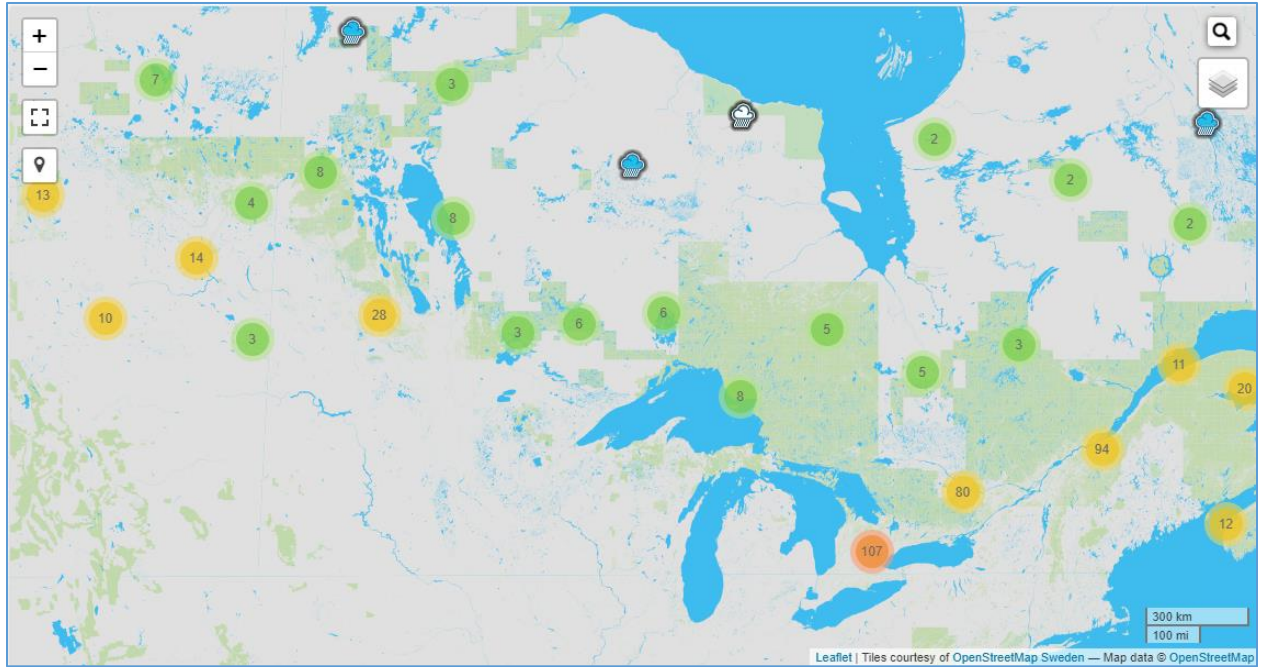


Figure 21. Clean background map

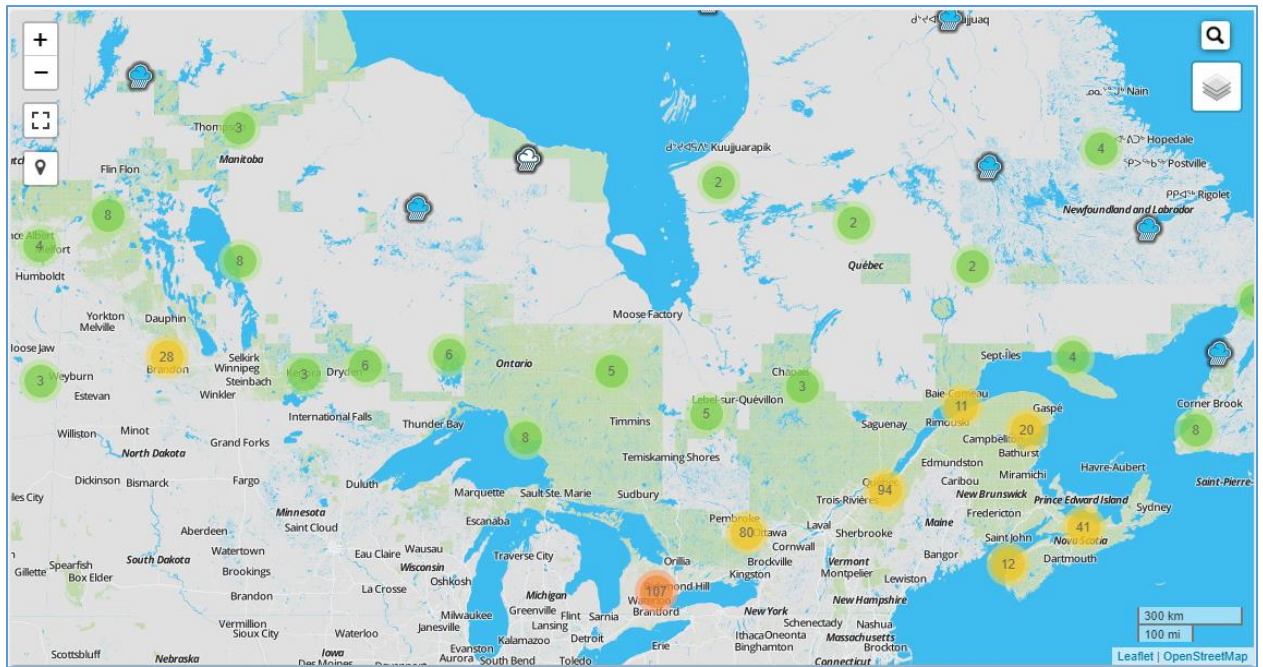


Figure 22. Simplified background map

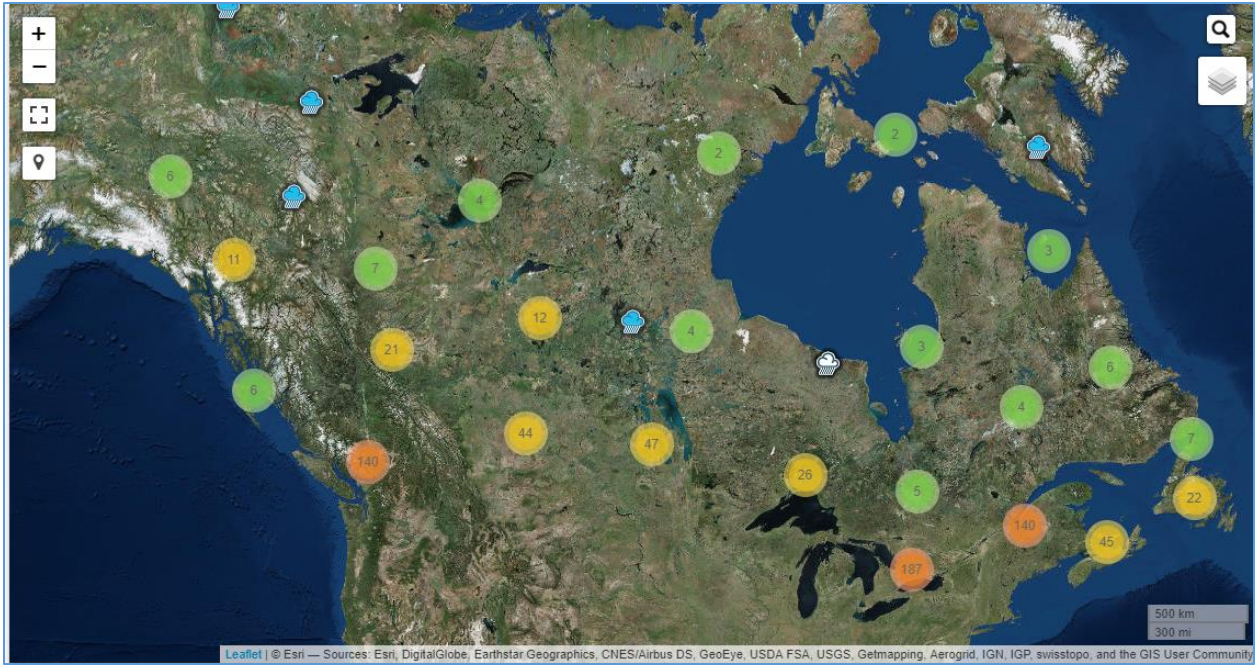


Figure 23. Arterial view background map – ESRI imagery

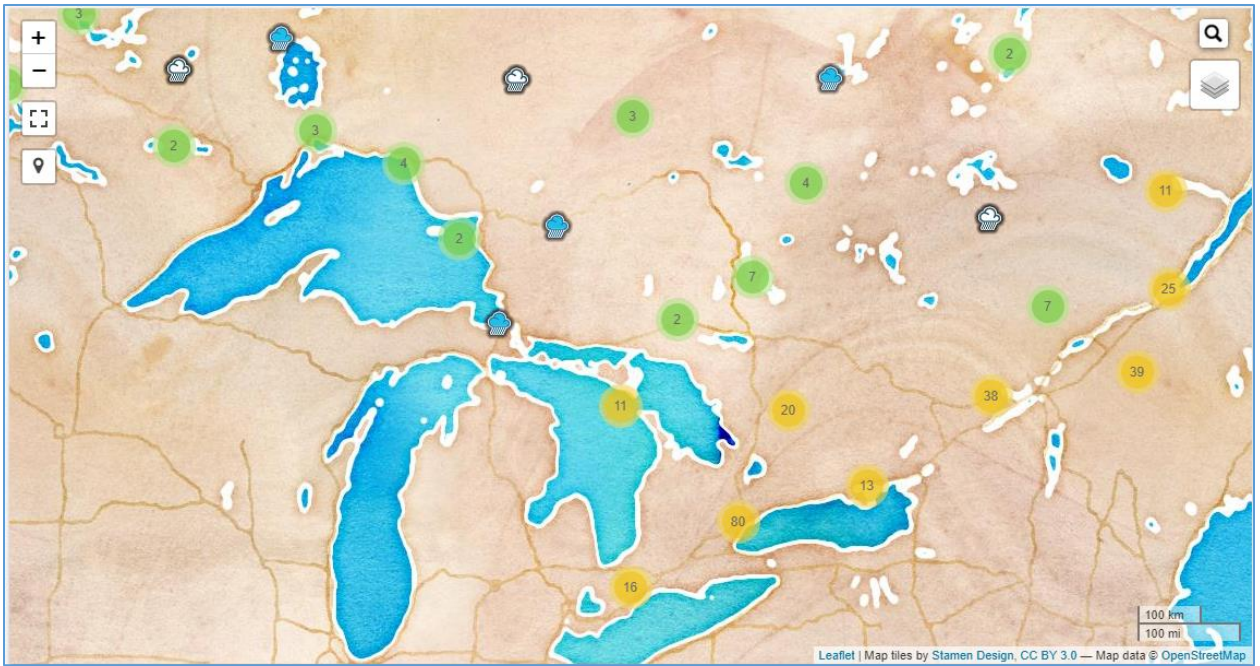


Figure 24. Water colour background map – ESRI imagery

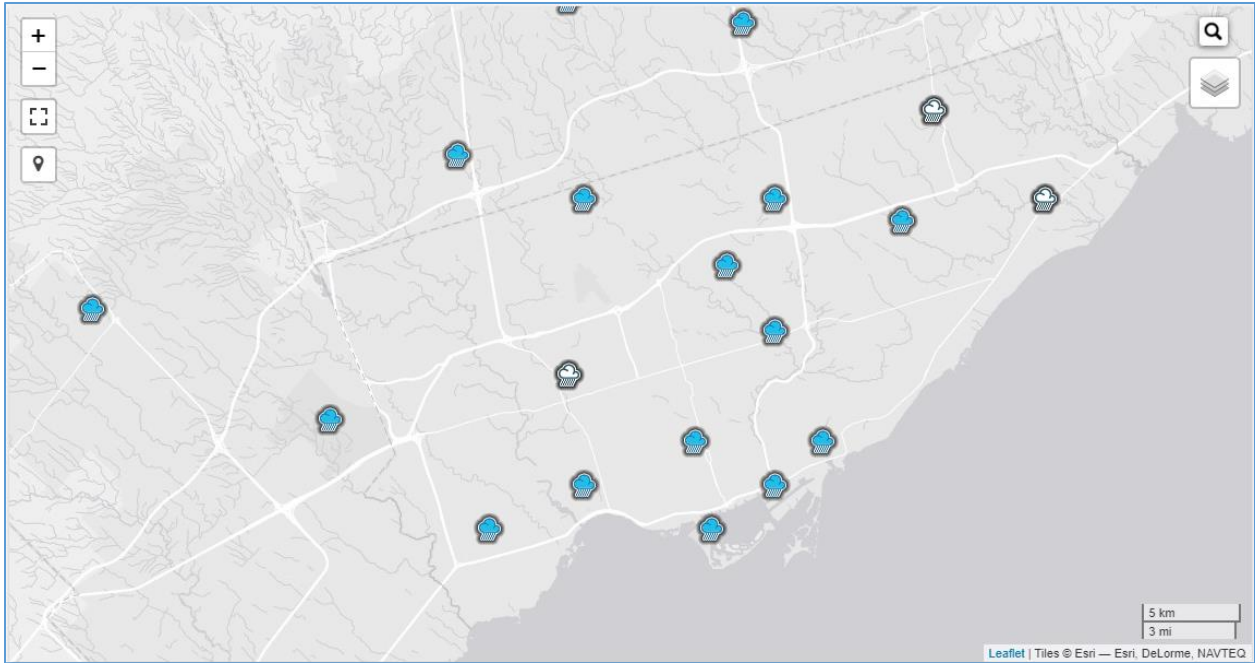


Figure 25. Grey background map – ESRI imagery

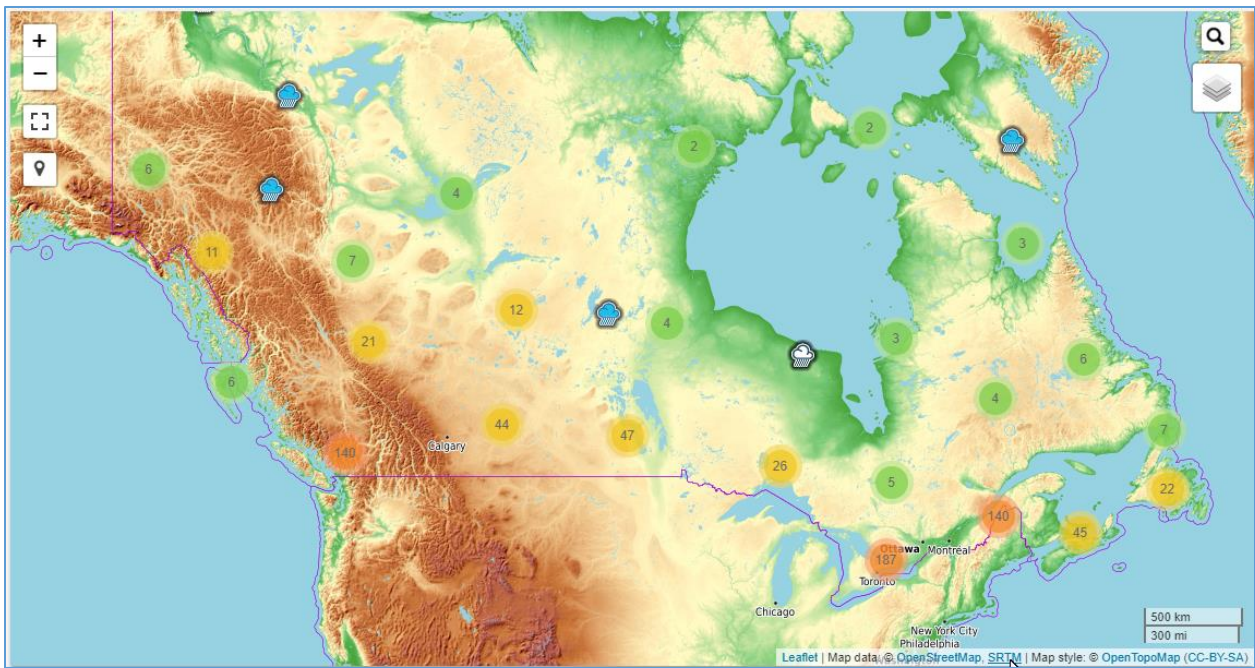


Figure 26. OpenTopoMap background map

The map also presents the source of the background map in use and the scale of the map, as shown in Figure 27.



Figure 27. Map source and map scale

2.5.1.3 *Creating Stations on the Map*

Another function on the context menu (activated by right click on the map) is “create station here” that can be used to create a station at the selected location. This option will open a new popup window with the new station page as presented in Figure 28. Using this function, some information will be automatically filled in for the user: latitude and longitude (in degrees), city and province (Figure 28).

Other information to be provided by the user to create a station includes:

- Name (required): station name.
- Station ID (required): unique ID has to be provided. The IDF_CC tool will check if provided ID is already in use.
- Description (optional): a description of the station.
- Sub-daily Maximums (required): the sub-daily precipitation maximums used or considered in the analysis. The defaults selected are: 5, 10, 15, 30 minutes, 1, 2, 6, 12, 24 hours.
- Additional Information (optional): any other relevant additional information about the station.
- City and Province (optional): city and province of the station location.

Create a new station

General information	Location
Station name* <input type="text"/>	Latitude (Ex: 40.70 for 40°42' N)* <input type="text" value="42.99761672705504"/>
ID* <input type="text"/>	Longitude (Ex: -80.30 for 80°18' W)* <input type="text" value="-81.22982025146484"/>
Province <input type="text" value="Ontario"/>	Elevation (in m, ex: 100.25) <input type="text"/>
City <input type="text" value="London"/>	Additional location information <input type="text"/>
Description <input type="text"/>	Select sub-daily maximums for this station <input checked="" type="checkbox"/> 5 min <input checked="" type="checkbox"/> 10 min <input checked="" type="checkbox"/> 15 min <input type="checkbox"/> 20 min <input checked="" type="checkbox"/> 30 min <input checked="" type="checkbox"/> 1 hr <input checked="" type="checkbox"/> 2 hr <input type="checkbox"/> 3 hr <input checked="" type="checkbox"/> 6 hr <input checked="" type="checkbox"/> 12 hr <input type="checkbox"/> 18 hr <input checked="" type="checkbox"/> 24 hr
<input type="button" value="Create station"/>	

Figure 28. Creating a station on the map

Create a new station

General information	Location
Station name* <input type="text"/> <div style="border: 1px solid gray; padding: 2px; display: inline-block;">Name is required ✕</div>	Latitude (Ex: 40.70 for 40°42' N)* <input type="text"/> <div style="border: 1px solid gray; padding: 2px; display: inline-block;">Latitude is required ✕</div>
ID* <input type="text"/> <div style="border: 1px solid gray; padding: 2px; display: inline-block;">ID is required ✕</div>	Longitude (Ex: -80.30 for 80°18' W)* <input type="text"/> <div style="border: 1px solid gray; padding: 2px; display: inline-block;">Longitude is required ✕</div>

Figure 29. Required input for creating a station








The user created station will be plotted on the map based on the provided coordinates. The coordinate system used is the World Geodetic System (WGS) also known as WGS 84 or EPSG 4326.

Stations created by users are visible only to the creators. The creator can share and make the station accessible to other users within the tool. Please see Section 2.6 for more detail.

The next section explains how to provide data for a station, generate the IDF's for historical and future periods, share stations and upload files.

2.5.1.4 Legend

The legend helps the user identify elements on the map. The elements are quickly described below. The legend becomes visible on the screen by selection “Show legend” option, as presented in Figure 30. The list of items are:

-  Regions with low density of stations (between 1 and 9)
-  Regions with medium density of stations (between 9 and 99)
-  Regions with high density of stations (above 100)
-  Stations created by the user
-  Stations from Environment Canada
-  Stations with less than 10 years of data
-  Stations shared with the user

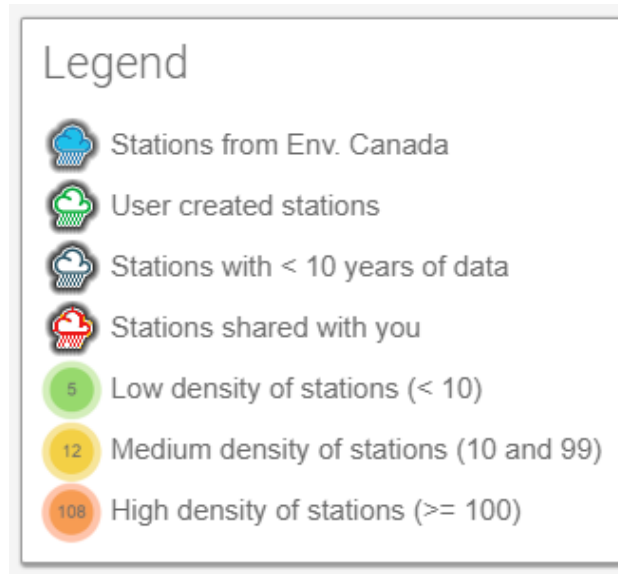


Figure 30. Legend

2.5.2 Managing Stations and Data

The user can access stations from the tool's map view. Additionally, the "Stations and Data" option from the main menu will open a station page as shown in Figure 31. This page will show all stations created by the user and allow (i) precipitation data editing, (ii) uploading files, and (iii) sharing the station with other users. These options are presented as tabs in Figure 31.

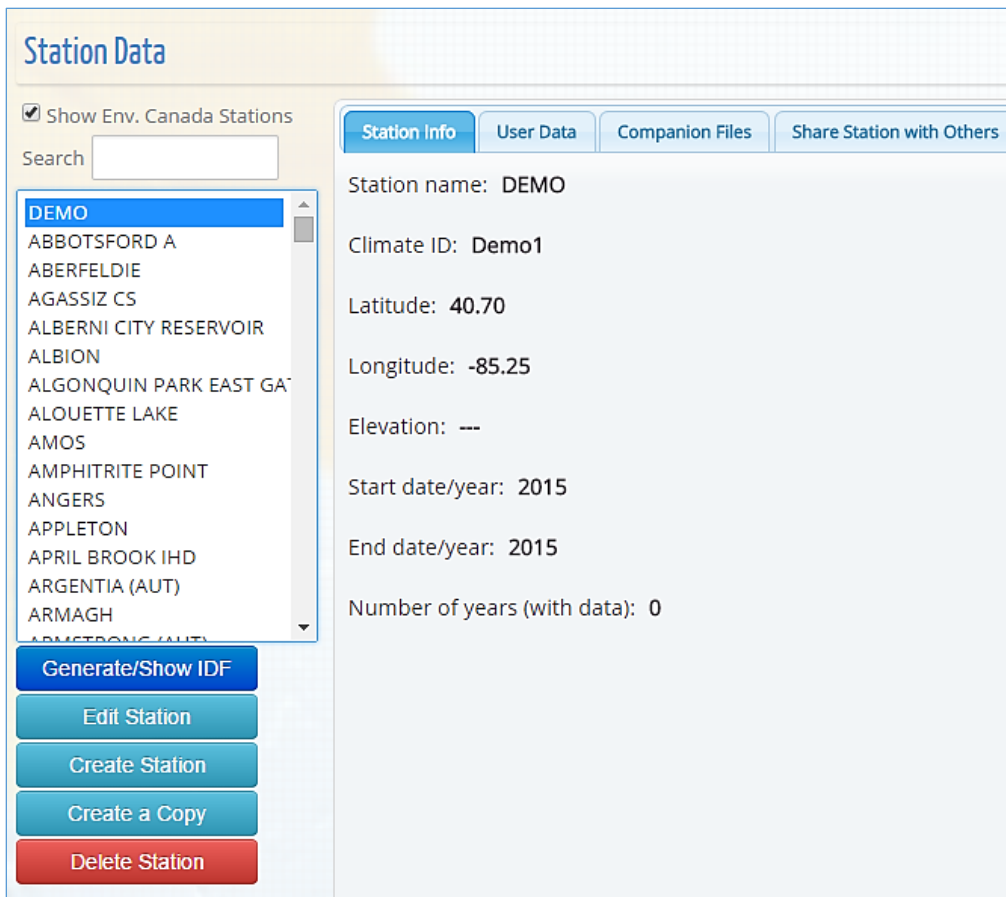


Figure 31. Station page: precipitation data editing, uploading files and sharing

The station list will only include stations created by the logged-in user and those shared with the user by other users, as in Figure 32. The user can search the list of stations by typing text within the search textbox above the list. A checkbox “Show Env. Canada Stations” allows user to see all stations in the database from Environment Canada, as shown in Figure 33. Stations that are shared as full access with the logged-in user will be identified with “(full access)” after the station’s name, as in Figure 32. If the other user shares the station as read-only, the “(read-only)” will be added instead of “(full access)”. For more information on sharing user generated stations and station data, see Section 2.6.3.

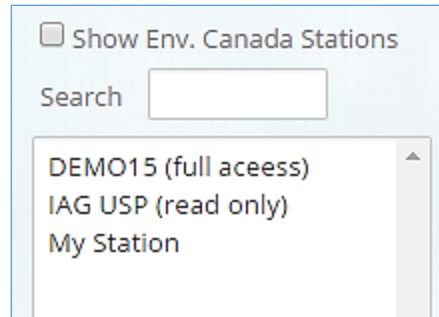


Figure 32. User created stations

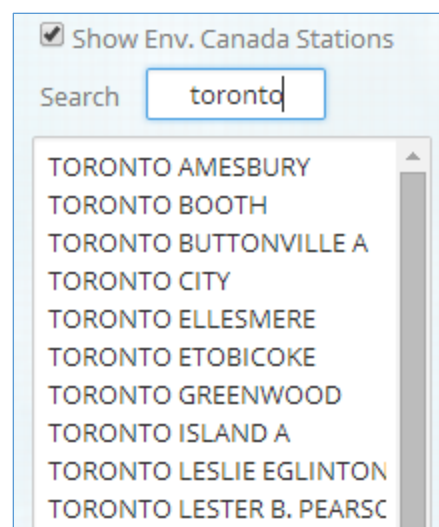


Figure 33. Stations from Environment Canada

Below the list of stations, a few additional functions are available when a specific station has been selected from the list, as illustrated in Figure 34:

- “Generate/Show IDF”: generates and shows the IDF curve and presents the page for updating IDF curves for future climate conditions. The user can also perform these functions by selecting a station on the map.
- “Edit Station”: allows user to edit station’s basic information (location, name, ID, etc.).
- “Create Station”: allows user to create a new station, and serves as an alternative to creating a station by right clicking on the map. When using this approach for creating a new station, no information about coordinates and location (city/province) will be provided and the user will have to provide this information manually.

- “Delete Station”: allows user to delete station and all associated data, and serves as an alternative to deleting the station directly from the map.
- “Create a Copy”: allows user to copy a station to their account. Users can copy stations from Environment Canada and add or modify data. Similar to user created stations, copied stations can be deleted and edited by users.



Figure 34. Options available for a selected station on list

When the selected station is from an official source (e.g., Environment Canada), the “Edit Station” and “Delete Station” options will not be available, as shown in Figure 35.

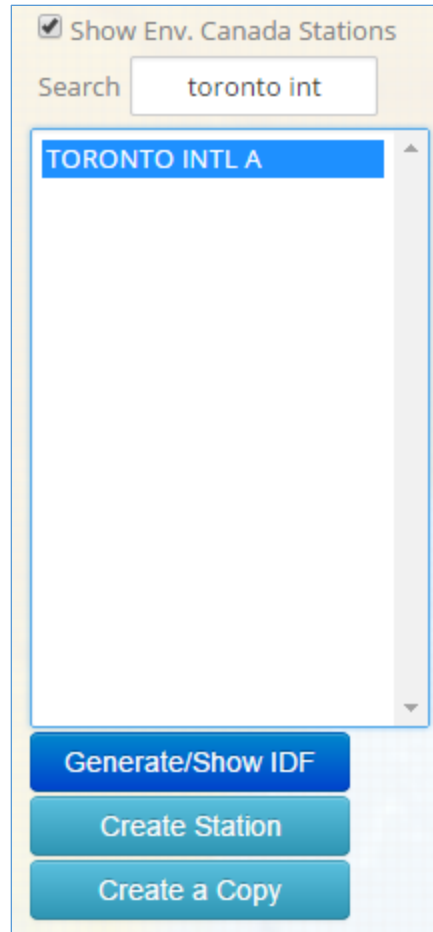


Figure 35. Users are not able to delete or edit station data for stations from official sources, including Environment Canada

Selecting (clicking) one station from the list will enable the *Tabs* on the right side of the page, as shown in Figure 36. Each *Tab* is described as follows:

- Station Info: basic station information, name, coordinates, ID
- User Data: data provided by the user. This is presented in detail in section 2.6.1.
- Official Data: data from Environment Canada. No editing is possible and the yearly sub-daily precipitation maximums are presented as “read only” data to the user.
- Companion Files: allows user to upload or download supporting files (see Section 2.6.2).
- Share Station: share station with other users registered with the IDF_CC tool (see Section 2.6.3).

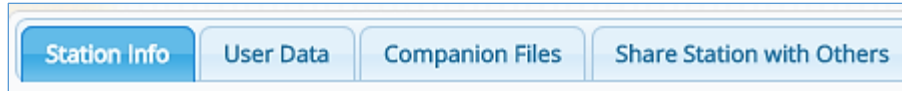


Figure 36. List tabs available on the station data page.

2.5.3 Preparing and Providing Data for User-Created Stations

The IDF_CC tool allows users to provide precipitation data in two formats: daily sub-daily maximums or yearly sub-daily maximums (Figure 37). When selecting the option “Daily Maximums” the starting and ending date for the precipitation series is requested. Once the date range is defined the “Change Dates” button, when selected, will prepare the spreadsheet and allow the user to provide precipitation data within the specified range. As shown in Figure 37 the dates are shown continuously from start to the end date. Days without precipitation events can be left blank (null) or with negative values. In the processing steps the IDF_CC tool’s algorithms will ignore null or negative values. It is recommended that the user prepare data using a spreadsheet processor, like Microsoft Excel™, and then copy data into the IDF_CC tool by using Ctrl + C (to copy) from Excel and Ctrl + V (to paste) into the IDF_CC tool’s spreadsheet. After the data is pasted into the spreadsheet, it can be saved to the database by selecting “Save Daily Data”. Other data formats can also be used, such as formatted text files. Excel spreadsheets and text files (Figure 38) should be organized in columns, where each column represents a sub-daily maximum following the order in the IDF_CC tool’s spreadsheet (Figure 37). The user will need to provide data for sub-daily durations specified in station information (i.e., 5min, 10min ... 1hr, 2hr ... 24h), otherwise the IDF_CC tool will neither be able to fit the IDF curves nor to update them.

Select the type of data you would like to use for IDF generation:

Daily maximums Yearly maximums

Daily maximums Yearly maximums

Starting date Ending date **Apply** (use dd/mm/yyyy format)

Save Daily Data

Date (yyyy-mm-dd)	5 min	10 min	15 min	30 min	1 hr	2 hr	6 hr	12 hr	24 hr
2015-02-01									
2015-02-02									
2015-02-03									
2015-02-04									
2015-02-05									
2015-02-06									
2015-02-07									
2015-02-08									
2015-02-09									
2015-02-10									
2015-02-11									
2015-02-12									
2015-02-13									
2015-02-14									

Figure 37. Editing/saving sub-daily daily maximums

Data.txt - Notepad

File	Edit	Format	View	Help					
7.6	11.7	15.2	18.5	21.3	22.4	33.8	39.4	41.4	
10.4	16	21.8	24.6	25.9	27.7	34.3	36.1	41.7	
9.4	11.7	14.5	22.9	31.2	33.8	80.8	110.7	137.4	
7.1	11.7	15.7	20.3	20.6	20.6	35.1	52.8	58.7	
11.9	17.8	21.1	24.4	24.6	30	46	46.5	46.7	
7.4	10.2	13	17.8	21.3	28.7	46	53.8	54.1	
5.8	6.1	6.1	8.1	8.9	11.2	20.3	30	32.3	
7.1	8.4	8.6	9.9	10.4	14	22.4	27.9	29.5	
6.1	11.2	13.5	17.8	27.2	38.6	43.9	43.9	43.9	
9.4	10.7	11.2	17	19.6	24.6	30	33.5	33.5	
17	20.8	23.4	31.5	32.5	33	46.2	80.3	88.9	
10.7	14.2	19.8	21.8	22.4	33.5	33.8	37.1	38.4	

Figure 38. Formatting data in text files to paste on the IDF_CC tool's website

When yearly sub-daily maximums are available, they can be entered into the system instead of daily data (see Figure 39). Starting and ending year are required for yearly sub-daily maximums. After defining the range and applying changes with the “Change Years” menu button, the spreadsheet will be ready to receive data. Data can also be copied using Microsoft Excel™ or formatted text files. Each column represents one sub-daily duration. Users are requested to provide data for sub-daily durations (i.e., 5 min, 10 min, 15 min, 30 min, 1hr ... 24hr) specified in the station information otherwise the IDF_CC tool will neither be able to fit the IDF curves nor update them.

Select the type of data you would like to be used for IDF generation:
 Daily Maximums Yearly Maximums

Starting Year (yyyy) Ending Year (yyyy)

Year	10 min	20 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr
1931	10.1	17.7	25.0	37.5	68.4	90.4	116.6	116.6	116.6
1932	11.7	21.7	26.5	32.1	32.1	32.1	35.6	35.6	35.6
1933	11.7	16.5	16.6	27.0	32.9	36.6	45.1	45.7	65.4
1934	16.9	19.3	21.6	29.0	35.9	38.7	38.7	38.7	58.6
1935	15.0	23.0	26.3	31.0	36.2	36.5	44.5	54.7	56.4
1936	11.3	17.9	20.2	23.4	29.6	35.5	43.9	60.5	60.5
1937	22.0	39.0	50.7	55.9	56.4	56.4	56.6	56.6	83.0
1938	8.3	16.6	19.8	24.7	42.2	47.9	54.2	72.2	86.6
1939	16.9	17.1	18.5	28.7	28.9	29.0	39.5	50.2	51.5
1940	12.1	21.7	27.8	44.8	55.3	57.4	61.2	61.2	79.4
1941	14.1	23.5	29.4	39.3	54.0	55.2	55.5	55.5	59.0
1942	12.0	19.6	25.1	39.7	46.4	49.0	50.7	66.3	67.3

Figure 39. Saving/editing sub-daily yearly maximums

2.5.4 Companion Files

Additional files can be uploaded and downloaded for each station using the “Companion Files” tab. The types of files that can be uploaded include documents, spreadsheets, text and PDF files. These files will be available for download by the user who created the station and users with

which the user has shared the station. Shared users will have either full access or read only access as specified by the user who created and shared the station (Figure 40). The file name, file size, and file type (icon) are also presented in the *Tab*. Users may delete uploaded documents by selecting the red “x” in the last column, if authorized to do so.

This section is reserved to upload and download files (documents, spreadsheets, text, data) that may support the data and IDF for this station

Select Files to Upload















File Name	Size	Type	Action
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.pdf	46.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.png	159.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS.txt	11.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_qq.pdf	70.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_qq.png	187.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_r.pdf	72.0 KB		
idf_v2-2_2012_02_09_614_ON_6144478_LONDON_CS_r.png	242.0 KB		

Figure 40. Uploading files

2.5.5 Sharing User Created Stations

The “Share Station” *Tab* allows the user to share their user created stations with other users as illustrated in the Figure 41. There are two different levels of access: 1) “Full Access” allows the user to change data and information and view historical and updated IDFs; and 2) “Read Only” allows read only access to the specific station. This type of access will allow users who have been granted access to the station to view and generate updated IDFs, but will not allow these users to edit or delete station data. The station is shared providing the email of the person with whom the user would like to share the station. If the email is associated with an account already registered within the Tool’s database, the user will only receive an email with an invitation to view the station. If the email is not registered, a temporary account will be created and on the first access the user will need to complete their registration for an account (requiring Name, Email, Affiliation, etc.). The creator of the station

can also change editing/viewing permissions for users with which they have shared stations using the “Remove shared” option.

Please type the email of the person with which you would like to share this station. You may make the station available as “read only” preventing the shared user from editing the data, or you may grant the user “full access” so they may view and edit the station data.

Email:

Station shared with:

Name	Email	Access Level	
[Please Update your name]	abcde@gmail.com	Read Only	Remove Shared
Test User	schardongandre@gmail.com	Read Only	Remove Shared
[Please Update your name]	acdfsadfa@gmail.com	Read Only	Remove Shared
[Please Update your name]	acdfsadfadfa@gmail.com	Read Only	Remove Shared
Andre Schardong -uwo	aschardo@uwo.ca	Read Only	Remove Shared
[Please Update your name]	fadskfjsadkf@gmail.com	Full Access	Remove Shared

Figure 41. Sharing stations with other users

2.6 IDF curves for Ungauged locations

The version 6.5 of the IDF_CC tool includes and ungauged site gridded IDFs module. This module allows the user to obtain IDF curves for any location in Canada.

The IDF_CC tool uses a GIS based map tool to assist the user in selecting locations (coordinates) to obtain the gridded IDFs (Figure 42). By clicking on the map, the IDF_CC tool will select the nears grids to the selected location, and its corresponding IDF estimates, interpolate and present the result to the user. An example of an IDF for a location selected form the Map is presented in Figure 43 (coordinate) and Figure 44 (IDF estimates).

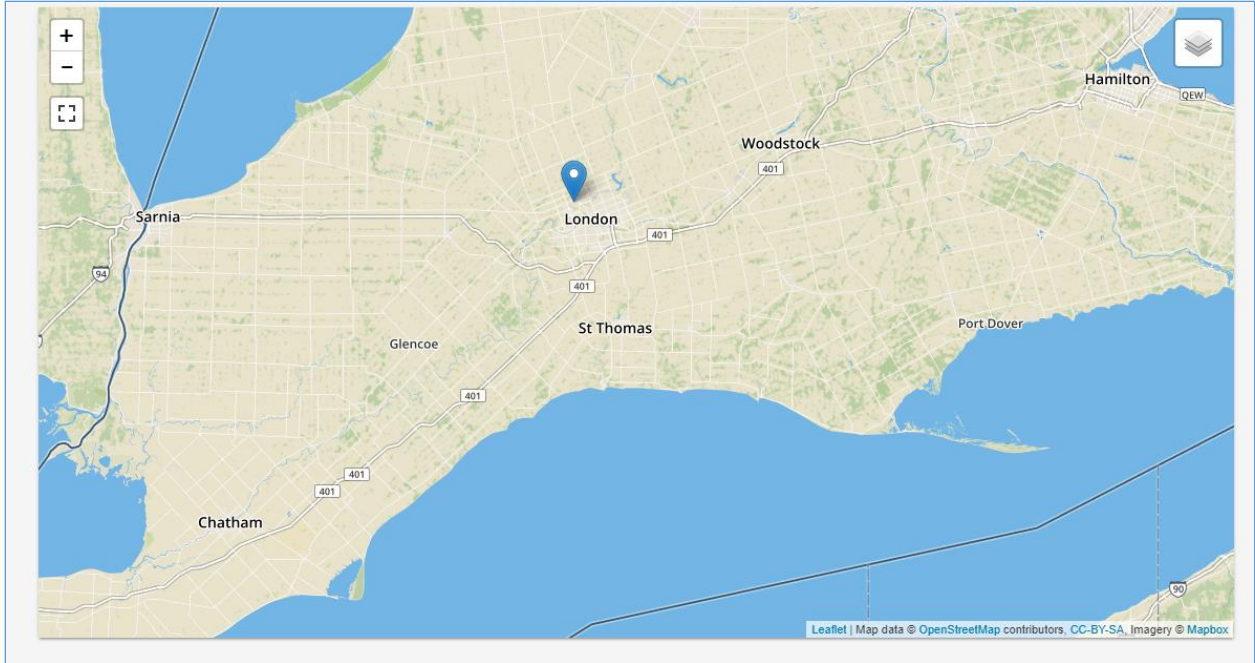


Figure 42. Screenshot with map of Canada showing stations from Environment Canada and/or user provided stations

Gridded IDF for: Lat: 43.26521 °, Lon: -80.75912 °

Station Info IDF, historical data ? IDF under climate change ?

Station name: Gridded IDF

Gridded IDF for the following coordinates:

Latitude: 43.26521 °

Longitude: -80.75912 °

Figure 43. Example of the coordinates for the selected location from the Map

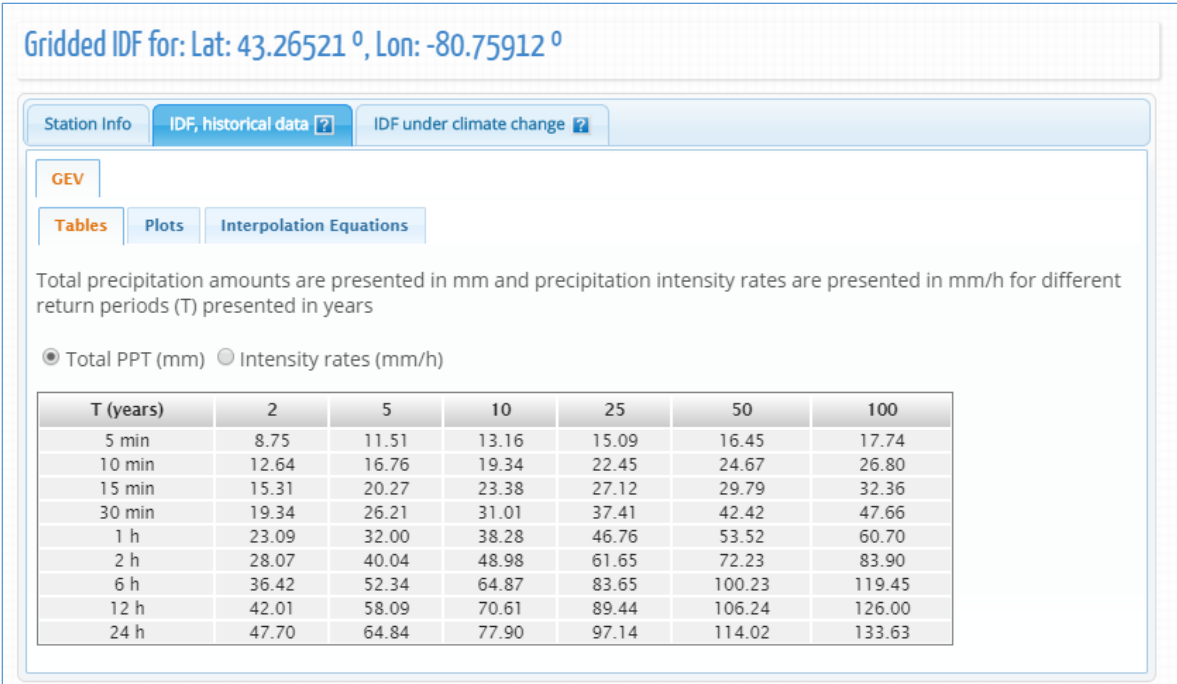


Figure 44. IDF table estimates for the selected coordinates from the Map

3 Development and Updating of IDF Curves

The IDF_CC tool allows users to simply generate and view IDF curves for any hydro-meteorological station. By selecting a station from the map or using the option “Generate/Show IDF” option described in the previous section, a new pop-up window appears (Figure 45). The first tab (“Station Info”) presents the name, ID, location and information and record lengths for the station. The other two tabs, “IDF, historical data” and “IDF under climate change” are described in sections 3.1 and 3.2, respectively.

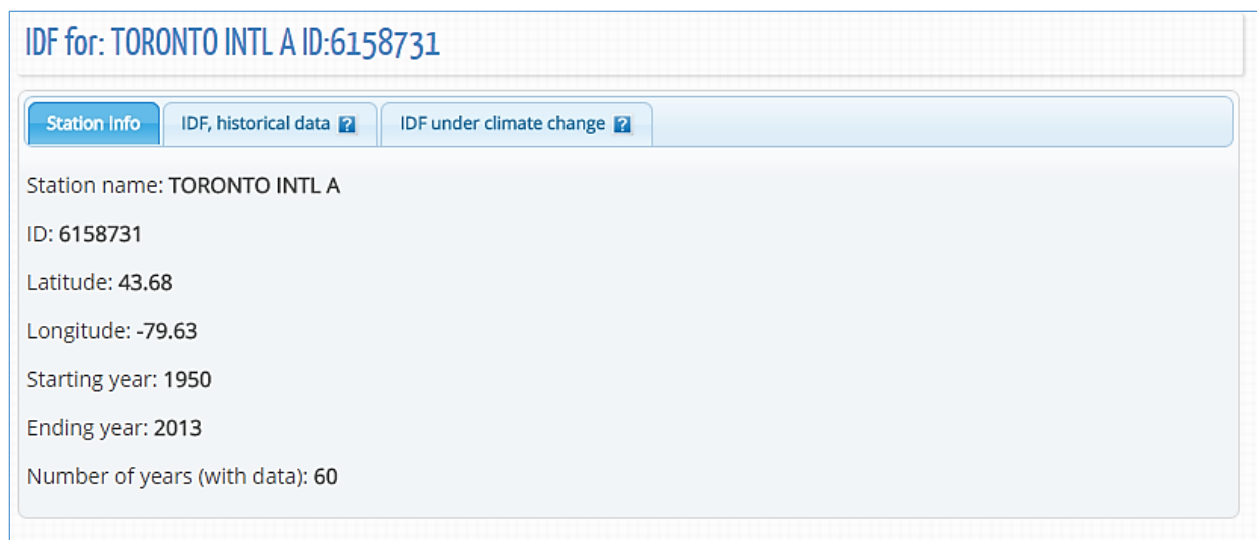


Figure 45. IDF_CC tool page with station information, historical and future IDF

3.1 IDF curves for Gauged locations

When the user requests to view an IDF for a station, the IDF_CC tool triggers a calculation process using mathematical models in the background. When the “IDF, historical data” tab is selected, an IDF curve based on the observed historical precipitation data available is presented to the user. The background data analysis steps are as follows:

- 1) Read and organize data from the database for the selected station.
- 2) Data analysis (ignore negative and zero values) and extraction of yearly maximums.

- 3) Calculate statistical distributions parameters for GEV and Gumbel using L-moments and method of moments, respectively. For more details on Gumbel distribution please refer to *TechMan* section 3.1.1 and 3.1.2.
- 4) Calculate IDF (please refer to *TechMan* section 2.1 and 3.1 for more detail).
- 5) Fit interpolated equations to the IDF curve using optimization algorithm (Differential Evolution): refer to Storn and Price (1997) and Vasan (2008) for more details on Differential Evolution optimization (available in Appendix A).
- 6) Organize data for display (tables, plots, and equations).

After the calculation steps are completed the IDF is presented in the form of tables, total precipitation, intensity graphs and the fitted equation. These results are presented by selecting “IDF, historical data” *Tab* as in Figure 46. The IDF is fitted to the historical data using GEV and Gumbel distribution and results are presented in the following forms:

- 1) Tables: the IDFs are presented in traditional tabular format with duration (in minutes and hours) and return period (T) as in Figure 46. Both total precipitation (Figure 46 in mm and intensity (Figure 47) in mm/h are presented and the user can toggle between these two options.

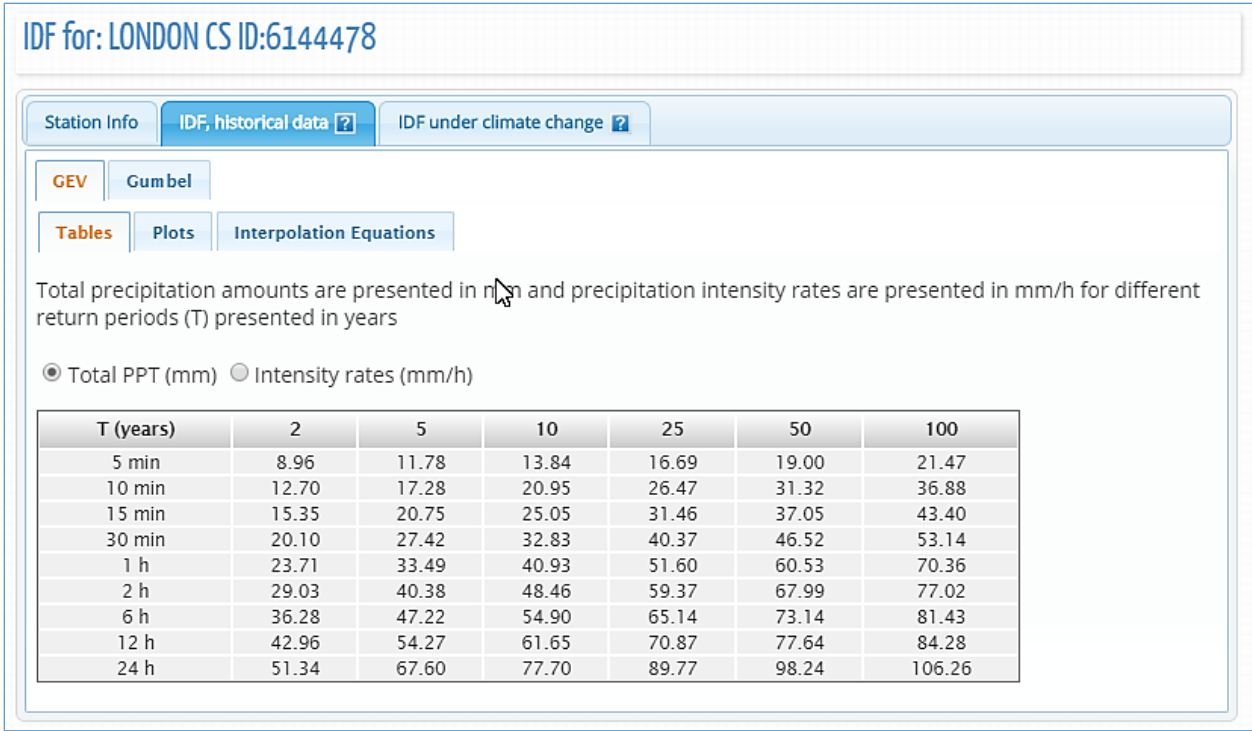


Figure 46. Total precipitation (in mm) IDF table

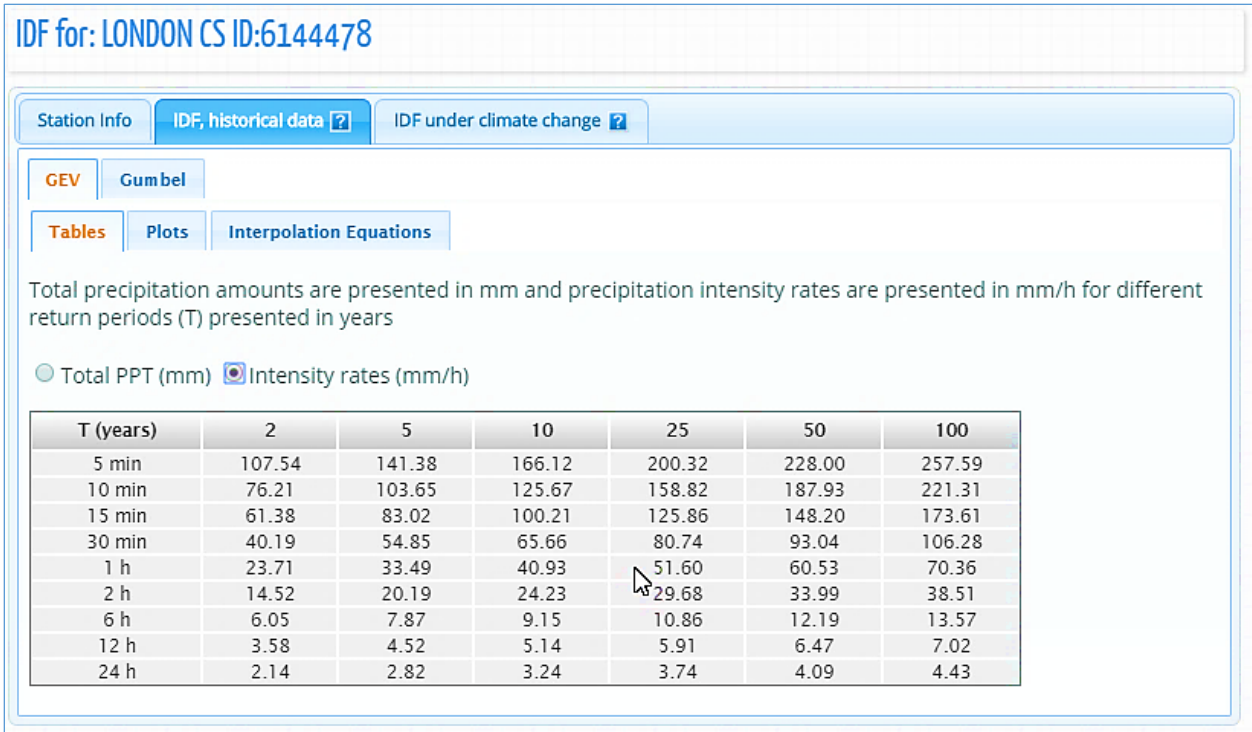


Figure 47. Rainfall intensity (in mm/h) IDF table

2) Plots: the plots or graphs are also presented as *Total Precipitation* (in mm) and *Intensity* (mm/h) as shown in Figure 48 and Figure 49, respectively. The user can hide or show the IDF curve for each return period by clicking on individual return periods in the legend below the graph. Zoom is also available and is performed by dragging out a rectangle in the chart with the mouse pointer. The map will enlarge the selected area (Figure 50) and a “Reset zoom” button is provided. The “Reset zoom” option will revert the initial zoom level (Figure 48). By hovering the mouse pointer over dots, the user can view precipitation, intensity and duration values for each point on the plot. The dots are calculated IDF values and the lines are plotted using the fitted equation that is presented under the “Interpolation Equation” tab. A button on the top left of the plot (☰) allows user to print and export/download the graph to images file (Figure 51).

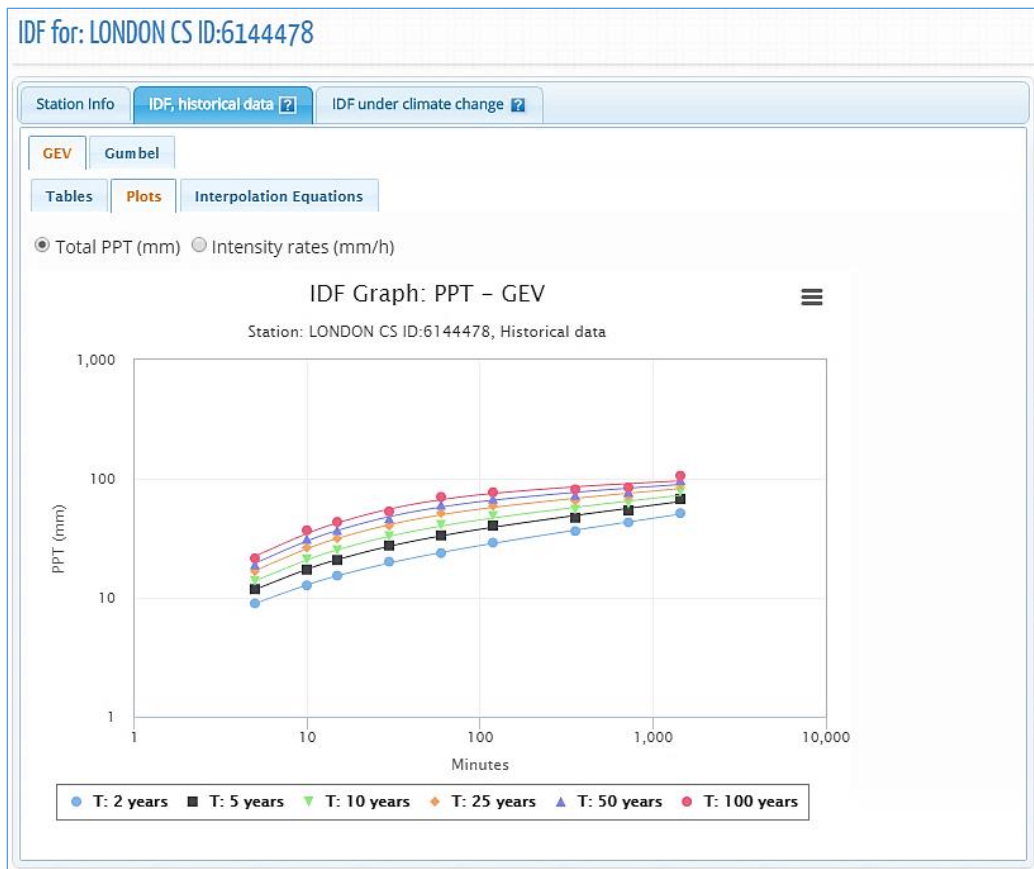


Figure 48. Total precipitation (in mm) IDF graph for different return periods

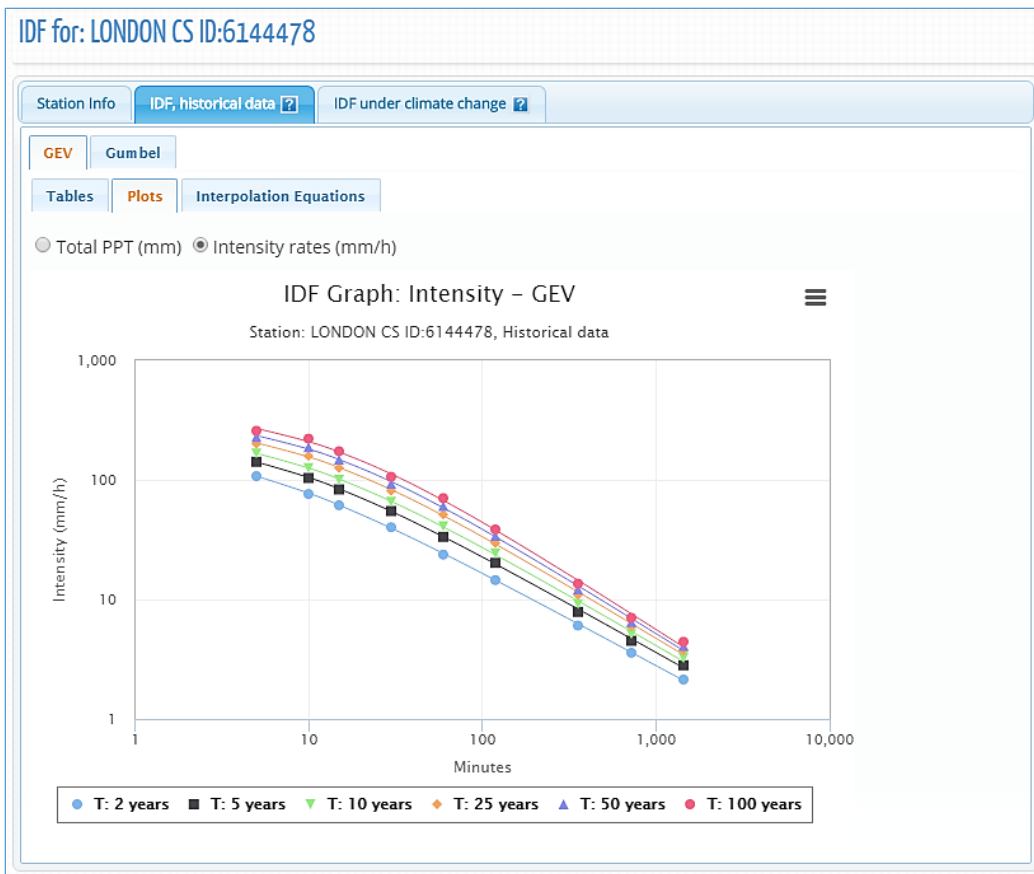


Figure 49. Rainfall intensity (in mm/h) IDF graph for different return periods

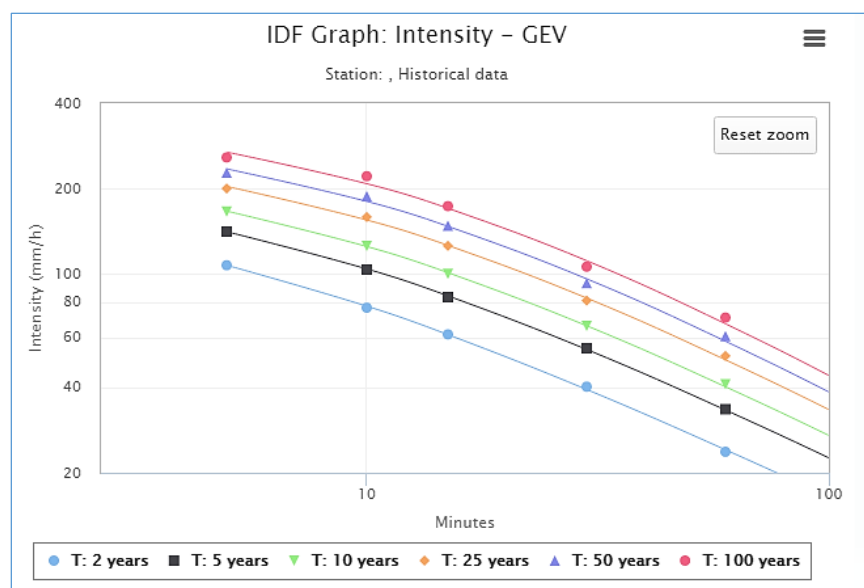


Figure 50. Zooming on a plot and resetting zoom level

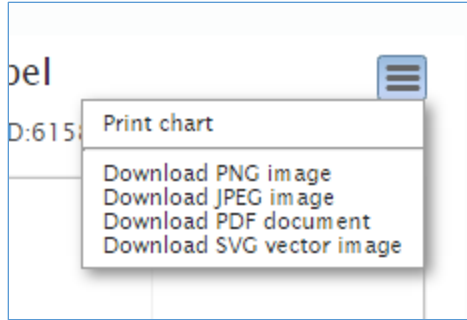


Figure 51. Printing and exporting a plot as image

3) Interpolation Equations: an optimization algorithm is used to fit equations to the calculated IDF values. The equations are presented under the “Interpolation Equations” *Tab* as shown in Figure 52. Three coefficients A , B and t_0 are calculated by the optimization algorithm for each return period (T) and presented as a table in Figure 52. This equation can be applied as a fast method for interpolation and calculation of design storms.

IDF for: LONDON CS ID:6144478

Station Info
IDF historical data ?
IDF under climate change ?

GEV
Gumbel

Tables
Plots
Interpolation Equations

The table below provides coefficients for the interpolation equations fitted to the IDF curve using the GEV distribution.

T (years)	Coefficient A	Coefficient B	Coefficient t_0
2	26.0	-0.795	0.090
5	36.7	-0.825	0.118
10	44.5	-0.845	0.133
20	52.6	-0.863	0.145
25	55.3	-0.868	0.148
50	64.1	-0.885	0.158
100	73.3	-0.901	0.165

Use the coefficients provided in the table above with the following equation:

$$i\left(\frac{mm}{h}\right) = A \cdot (t + t_0)^B$$

Where:

- i is the precipitation intensity rate in $\frac{mm}{h}$
- A , B and t_0 , are the coefficients for each return period (T) in years
- t , the time (duration) of the precipitation event in hours (h)

Figure 52. Fitted IDF equation to historical precipitation data

3.2 IDF curves for Ungauged locations

With the version 6.5 of the IDF_CC tool, a new dataset of gridded IDF curves for Canada is available. With the new module, users can obtain IDF curves for any location in the country, especially in regions where no observations are available. The IDF estimates are calculated according to the methodology described in *TechMan* section 3.2. For a selected location from the map the IDF_CC tool will present the Gridded IDFs in similar format as the ones based on gauges observations (describe on item 3.1).

The user will select the location (coordinates) from the Map, and based on the input, the IDF_CC tool will identify the nearest grids, and present the IDF curves. Figure 53 presents a screenshot with the coordinates of the selected location. The elements are presented in similar format

to the gauged based IDF: tables (Figure 54), interactive graphs (Figure 55) and the fitted equation (Figure 56).



Figure 53. IDF_CC tool page with the coordinates of the selected location for the Gridded IDF

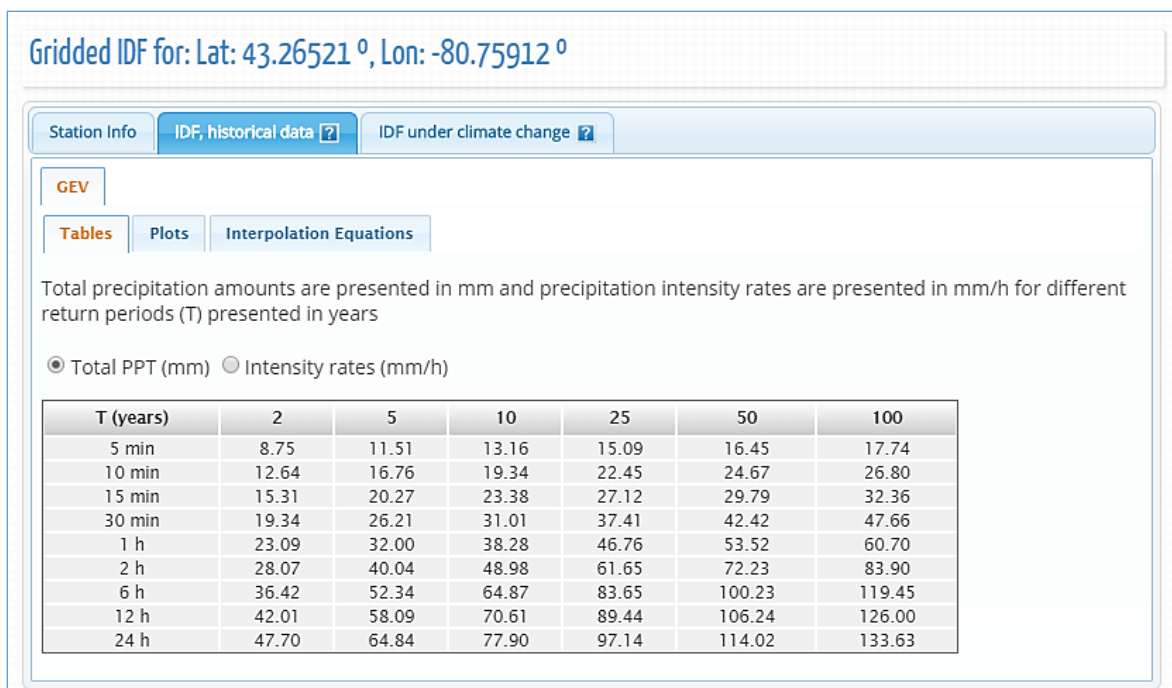


Figure 54. Total precipitation (in mm) IDF table for the selected coordinates

Gridded IDF for: Lat: 42.93833 °, Lon: -81.32767 °



Figure 55. Total precipitation (in mm) IDF graph for different return periods

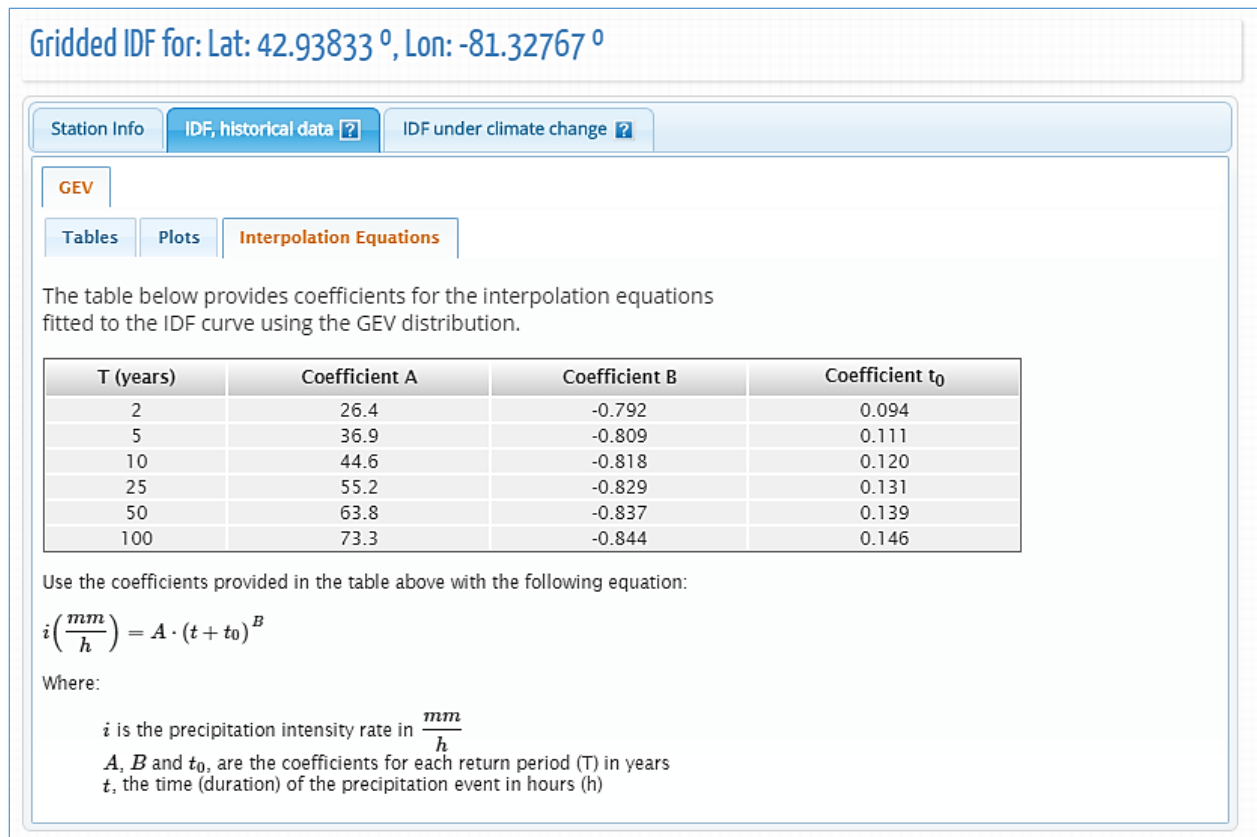


Figure 56. Fitted IDF equation to precipitation data for the selected location

3.3 Updated IDF curves under Climate Change

By selecting the “IDF under climate change” tab, the user can generate IDF curves that account for future climate conditions. To generate the updated IDFs for future climate, the user can select all models (ensemble option) or individual GCM and projection period as shown in Figure 57. There are 30 GCMs from CMIP6 (Table 1), 24 GCMs from CMIP5 (Table 2), 26 bias-corrected models based on CMIP6 raw GCMs from PCIC (Table 4) and 24 bias-corrected models based on CMIP5 raw GCMs from PCIC (Table 4), resulting in a total of 104 GCM datasets available with the IDF_CC tool. The dataset used for the updating procedure is a choice of the user: **CMIP6 GCMs**, **CMIP5 GCMs**, **PCIC - Bias Corrected (CMIP6)** and **PCIC - Bias Corrected (CMIP5)**. The available range for the future time period is 2015 to 2100 (Step 1 in Figure 57). The updating procedure applies for both gauged and gridded IDFs. If **CMIP6 GCMs** is selected, the user will be presented with four SSP outputs (Figure 57) and three SSPs when the PCIC bias-corrected models based on

CMIP6 option is selected (Figure 58). If CMIP5 raw or bias-corrected models from PCIC are selected, three RCPs will be presented (Figure 59).

With respect to GCM selection, to generate IDF curves that account for climate change, the user has two options: select all models (ensemble option), or select any model from the list of GCMs provided with the tool (Step 2 in Figure 57 and Figure 59). The users are encouraged to test different models due to uncertainty associated with climate modeling. The climate modelling community does not “compare” global climate models to identify superior/inferior models for specific locations. Thus, users should not think that there is no “right” GCM for any given location. Users are provided access all available models in the IDF_CC tool to allow them to understand uncertainty associated with potential climate change impacts.

The updated IDF curves are available for both distributions: GEV and Gumbel as in Figure 57.

The following steps are performed by the IDF_CC tool to update IDF curves for future climate. Please see *TechMan* section 3.2 for more information on each of the steps:

- 1) Extract precipitation data series from GCM grid points for the selected station (e.g., using BCCAQ with the Canadian CanESM2 model).
- 2) Organize data and extract yearly maximums.
- 3) Apply Equidistant Quantile Matching (EQM) algorithm (refer to *TechMan* section 3.2).
- 4) Estimate distribution parameters and calculate IDFs for each future climate scenario (SSPs or RCPs).
- 5) Generate median IDF from the results of step 4 for each SSP or RCP.
- 6) Organize data for display (tables, plots, and equations, uncertainty range plot).

Table 1 – Selected CMIP6 models and their attributes which has all the three emission scenarios (SSP1.26, SSP2.45, SSP3.70 and SSP5.85)

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPT)	GCM Resolutions (Lon. vs Lat.)
Australia	CSIRO-ARCCSS	ACCESS-CM2	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Aspendale, Victoria 3195, Australia), ARCCSS (Australian Research Council Centre of Excellence for Climate System Science)	3	1.875×1.25
Australia	CSIRO	ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organisation, Aspendale, Victoria 3195, Australia	9	1.875×1.25
China	BCC	BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration	1	1.0 x 1.0
China	CAMS	CAMS-CSM1-0	Chinese Academy of Meteorological Sciences, Beijing 100081, China	5	1.125 x 1.125
Canada	CCCma	CanESM5	Canadian Centre for Climate Modelling and Analysis	25	2.8125 x 2.8125
USA	NCAR	CESM2	National Center for Atmospheric Research	1	1.25 x 0.9375
USA	NCAR	CESM2-WACCM	National Center for Atmospheric Research	1	1.25 x 0.9375
Italy	CMCC	CMCC-CM2-SR5	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce 73100, Italy	1	1.25 x 0.9375
Italy	CMCC	CMCC-ESM2	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce 73100, Italy	1	1.25 x 0.9375
France	CNRM-CERFACS	CNRM-CM6-1	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1	1.4 × 1.4
France	CNRM-CERFACS	CNRM-ESM2-1	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1	1.875 x 1.875
Various	EC-Earth-Consortium	EC-Earth3	EC-Earth consortium, Rossby Center, Swedish Meteorological and Hydrological Institute/SMHI, SE-601 76 Norrkoping, Sweden	6	1.125 x 1.125
Various	EC-Earth-Consortium	EC-Earth3-Veg	EC-Earth consortium, Rossby Center, Swedish Meteorological and Hydrological Institute/SMHI, SE-601 76 Norrkoping, Sweden	3	1.125 x 1.125
Various	EC-Earth-Consortium	EC-Earth3-Veg-LR	EC-Earth consortium, Rossby Center, Swedish Meteorological and Hydrological Institute/SMHI, SE-601 76 Norrkoping, Sweden	3	1.125 x 1.125
China	CAS	FGOALS-g3	Chinese Academy of Sciences, Beijing 100029, China	3	2.0 x 2.25
USA	NOAA-GFDL	GFDL-ESM4	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA	1	1.0 x 1.0
India	CCCR-IITM	IITM-ESM	Centre for Climate Change Research, Indian Institute of Tropical Meteorology Pune, Maharashtra 411 008, India	1	1.875 x 1.915
Russia	INM	INM-CM4-8	Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia	1	2.0 x 1.5
Russia	INM	INM-CM5-0	Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia	1	2.0 x 1.5
France	IPSL	IPSL-CM6A-LR	Institut Pierre Simon Laplace	4	2.8 x 2.8
South Korea	NIMS-KMA	KACE-1-0-G	National Institute of Meteorological Sciences/Korea Meteorological Administration, Climate Research Division,	3	1.875 x 1.25

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPT)	GCM Resolutions (Lon. vs Lat.)
			Seoho-bukro 33, Seogwipo-si, Jejudo 63568, Republic of Korea		
Japan	MIROC	MIROC6	Japan Agency for Marine-Earth Science and Technology	3	1.0 x 0.703125
Japan	MIROC	MIROC-ES2L	Japan Agency for Marine-Earth Science and Technology	1	2.8125 x 2.8125
Germany	DKRZ	MPI-ESM1-2-HR	Deutsches Klimarechenzentrum, Hamburg 20146, Germany	2	0.9375 x 0.9375
Germany	MPI-M	MPI-ESM1-2-LR	Max Planck Institute for Meteorology	10	1.875 x 1.875
Japan	MRI	MRI-ESM2-0	Meteorological Research Institute	1	1.875 x 1.875
Norway	NCC	NorESM2-LM	Norwegian Climate Centre	1	2.5 x 1.875
Norway	NCC	NorESM2-MM	Norwegian Climate Centre	1	1.25 x 0.9375
Taiwan	AS-RCEC	TaiESM1	Research Center for Environmental Changes, Academia Sinica, Nankang, Taipei 11529, Taiwan	1	1.25 x 0.9375
UK	MOHC	UKESM1-0-LL	Met Office Hadley Centre	17	1.875 x 1.875

Table 2 – Selected CMIP5 models and their attributes which has all the three emission scenarios (RCP2.6, RCP4.5 and RCP8.5)

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPT)	GCM Resolutions (Lon. vs Lat.)
China	BCC	bcc_csm1_1	Beijing Climate Center, China Meteorological Administration	1	2.8 x 2.8
China	BCC	bcc_csm1_1 m	Beijing Climate Center, China Meteorological Administration	1	
China	BNU	BNU-ESM	College of Global Change and Earth System Science	1	2.8 x 2.8
Canada	CCCma	CanESM2	Canadian Centre for Climate Modeling and Analysis	5	2.8 x 2.8
USA	CCSM	CCSM4	National Center of Atmospheric Research	1	1.25 x 0.94
France	CNRM	CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1	1.4 x 1.4
Australia	CSIRO3.6	CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	10	1.8 x 1.8
USA	CESM	CESM1-CAM5	National Center of Atmospheric Research	1	1.25 x 0.94
E.U.	EC-EARTH	EC-EARTH	EC-EARTH	1	1.125 x 1.125
China	LASG-CESS	FGOALS_g2	IAP (Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China) and THU (Tsinghua University)	1	2.55 x 2.48
USA	NOAA GFDL	GFDL-CM3	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
USA	NOAA GFDL	GFDL-ESM2G	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0

Country	Centre Acronym	Model	Centre Name	Number of Ensembles (PPT)	GCM Resolutions (Lon. vs Lat.)
USA	NOAA GFDL	GFDL-ESM2M	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory		2.5 x 2.0
United Kingdom	MOHC	HadGEM2-AO	Met Office Hadley Centre	1	1.25 x 1.875
United Kingdom	MOHC	HadGEM2-ES	Met Office Hadley Centre	2	1.25 x 1.875
France	IPSL	IPSL-CM5A-LR	Institut Pierre Simon Laplace	4	3.75 x 1.8
France	IPSL	IPSL-CM5A-MR	Institut Pierre Simon Laplace	4	3.75 x 1.8
Japan	MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology	3	1.4 x 1.41
Japan	MIROC	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
Japan	MIROC	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
Germany	MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology	3	1.88 x 1.87
Germany	MPI-M	MPI-ESM-MR	Max Planck Institute for Meteorology	3	1.88 x 1.87
Japan	MRI	MRI-CGCM3	Meteorological Research Institute	1	1.1 x 1.1
Norway	NOR	NorESM1-M	Norwegian Climate Center	3	2.5 x 1.9

Table 3 – PCIC bias-corrected and downscaled CMIP6 models and their attributes which has all the three emission scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) using the BCCAQ v2 method

Country	Centre Acronym	Model	Centre Name	Original (Lon. Vs Lat.)	Bias corrected (Lon. Vs Lat.)
Australia	ACCESS	ACCESS-CM2	Australian Community Climate and Earth System Simulator	1.875 x 1.25	
Australia	ACCESS	ACCESS-ESM1.5	Australian Community Climate and Earth System Simulator	1.875 x 1.25	
China	BCC	BCC-CSM2-MR	Beijing Climate Center	1.0 x 1.0	
Canada	CCCma	CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8 x 2.8	
Italy	CMCC	CMCC-ESM2	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce 73100, Italy	1.25 x 0.9375	
France	CNRM-CERFACS	CNRM-CM6-1	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1.4 x 1.4	0.0833 x 0.0833
France	CNRM-CERFACS	CNRM-ESM2-1	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1.875 x 1.875	
Various	EC-Earth-Consortium	EC-Earth3	EC-Earth consortium, Rossby Center, Swedish Meteorological and Hydrological Institute/SMHI, SE-601 76 Norrkoping, Sweden	1.125 x 1.125	
Various	EC-Earth-Consortium	EC-Earth3-Veg	EC-Earth consortium, Rossby Center, Swedish Meteorological and Hydrological Institute/SMHI, SE-601 76 Norrkoping, Sweden	1.125 x 1.125	
China	CAS	FGOALS-g3	Chinese Academy of Sciences, Beijing 100029, China	2.0 x 2.25	

Country	Centre Acronym	Model	Centre Name	Original (Lon. Vs Lat.)	Bias corrected (Lon. Vs Lat.)
USA	NOAA-GFDL	GFDL-ESM4	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA	1.0 x 1.0	
UK	MOHC	HadGEM3-GC31-LL	Met Office Hadley Centre	1.25 x 1.875	
Russia	INM	INM-CM4-8	Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia	2.0 x 1.5	
Russia	INM	INM-CM5-0	Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia	2.0 x 1.5	
France	IPSL	IPSL-CM6A-LR	Institut Pierre Simon Laplace	2.8 x 2.8	
South Korea	NIMS-KMA	KACE-1-0-G	National Institute of Meteorological Sciences/Korea Meteorological Administration, Climate Research Division, Seoho-bukro 33, Seogwipo-si, Jeju-do 63568, Republic of Korea	1.875 x 1.25	
South Korea	KIOST	KIOST-ESM	Korea Institute of Ocean Science & Technology (KIOST)	1.875 x 1.875	
Japan	MIROC	MIROC6	Japan Agency for Marine-Earth Science and Technology	1.0 x 0.703125	
Japan	MIROC	MIROC-ES2L	Japan Agency for Marine-Earth Science and Technology	2.8125 x 2.8125	
Germany	DKRZ	MPI-ESM1-2-HR	Deutsches Klimarechenzentrum, Hamburg 20146, Germany	0.9375 x 0.9375	
Germany	MPI-M	MPI-ESM1-2-LR	Max Planck Institute for Meteorology	1.875 x 1.875	
Japan	MRI	MRI-ESM2-0	Meteorological Research Institute	1.875 x 1.875	
Norway	NCC	NorESM2-LM	Norwegian Climate Centre	2.5 x 1.875	
Norway	NCC	NorESM2-MM	Norwegian Climate Centre	1.25 x 0.9375	
Taiwan	AS-RCEC	TaiESM1	Research Center for Environmental Changes, Academia Sinica, Nankang, Taipei 11529, Taiwan	1.25 x 0.9375	
UK	MOHC	UKESM1-0-LL	Met Office Hadley Centre	1.875 x 1.875	

Table 4 – PCIC selected bias corrected and downscaled CMIP5 models and their attributes which has all the three emission scenarios (RCP2.6, RCP4.5 and RCP8.5) using the BCCAQ v2 method

Country	Centre Acronym	Model	Centre Name	Original (Lon. vs Lat.)	Bias corrected (Lon. vs Lat.)
China	BCC	bcc_csm1_1	Beijing Climate Center, China Meteorological Administration	2.8 x 2.8	
China	BCC	bcc_csm1_1 m	Beijing Climate Center, China Meteorological Administration		
China	BNU	BNU-ESM	College of Global Change and Earth System Science	2.8 x 2.8	
Canada	CCCma	CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8 x 2.8	
USA	CCSM	CCSM4	National Center of Atmospheric Research	1.25 x 0.94	
France	CNRM	CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1.4 x 1.4	
Australia	CSIRO3.6	CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	1.8 x 1.8	
USA	CESM	CESM1-CAM5	National Center of Atmospheric Research	1.25 x 0.94	
China	LASG-CESS	FGOALS_g2	IAP (Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China) and THU (Tsinghua University)	2.55 x 2.48	
USA	NOAA GFDL	GFDL-CM3	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	2.5 x 2.0	
USA	NOAA GFDL	GFDL-ESM2G	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	2.5 x 2.0	
USA	NOAA GFDL	GFDL-ESM2M	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	2.5 x 2.0	0.0833 x 0.0833
United Kingdom	MOHC	HadGEM2-AO	Met Office Hadley Centre	1.25 x 1.875	
United Kingdom	MOHC	HadGEM2-ES	Met Office Hadley Centre	1.25 x 1.875	
France	IPSL	IPSL-CM5A-LR	Institut Pierre Simon Laplace	3.75 x 1.8	
France	IPSL	IPSL-CM5A-MR	Institut Pierre Simon Laplace	3.75 x 1.8	
Japan	MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology	1.4 x 1.41	
Japan	MIROC	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology	2.8 x 2.8	
Japan	MIROC	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology	2.8 x 2.8	
Germany	MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology	1.88 x 1.87	
Germany	MPI-M	MPI-ESM-MR	Max Planck Institute for Meteorology	1.88 x 1.87	
Japan	MRI	MRI-CGCM3	Meteorological Research Institute	1.1 x 1.1	
Norway	NOR	NorESM1-M	Norwegian Climate Center	2.5 x 1.9	
Norway	NOR	NorESM1-ME	Norwegian Climate Center	2.5 x 1.9	

IDF for: LONDON CS ID:6144478

Station Info | IDF historical data ? | **IDF under climate change ?**

GEV | Gumbel

Climate Model Selection | SSP1.26 ? | SSP2.45 ? | SSP3.70 ? | SSP5.85 ? | Comparison Graphs ?

1. Select the time period to update the IDF curve under climate change. The tool will use Climate Model data for the selected range. The available range is 2015 to 2100. Please select at least a 30 year projection period.

From 2015 to 2100

2. Select a Climate Model to see results. Climate models are listed by name:

CMIP6: Raw GCMs PCIC - Bias Corrected
 CMIP5: Raw GCMs PCIC - Bias Corrected

All Models
 Ensemble, Ensemble

Continue Export Results

Figure 57. Selection of the CGM CMIP6 model and projection period

IDF for: LONDON CS ID:6144478

Station Info | IDF historical data ? | **IDF under climate change ?**

GEV | Gumbel

Climate Model Selection | SSP1.26 ? | SSP2.45 ? | SSP5.85 ? | Comparison Graphs ?

1. Select the time period to update the IDF curve under climate change. The tool will use Climate Model data for the selected range. The available range is 2015 to 2100. Please select at least a 30 year projection period.

From 2015 to 2100

2. Select a Climate Model to see results. Climate models are listed by name:

CMIP6: Raw GCMs PCIC - Bias Corrected
 CMIP5: Raw GCMs PCIC - Bias Corrected

All Models
 Ensemble, Ensemble

Continue Export Results

Figure 58. Selection of PCPC Bias corrected CMIP6 CGM models and projection period

Station Info | IDF historical data | **IDF under climate change**

GEV | Gumbel

Climate Model Selection | Scenario RCP 2.6 | Scenario RCP 4.5 | Scenario RCP 8.5 | Comparison Graphs

1. Select the time period to update the IDF curve under climate change. The tool will use Climate Model data for the selected range. The available range is 2015 to 2100. Please select at least a 30 year projection period.

From 2015 to 2100

2. Select a Climate Model to see results. Climate models are listed by name:

CMIP6: Raw GCMs PCIC - Bias Corrected

CMIP5: Raw GCMs PCIC - Bias Corrected

All Models
Ensemble, Ensemble

Continue | Export Results

Figure 59. Selection of CMIP5 or PCIC Bias corrected CMIP5 CGM models and projection period

The Fifth Assessment Report (AR5) (IPCC, 2013) provides four RCP scenarios: RCP2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The following definitions are directly adopted from AR5 and the RCPs are briefly described below (refer to *TechMan* section 2.3 for more details):

- **RCP 2.6:** pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines;
- **RCP 4.5 and RCP6.0:** Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100;
- **RCP 8.5:** high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some time.

For CMIP5, the future emission scenarios used in the IDF_CC tool are RCP 2.6, RCP 4.5 and RCP 8.5. RCP 2.6 represents a low greenhouse gas concentration scenario, followed by RCP 4.5 as an intermediate scenario and RCP 8.5 as a high concentration scenario. The RCP 4.5 scenario was selected over RCP 6.0 as an intermediate scenario largely because more GCM models have results for RCP 4.5 than RCP 6.0.

In the lead up to the IPCC Assessment Report 6, the energy modelling community has developed a new set of emissions scenarios driven by different socioeconomic assumptions. These are

the named Shared Socioeconomic Pathways (SSPs). A number of these SSP scenarios have been selected to drive climate models for CMIP6. The most common SSPs selected by climate modeling centers and for which outputs are produced are the following (O'Neil et al., 2016):

- **SSP1-2.6:** This scenario with 2.6 W/m² by the year 2100 is a remake of the optimistic scenario RCP2.6 and was designed with the aim of simulating development that is compatible with the 2°C target. This scenario assumes climate protection measures are applied;
- **SSP2-4.5:** As an update to scenario RCP4.5, SSP2-4.5, with an additional radiative forcing of 4.5 W/m² by the year 2100, represents a medium pathway of future greenhouse gas emissions. This scenario assumes that climate protection measures are applied;
- **SSP3-7.0:** With 7 W/m² by the year 2100, this scenario is in the upper-middle part of the full range of scenarios. It was newly introduced after the RCP scenarios, closing the gap between RCP6.0 and RCP8.5;
- **SSP5-8.5:** With an additional radiative forcing of 8.5 W/m² by the year 2100, this scenario represents the upper boundary of the range of scenarios described in the literature. It can be understood as an update of the CMIP5 scenario RCP8.5, now combined with socioeconomic reasons..

3.4 Viewing and Exploring Results

Upon completion of the IDF update calculations, the results are presented in the form of tables, total precipitation, rainfall intensity graphs and uncertainty range graphs. These results are presented for each future scenario: SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 if a CMIP6 model is selected and RCP 2.6, 4.5 and 8.5 if a CMIP5 raw or bias-corrected model is selected. Each scenario is displayed as a set of *Tabs* as shown in Figure 60 and Figure 61 respectively.

Updated IDF curves for future climate conditions for all future projected scenarios (four SSPs for CMIP6 raw models, three SSPs for PCIC bias-corrected models from CMIP6 and three RCPs for CMI5 raw or PCIC bias-corrected models) are presented as tables, plots and uncertainty ranges, as described here:

- 1) Tables: the IDF is presented in the traditional table format for all durations (in minutes and hours) and return periods (T) as illustrated in Figure 61. Both total precipitation in mm (Figure

61) and rainfall intensity in mm/h (Figure 62) are available and the user can toggle between these two options using the available radio buttons. The IDF curves presented in Figure 61 and Figure 62 are a median from all models selected for each emission scenario (see *TechMan* section 2.3).

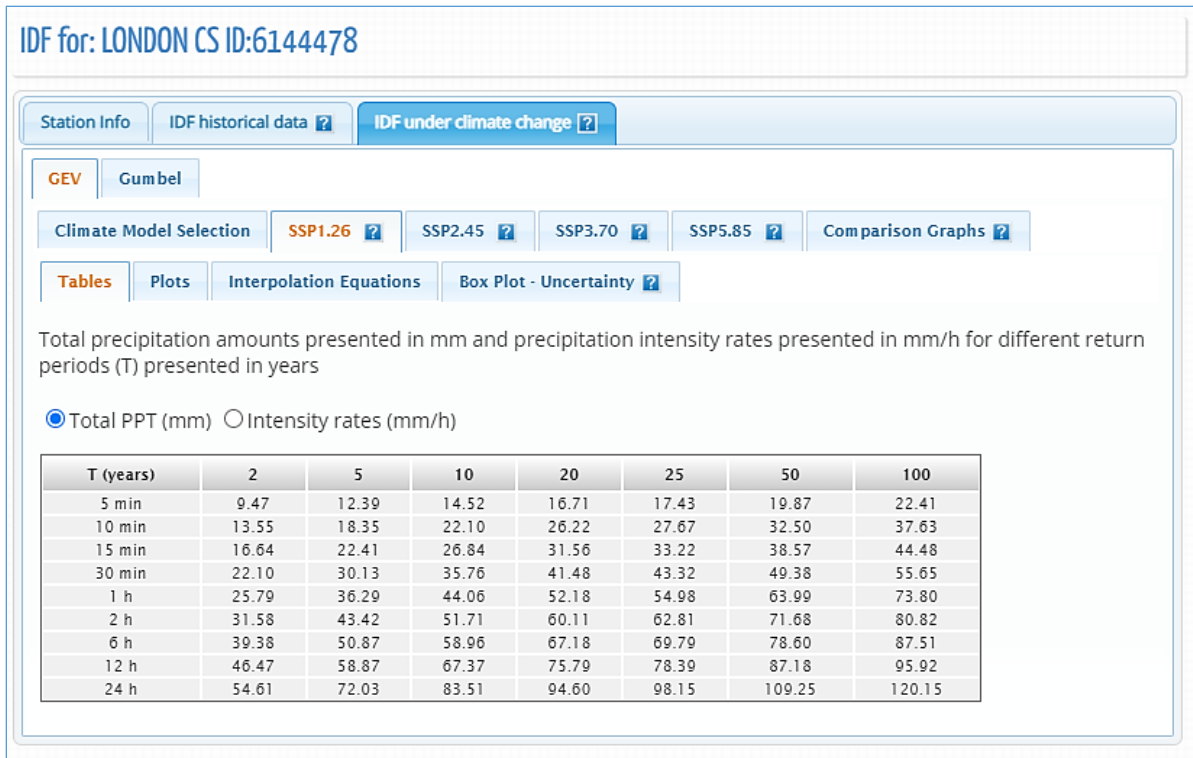


Figure 60. Updated IDF tables for future climate conditions – total precipitation in mm using CMIP6 GCMs

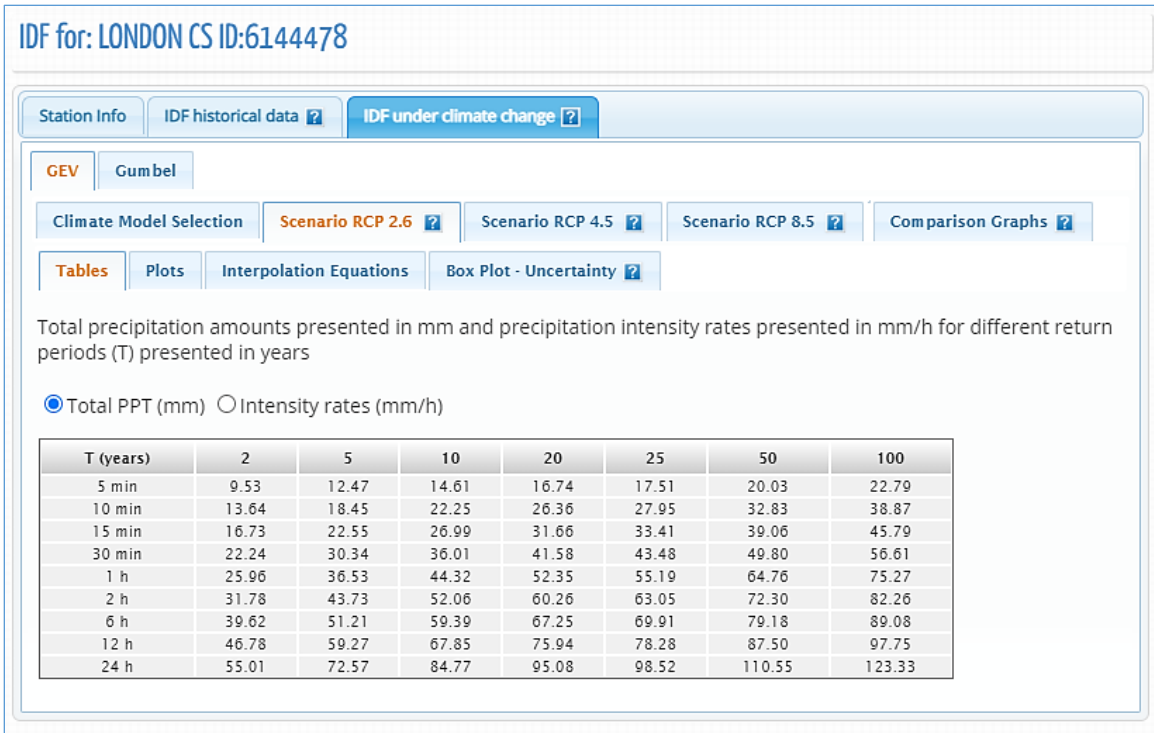


Figure 61. Updated IDF tables for future climate conditions – total precipitation in mm using CMIP5 GCMs

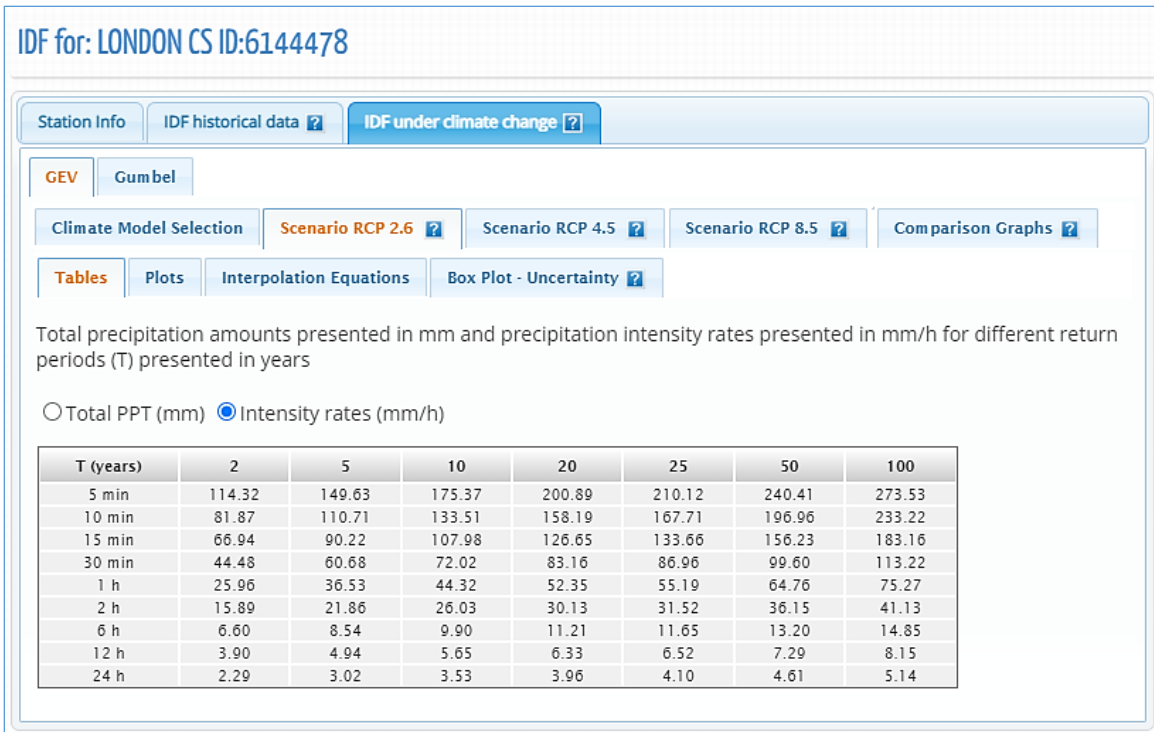


Figure 62. Updated IDF tables for future climate conditions – rainfall intensity in mm/h

2) Plots: the plots or graphs are also available for total precipitation (in mm) and rainfall intensity (mm/h) as presented in Figure 63 and Figure 64, respectively. The user can hide or show the IDF curve for each return period by clicking on individual return periods in the legend below the graph. Zoom is also available and is performed by dragging out a rectangle in the chart with the mouse pointer. The area selected is zoomed-in (Figure 50) and a “Reset zoom” button will be visible. The “Reset zoom” option will revert the zoom level to the original state. By hovering the mouse pointer over dots, the user can view precipitation, intensity and duration values for each point on the plot. The dots are calculated IDF values and the lines are plotted using the fitted equation that is presented under “Interpolation Equations” tab. The same procedure can be applied with the CMIP6 or the bias-corrected models.



Figure 63. Total precipitation (in mm) updated IDF graph for different return periods

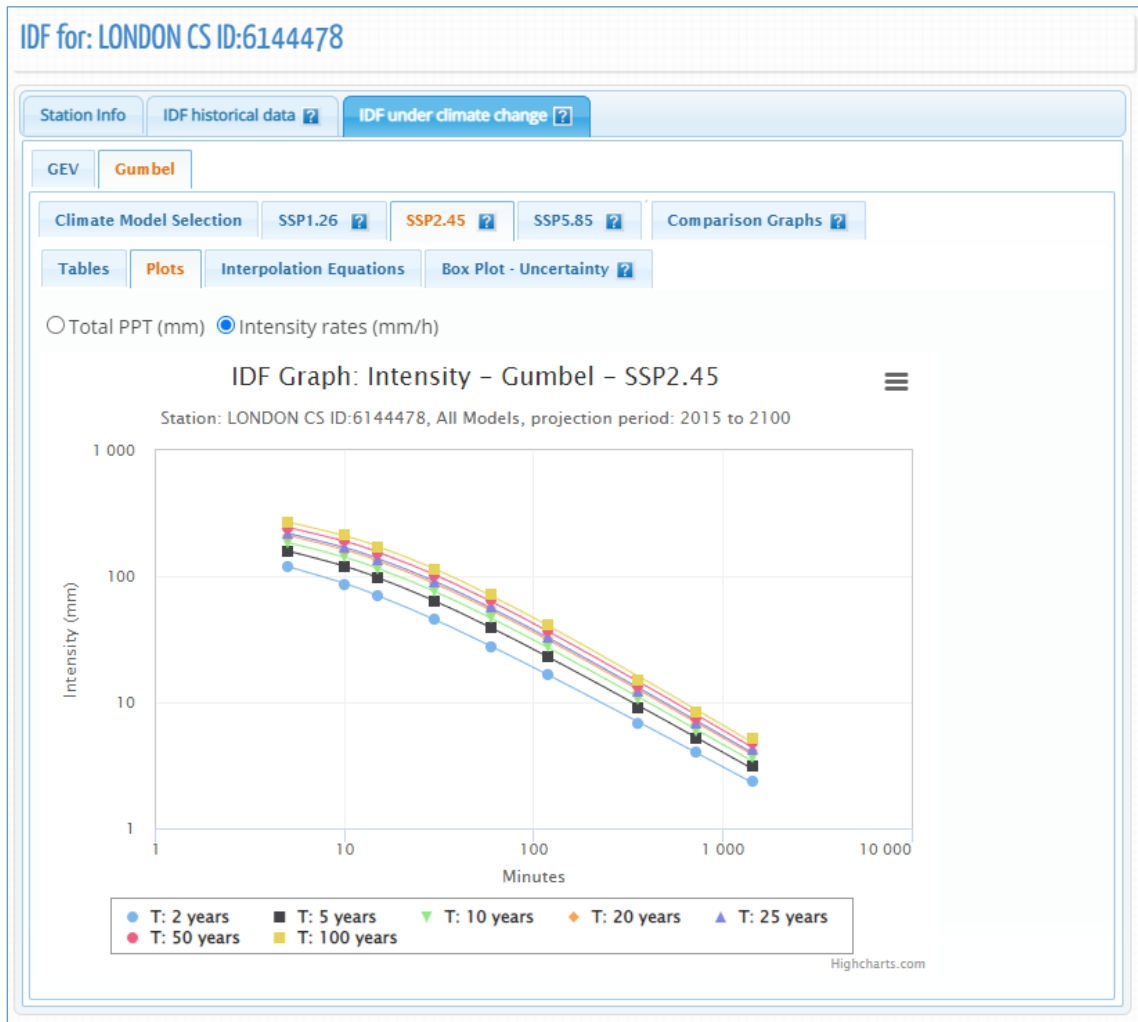


Figure 64. Rainfall intensity (in mm/h) updated IDF graph for different return periods

3) “Interpolation Equations”: an optimization algorithm is used to fit equations to the calculated IDF values. The equations are presented under the “Interpolation Equations” *Tab* as shown in Figure 65. Three coefficients A , B and t_0 are calculated by the optimization algorithm for each return period (T) and presented as a table in Figure 65. This equation can be applied as an expedite method for interpolation and calculation for design storms. The same procedure can be applied with the CMIP6 or the bias-corrected models.

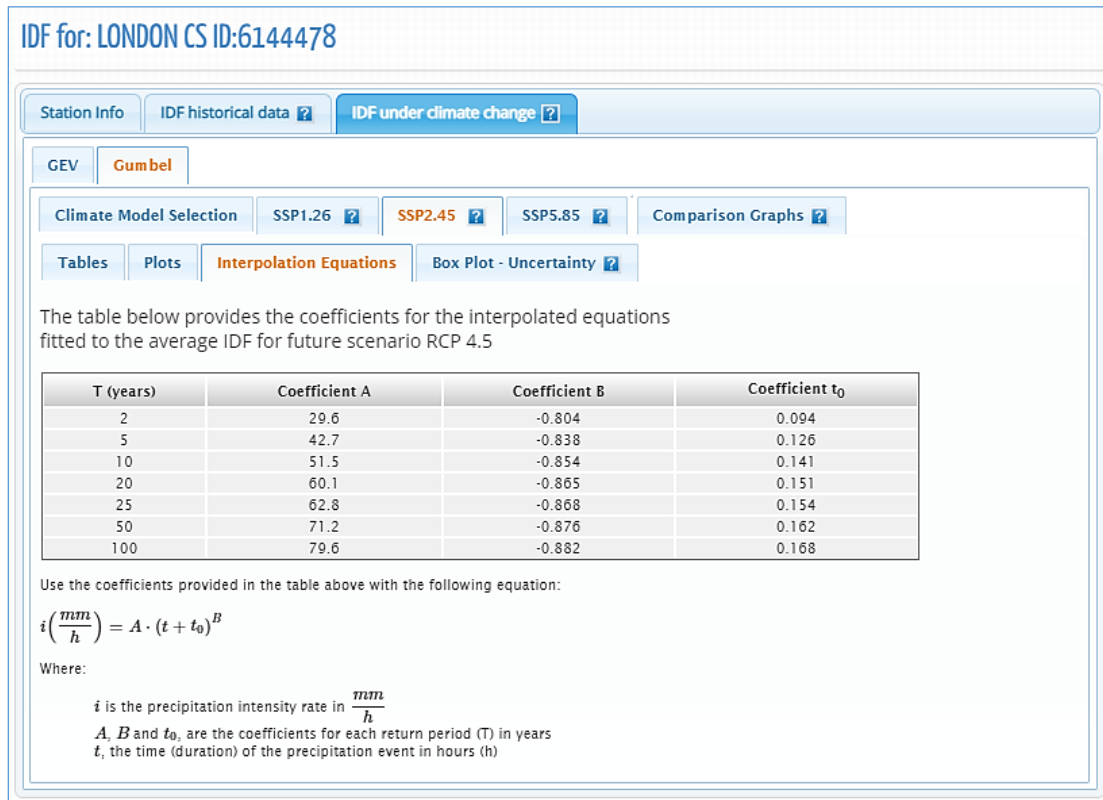


Figure 65. Fitted IDF equation for future scenario

4) Box Plot Uncertainty: Users can quickly view the distribution of results produced by each of the GCMs available within the tool by selecting the “Box Plot – Uncertainty” tab when generating future IDF curves using the “All Models” GCM option. Figure 66 provides an example of an uncertainty plot output. The plot was generated for the London CS rain station, using the “All Models” GCM option for the period 2006-2100, RCP 2.6. The plot indicates the range of values generated for each of the GCM datasets for this future scenario. See the Figure 67 for illustration of how to read the Box Plots. The same procedure can be applied with the CMIP6 or the bias-corrected (PCIC) models.

IDF for: LONDON CS ID:6144478

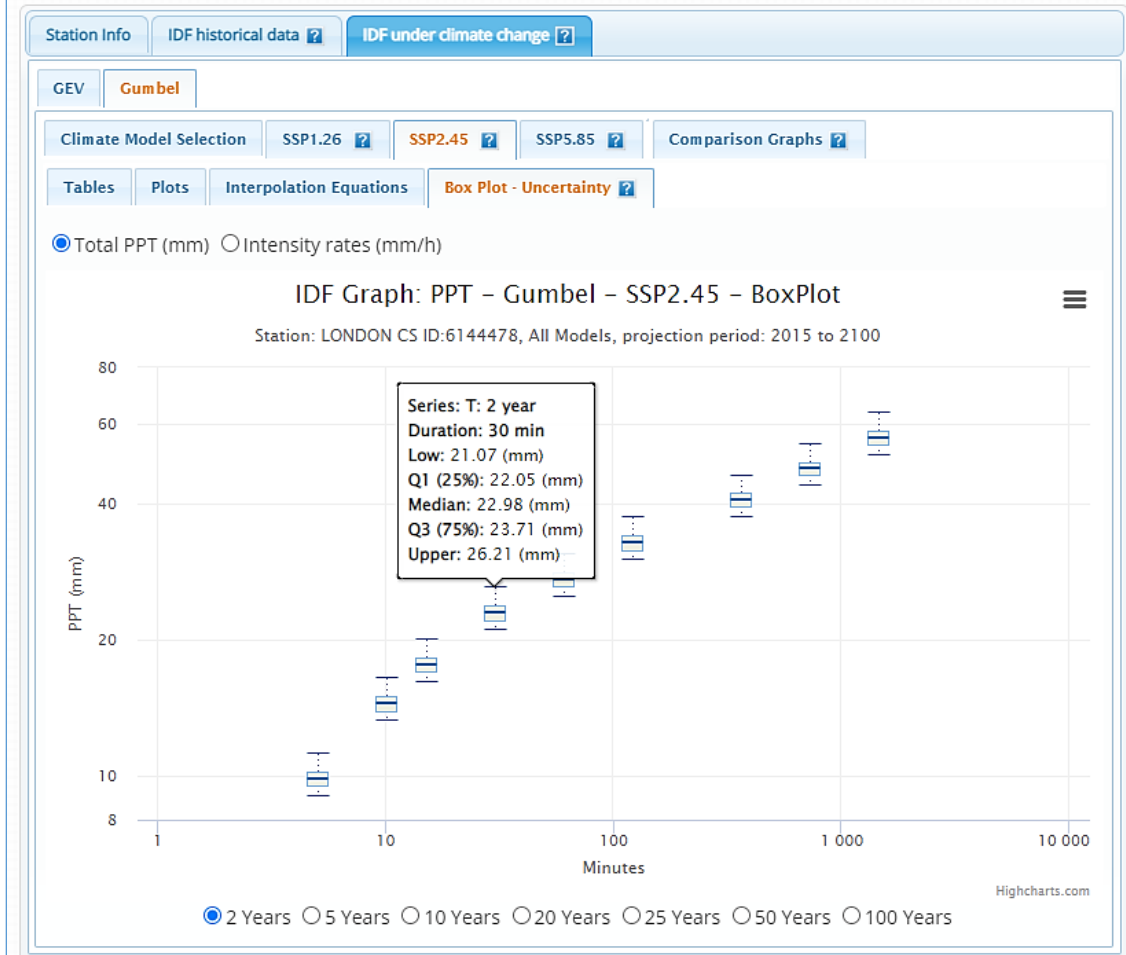


Figure 66. Box Plot – Uncertainty

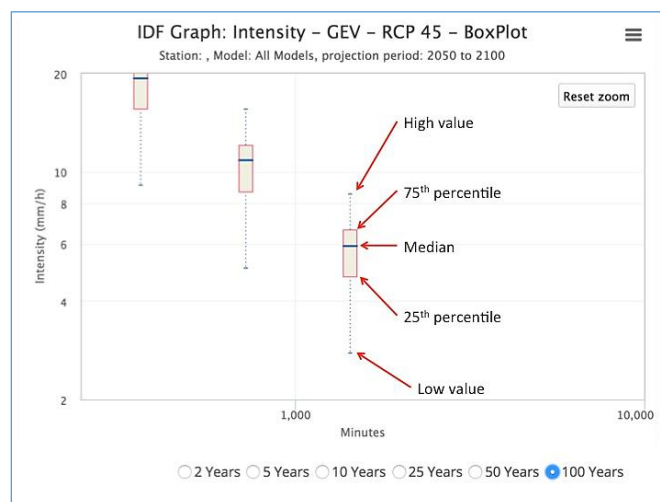


Figure 67. Reading Box Plots

5) Comparison Graphs: this option presents the summary and comparison between the IDF based on historical data and the median IDF for future periods (three RCPs of CMIP5 models or bias-corrected models, three SSPs if bias-corrected CMIP6 models are selected or four SSPs scenarios if raw CMIP6 models are selected) as shown in Figure 68. The graphs are presented for each return period, i.e.: 2, 5, 10, 25, 50 and 100 years. The dots in Figure 68 represent the IDF table and the lines are plotted from the Interpolation Equations.

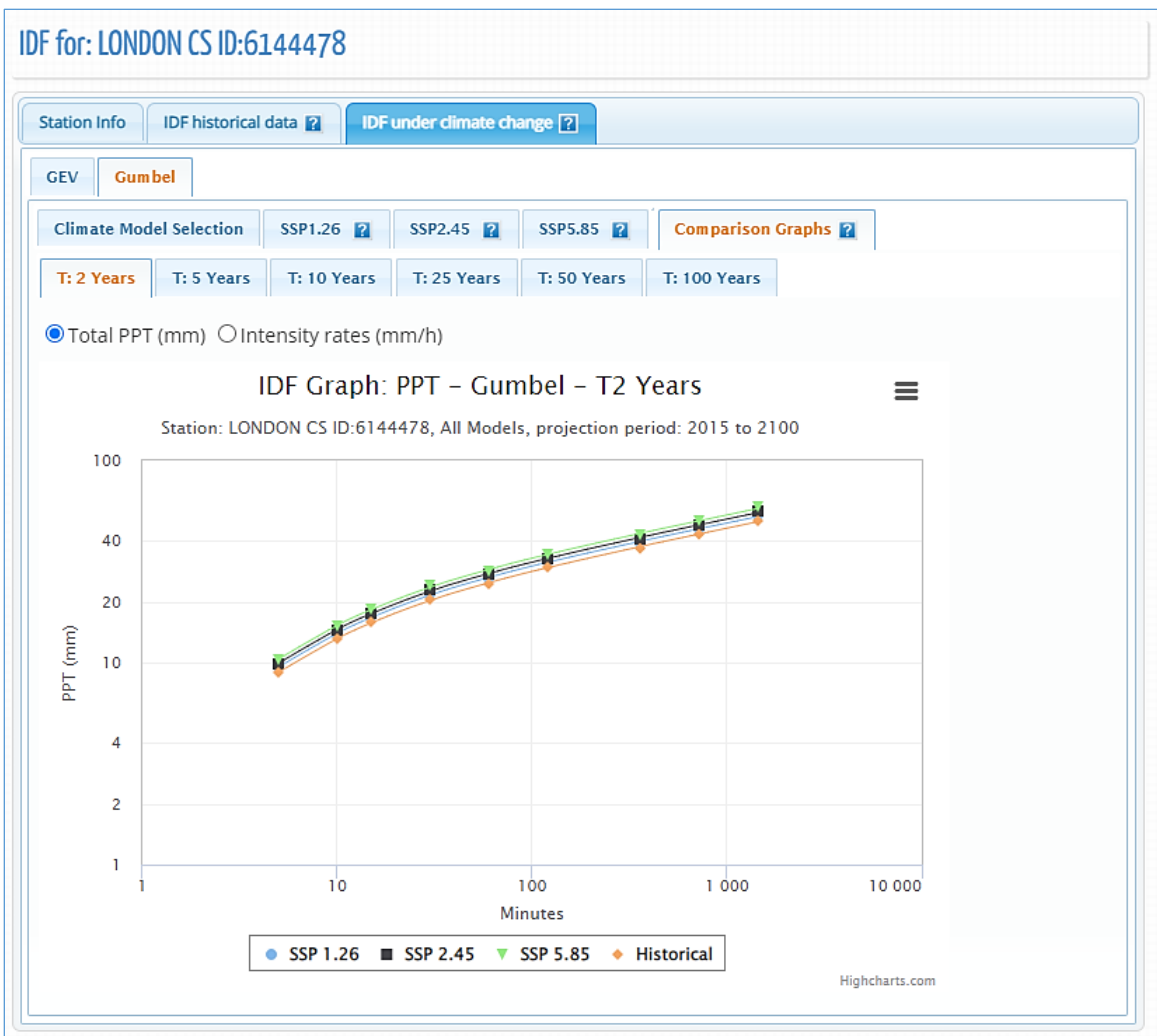


Figure 68. IDF comparison graphs

4 Review of IDF Updating Procedures

The IDF_CC tool version 6.5 offers three ways to obtain the updated IDF curves for future climatic conditions based on the selected GCM models. The first and more direct way is to use an existing station from the Environment Canada stations. The user should follow the three easy steps to update the IDF for future climatic conditions as illustrated in Figure 69: 1) select one station, either from the map or from the list of stations; 2) calculate the IDF curves using the historical data (intermediate step) that can be used for comparison with the updated IDF for the future climatic conditions; and 3) select the GCM model and projection period and generate updated IDF curves for future climatic conditions.

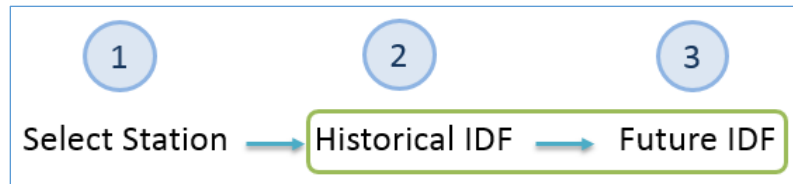


Figure 69. Updating IDF for future climatic conditions for an Environment Canada station

The second option includes one additional step where the user creates their own station by providing information and data as shown in Figure 70. The remaining steps are the same as in the previous option.

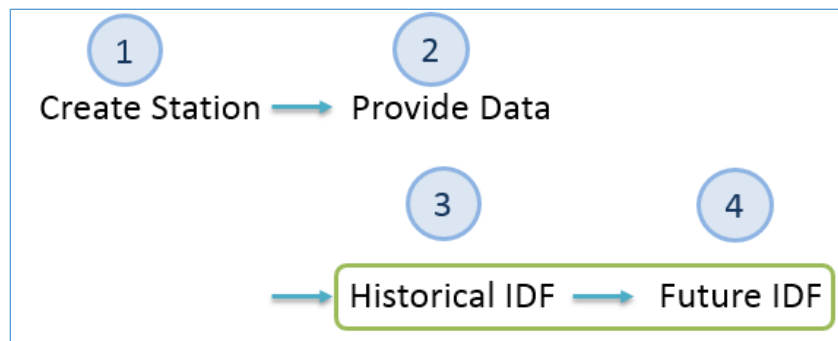


Figure 70. Updating IDF for future climatic conditions for a user provided station

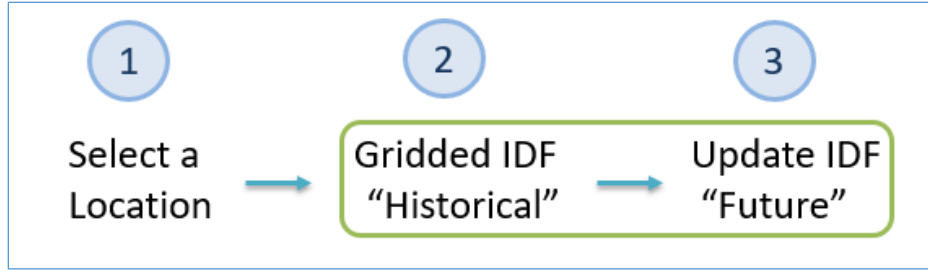


Figure 71. Updating IDFs for future climatic conditions for a selected location within Canada (Gridded IDFs)

5 Final Comments

This report presents the User's Manual for the *Computerized IDF_CC tool for the Development of Intensity-Duration-Frequency-Curves Under a Changing Climate Version 6.5*. It aims to assist in the updating of IDF curves for future climatic conditions. The IDF_CC tool uses a sophisticated though efficient methodology that incorporates changes in the distributional characteristics of GCMs between the baseline period and the projection period. The IDF_CC tool is easy to use and radically simplifies the IDF update process by automating very demanding procedures like downloading, extracting and manipulating data from various GCM models. The IDF_CC tool's website www.idf-cc-uwo.ca should be regularly visited for the latest updates of the IDF_CC tool, new functionalities and updated documentation.

Acknowledgments

The authors would like to acknowledge the financial support by the Canadian Water Network Project under the Evolving Opportunities for Knowledge Application Grant to the second author for the initial phase of the project, and the Institute for Catastrophic Loss Reduction for continuous support of this project.

References

- Allan R.P, and B.J. Soden, (2008). Atmospheric warming and the amplification of precipitation extremes. *Science* 321: 1480–1484.
- Barnett D.N., S.J. Brown, J.M. Murphy, D.M.H. Sexton, and M.J. Webb, (2006). Quantifying uncertainty in changes in extreme event frequency in response to doubled CO₂ using a large ensemble of GCM simulations. *Climate Dynamics* 26(5): 489–511, DOI: 10.1007/S00382-005-0097-1.
- Department of Energy Lawrence Livermore National Laboratory (2021) CMIP6 - Coupled Model Intercomparison Project Phase 6, <https://pcmdi.llnl.gov/CMIP6/>, last accessed July 2021.
- Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, *Geosci. Model Dev.*, 9, 1937–1958, <https://doi.org/10.5194/gmd-9-1937-2016>, 2016.
- Gaur, A., Schardong, A., Simonovic, S.P. Gridded extreme precipitation Intensity—Duration-Frequency estimates for the Canadian landmass. *J. Hydrol. Eng.* 2020, 25.
- IPCC, (2013). Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- O’Neill et al. 2016: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6, *Geosci. Model Dev.*, 9, 3461–3482, 2016, doi:10.5194/gmd-9-3461-2016
- Pacific Climate Impacts Consortium (PCIC), (2013). *Statistically downscaled climate scenarios*, <https://pacificclimate.org/data/statistically-downscaled-climate-scenarios> last accessed July 15, 2017.
- Sandink, D., S.P. Simonovic, A. Schardong, and R. Srivastav, (2016) A Decision Support System for Updating and Incorporating Climate Change Impacts into Rainfall Intensity-Duration-Frequency Curves: Review of the Stakeholder Involvement Process, *Environmental Modelling & Software Journal*, 84:193-209.

- Schardong, A., S. P. Simonovic, A. Gaur, and D. Sandink (2020) Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate at Gauged and Ungauged Locations, *Water, Special Issue Extreme Value Analysis of Short-Duration Rainfall and Intensity–Duration–Frequency Models*, 12, 1243; doi:10.3390/w12051243, open access, <https://www.mdpi.com/2073-4441/12/5/1243/pdf>.
- Simonovic, S.P., A. Schardong, D. Sandink, and R. Srivastav, (2016) A Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate, *Environmental Modelling & Software Journal*, 81:136-153.
- Solaiman, T.A. and S.P. Simonovic, (2011). Development of Probability Based Intensity-Duration Frequency Curves under Climate Change. *Water Resources Research Report no. 072*, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 89 pp. ISBN: (print) 978-0-7714-2893-7; (online) 978-0-7714-2900-2.
- Solaiman, T.A., L.M. King, and S.P. Simonovic, (2011), Extreme precipitation vulnerability in the Upper Thames River basin: uncertainty in climate model projections. *Int. J. Climatol.*, 31: 2350–2364. doi:10.1002/joc.2244
- Srivastav, R.K., A. Schardong., and S.P. Simonovic, (2014) Equidistance Quantile Matching Method for Updating IDF Curves under Climate Change, *Water Resources Management*. DOI 10.1007/s11269-014-0626-y.
- Storn, R. and K. Price, (1997) ‘Differential Evolution - A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces’, *Journal of Global Optimization*, 11, pp. 341–359.
- Wilcox, E.M., Donner L.J., (2007) The frequency of extreme rain events in satellite rain-rate estimates and an atmospheric general circulation model. *Journal of Climate* 20(1): 53–69.
- Vasan A., (2008) Optimization Using Differential Evolution. *Water Resources Research Report no. 060*, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 38 pp.

Appendix - A: Papers/Reports on Differential Evolution - DE

Vasan A. (2008) - Optimization Using Differential Evolution. *Water Resources Research Report no. 060*, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 38 pp:

<http://www.eng.uwo.ca/research/iclr/fids/publications/products/60.pdf>

Storn, R. and Price, K. (1997), 'Differential Evolution - A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces', *Journal of Global Optimization*, 11, pp. 341–359.

<http://link.springer.com/article/10.1023%2FA%3A1008202821328>

Appendix – B: Journal papers on the IDF_CC tool:

1. Sandink, D., S.P. Simonovic, A. Schardong, and R. Srivastav, (2016) A Decision Support System for Updating and Incorporating Climate Change Impacts into Rainfall Intensity-Duration-Frequency Curves: Review of the Stakeholder Involvement Process, *Environmental Modelling & Software Journal*, 84:193-209.

Article link: <https://doi.org/10.1016/j.envsoft.2016.06.012>

2. Simonovic, S.P., A. Schardong, D. Sandink, and R. Srivastav, (2016) A Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate, *Environmental Modelling & Software Journal*, 81:136-153.

Article link: <https://doi.org/10.1016/j.envsoft.2016.03.016>

3. Schardong, A., A., Gaur, and S.P. Simonovic, (2018) “Comparison of the theoretical Clausius-Clapeyron scaling and IDF_CC tool for updating Intensity-Duration-Frequency Curves under climate change for Canada”, *ASCE Journal of Hydrologic Engineering*, 23(9): 04018036-1.

Article: available upon request

4. Gaur, A., A. Schardong, and S.P. Simonovic, (2018) “Effects of Global Warming on Precipitation Extremes: Dependence on Storm Characteristics”, *Water Resources Management*.

Article link: <https://doi.org/10.1007/s11269-018-1949-x>

5. Schardong, A. and S.P. Simonovic, (2019) “Application of Regional Climate Models for updating Intensity-Duration-Frequency Curves under climate change”, *International Journal of Environment and Climate Change*, 9(5):311-330.

Article: available upon request

6. Schardong, A. and S.P. Simonovic, (2019) “Application of Regional Climate Models for updating Intensity-Duration-Frequency Curves under climate change”, *International Journal of Environment and Climate Change*, 9(5):311-330.

Article: available upon request

7. Gaur, A., A. Schardong, and S.P. Simonovic, (2020) “Gridded Intensity – Duration - Frequency estimates across Canada”, *ASCE Journal of Hydrologic Engineering*, 25(6): 05020006.

Article: available upon request

8. Schardong, A., S. P. Simonovic, A. Gaur, and D. Sandink (2020) “Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate at Gauged and Ungauged Locations”, *Water, Special Issue Extreme Value Analysis of Short-Duration Rainfall and Intensity–Duration–Frequency Models*, 12, 1243; doi:10.3390/w12051243, open access.

Article link: <https://www.mdpi.com/2073-4441/12/5/1243/pdf>