Technical Note

Project:	SADC ClimSA TA: Technical Assistance to the Intra-ACP Climate Services and Related Applications Programme for SADC Secretariat
Subject:	Manual for the Climate Forecasting Tool (CFT) Verification Module
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Document history

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Client signoff

Client	SADC Secretariat
Project	SADC ClimSA TA: Technical Assistance to the Intra-ACP Climate Services and Related Applications Programme for SADC Secretariat
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Client signature / date	

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1. Background

This manual provides a description of the CFT Verification Module that is implemented as a part of **SADC Climate Forecasting Tool** – a software for generation of seasonal forecast using statistical approaches that is used by the Climate Experts Meeting (CEM) to provide forecast as a basis of the Seasonal Outlook document issued by the Southern African Regional Climate Outlook Forum's (SARCOF).

The CFT Verification Module was initially developed by the Southern African Development Community's Climate Services Centre (SADC) under the SARCIS-DR project. It was further developed under funding from SADC ClimSA programme by the ClimSA Technical Assistance Team.

The objective of the CFT Verification Module is to extend the functionality of the SADC Climate Forecasting Tool (CFT) to enable **verification of an individual SARCOF forecast**, and in effect improving the seasonal forecasting process and its outcomes in the SADC region.

This is in response to the need for **objective verification of forecast products** required by the Objective Forecast Methodology (OSF), as defined in WMO Guidance on Operational Practices for Objective Seasonal Forecasting, (WMO, 2020).

The CFT Verification Module implements verification approaches recommended by **WMO Guidance on Verification of Operational Seasonal Climate Forecasts** (WMO, 2018) with respect to **individual forecast maps**.

2. Functionality, applicability, and limitations

2.1. Functionality

- Calculates skill measures for a single forecast.
- Implements a user-selected set of forecast skill measures (see **Error! Reference source not found.** below and Section 6).
- Skill measures are evaluated by comparing forecast to observations over the period for which the forecast was issued. Observed values over longer-term climatological period are used in the process too.
- The climatological period is user-defined.
- Observations can be provided in the form of time series of gridded maps or time series data for individual stations.
- Skill measures are presented in the form of:
    - spatial maps
    - average values over spatial regions
- The regions can be those for which the forecast was issued, or alternatively, a different set of zones can be provided by the user (e.g., country, or provincial boundaries).
- The maps are generated in the form of images (in jpeg format), but also in the form of data in netCDF or csv format. The data can be used for further analyses or plotting using alternative software.

2.2. Applicability

CFT Verification Module is designed to allow verification of forecast of type that is used in the SARCOF CEM process, i.e., a forecast that has the following characteristics:

- Forecasted variable is the mean seasonal, i.e., 3-month total rainfall. The Module can also be used to verify forecasts of 2-month and 1-month rainfall total.
- Issued for zones, with each zone assigned a single forecast category and a set of tercile probabilities (see Figure 1 below).

- Forecast is categorical, with four forecast categories, the so called **CEM categories: Below Normal, Normal to Below Normal, Normal to Above Normal and Above Normal.** In defining these categories, the central tercile category is split into two categories, as illustrated in Figure 2 below.
- Each CEM category has fixed, pre-determined probabilities of standard terciles (<33 percentile, 33-66 percentile and >66 percentile) (as per Table 1 and Figure 2 below).

CFT Verification Module can be used only to verify **a single forecast.**

2.3. Limitations

The CFT Verification Module currently does not provide functionality to work with forecasts that are:

- Generated in gridded form.
- Deterministic, or probabilistic, but with probabilities expressed as standard tercile probabilities.
- For variables other than monthly to seasonal rainfall.

It does not provide functionality to evaluate skill based on the time series of forecasts.

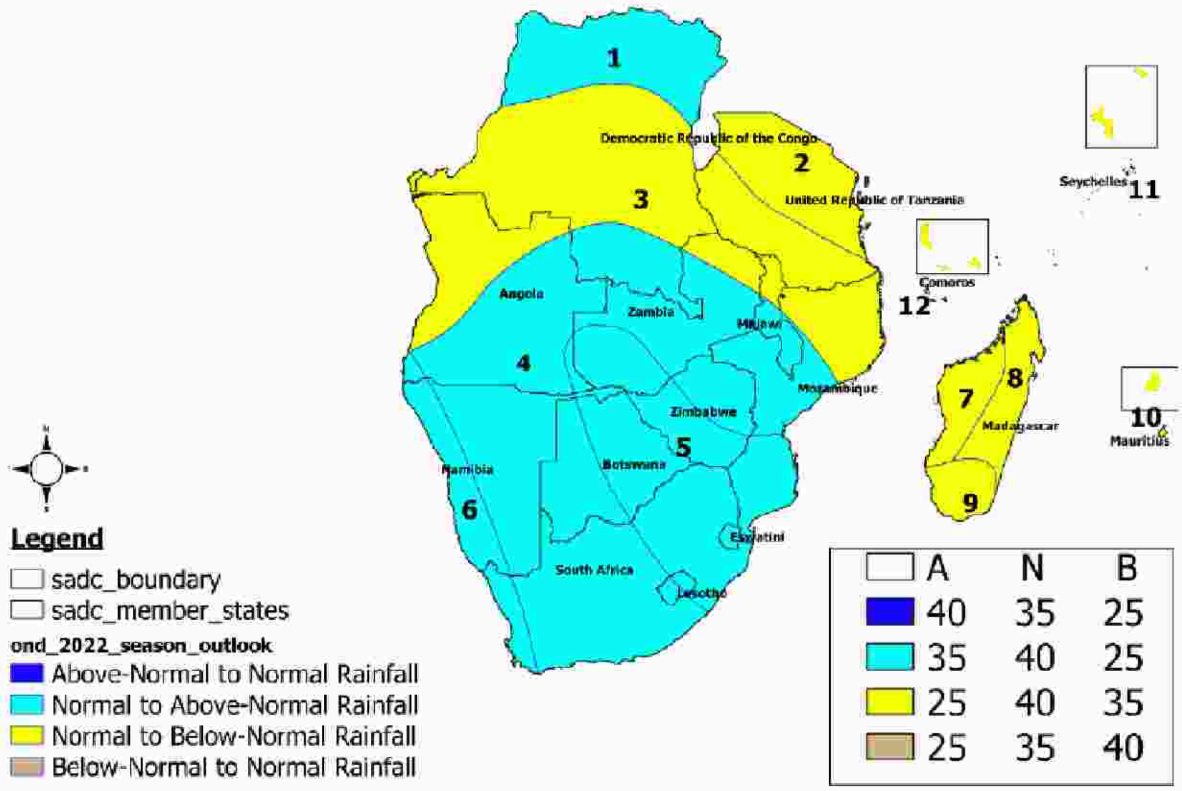


Figure 1 Example of SARCOF forecast using four CEM categories.

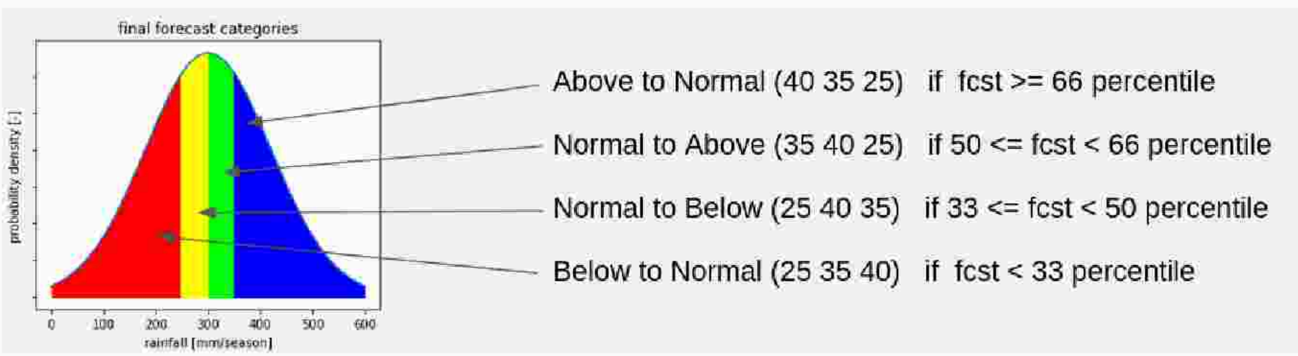


Figure 2: Definition of four CEM forecast categories. Numbers in brackets correspond to tercile probabilities associated with each CEM category. The CFT methodology assigns the CEM category based on percentile range into which the deterministic statistical forecast ("fcst" in the figure) falls into, with four categories obtained from standard terciles by splitting the central tercile into two categories around the 50th percentile.

Table 1: Tercile probabilities associated with the four CEM forecast categories

CFT forecast category	Code		
	<33 percentile	33-66 percentile	>66 percentile
Below Normal	40	35	25
Normal to Below Normal	35	40	25
Normal to Above Normal	25	40	35
Above Normal	25	35	40

3. Installation

The Verification Module is automatically installed when installing the CFT software program. For additional information on the CFT software program, – users are advised to consult the manual (CFT_manual.pdf). Steps provided below can be followed to install the entire CFT software, but with a focus on the functionality of the Verification Module.

3.1. Installing required software (QGIS)

1. The main software requirement for Climate Forecasting Toolbox (CFT) is Python v3 which can run on any operating system.
2. On Windows OS, it is recommended to link the CFT to a QGIS installation.
3. QGIS installation includes Python and there is no need to install Python separately.
4. The recommended QGIS version is 3.16 (or higher). If you have older version - please upgrade. If you are installing QGIS for the first time - use the most recent LTR (long term release). QGIS can be downloaded from https://www.qgis.org/en/site/forusers/download.html# (see Figure 3)

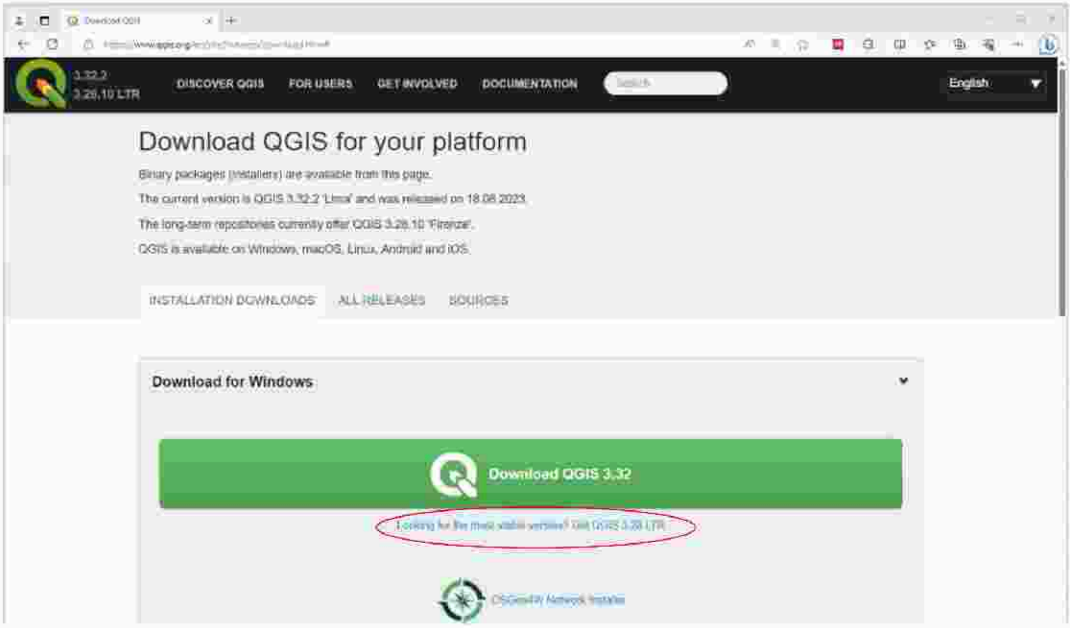


Figure 3: Webpage of where to download the QGIS software (the link to download the LTS version circled in red)

5. Step-by-step instructions on QGIS installation are provided in Section 9.1 - Appendix 1.

3.2. Installing CFT

1. The latest version of the CFT Forecasting Toolbox is available for download from the SADC-CSC GitHub repository, https://github.com/sadccsc/cft.
2. Download the latest release version of the toolbox (See Figure 4).

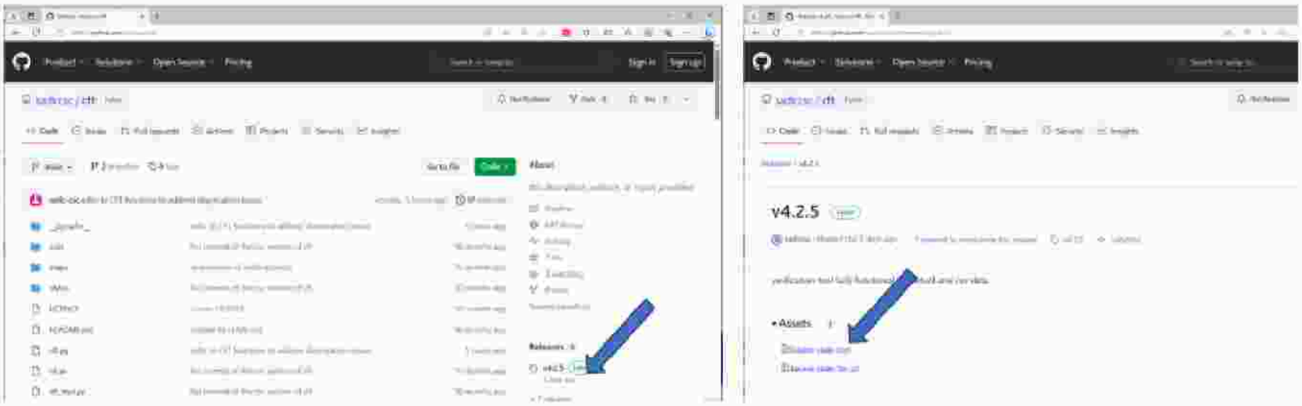


Figure 4: Webpage view of the SADC CSC GitHub repository where the CFT software toolbox can be downloaded from

3. Navigate to the folder where the downloaded zip file (e.g., cft-4.2.5.zip) is located (usually the Downloads Folder). When clicking on the zipped file, an 'Extract All' icon will appear (Figure 5 - arrow A). Click on the icon, and a pop-up window will appear (left – image), click on the 'Browse' button (Figure 5 – arrow B) to navigate to an installation directory (directory where you want to keep the CFT software). Once the directory is selected, click on the 'Extract' button, the extraction process will start, when it is done, a window will open showing the folder on which the CFT software is located (See Figure 6 – arrow A for path to folder).

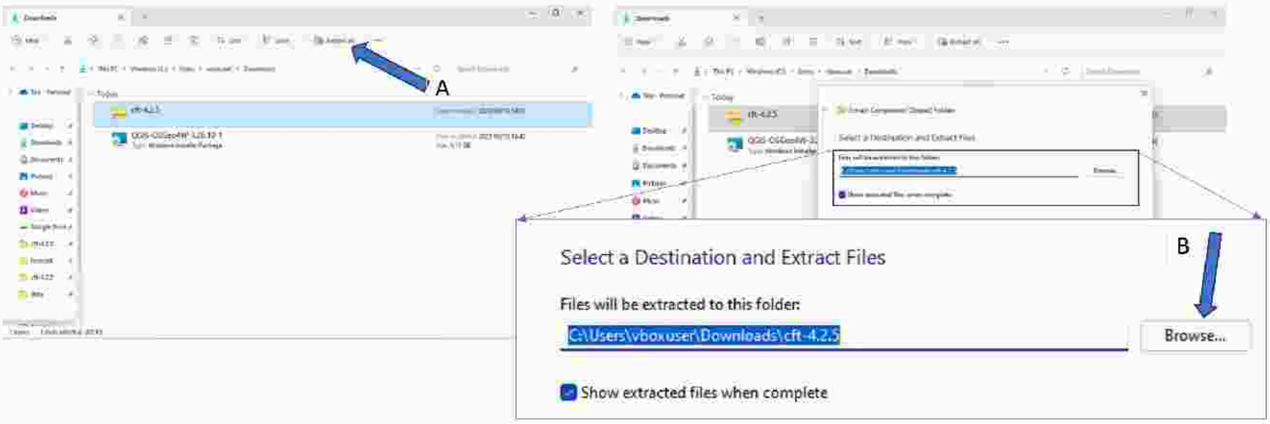


Figure 5: Where to find the downloaded zipped file of CFT and the extraction process.

4. Double click on the folder to see contents (Figure 6). The installation instructions for different platforms are provided in the README.md file which is part of the installation package (Figure 6– arrow B).

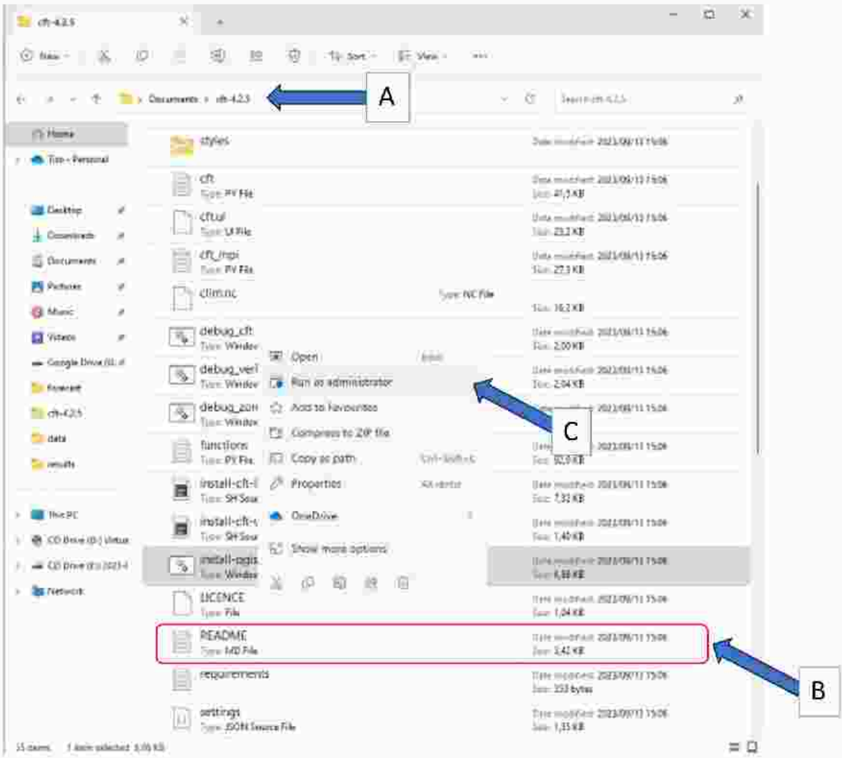


Figure 6: Location of extracted CFT software files

5. On Windows - installation is done by running install-qgis-Modules.bat as administrator (right click on the file and select 'Run as administrator' option (Figure 6 – arrow C) - this will download and install the needed python Modules. Sometimes a blue warning window will appear, click on the 'More info' hyperlink (Figure 7 – arrow A) and a 'Run anyway' button will appear (Figure 7 – arrow B). Once clicked, another window will appear, click on the 'Yes' option to allow installation (Figure 7 – arrow C). **Note: If you do not have administrative privileges on the computer, an administrator may be required to provide administrator credentials before the installation can proceed.**

Figure 7: Steps to follow to install the CFT toolbox software on Windows 11

6. During installation, a terminal window will appear (Figure 8 – top), with messages of installation progress being written to the screen, and when completed the terminal will return the message "Press any key to close" (Figure 8 – bottom). Press any key on the keyboard to close the window.

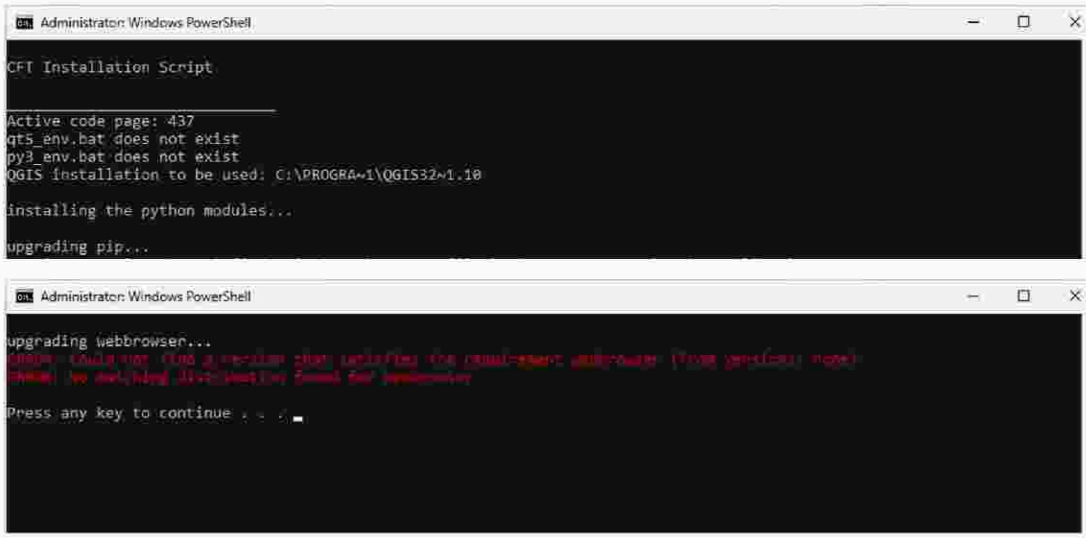


Figure 8: View of Windows terminal at the start (top) and end (bottom) of the CFT toolbox installation process on Windows 11

7. Once the installation is complete, a new shortcut icon (Figure 9 – arrow A) will appear in the CFT Toolkit installation folder, when double clicked, two windows must appear and the Verification Module can be launched by clicking on the ‘Verification’ button on the ‘Climate Forecasting Toolbox’ window (Figure 9 – arrow B). For additional information on how to use the Verification Module, refer to Section 5.

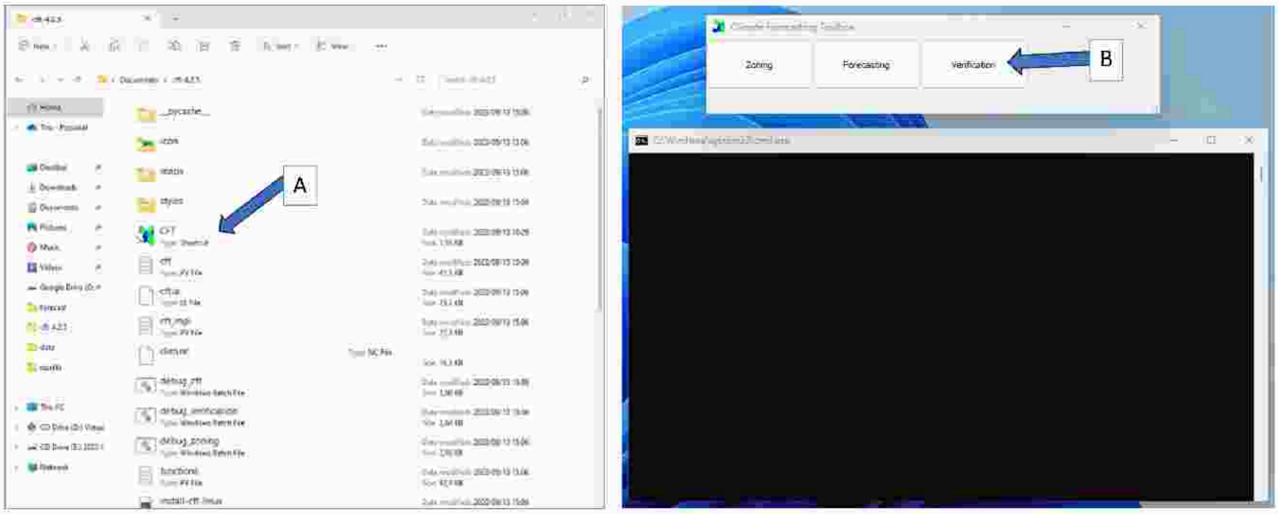


Figure 9: View of the CFT Toolbox folder on windows, location of short-cut (left) and windows that appear after launch (right) indicating successful installation.

4. Input and output data requirements and formats

4.1. Input data

The CFT Verification Module requires the following input data:

- Forecast map in geoJSON vector format (required)
- Time series of observations (required) of either of two types:
  - Gridded data in netCDF format
  - Station data in CSV format
- Map of zones for summarizing the skill scores in geoJSON format (optional)

4.1.1. Forecast data.

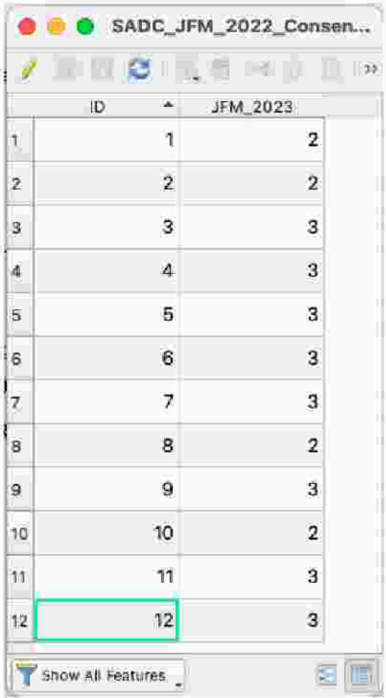
The forecast vector file accepted by the tool must be in a geoJSON format and it must include an attribute table with two attributes (columns)

1. an 'identifier' attribute or code that uniquely identifies each polygon feature. The name of the identifier column of the attribute table is not prescribed, but it is recommended that it is informative - for example ID, or CODE, or NAME. The identifier attribute must be unique, i.e., each polygon or feature must have an identifier attribute, and codes cannot repeat. The format and contents of the identifier attribute is not prescribed. It can be a numerical value (e.g., 1,2,10), or a string (e.g., North, Botswana). ***Note: the identifier attribute is used to label polygons and summary graph bars. It is thus recommended that the values are recognizable and human readable. Note, however, that longer codes will be truncated to 3 characters only. So, for example: "North" will be truncated to "Nor", "Botswana" will be truncated to "Bot", "1045" will be truncated to "104".***
2. the attribute that describes the CEM category of the forecast. The name of the forecast column of the attribute table is not prescribed, but it is recommended that it is informative - i.e., that it reflects the date of the forecast, for example SON_2023, or MAM_2022. It is recommended that the name does not contain spaces, but rather underscore character ("_"). Then forecast attribute column must contain code corresponding to forecast category as per Table 2. The format of the column should be integer. Including any other value than the ones listed in Table 2 will cause an error. Each polygon has to have a forecast code, i.e., the forecast code field cannot be empty.

Figure 10 below presents an example content of the geoJSON attribute table. Step-by-step instructions how to prepare the geoJSON file in QGIS are presented in Section 4.2

Table 2: Forecast category codes that should be used for defining forecast categories for use in the CFT verification Module.

CFT forecast category	Code
Below Normal	1
Normal to Below Normal	2
Normal to Above Normal	3
Above Normal	4



SADC_JFM_2022_Consen...

	ID	JFM_2023
1	1	2
2	2	2
3	3	3
4	4	3
5	5	3
6	6	3
7	7	3
8	8	2
9	9	3
10	10	2
11	11	3
12	12	3

Show All Features

Figure 10: Example of attributes table for the geoJSON file required for use with the CFT verification Module.

4.1.2. Time series of observations

Observations here refer to the observation dataset to be used to verify the forecast.

- Data must be of total monthly rainfall, with values expressed in mm/month.
- The time coverage of the dataset chosen for verification needs to cover the climatological reference period and the season of interest.
- It is recommended that the dataset used for verification is that used in the forecast generation process.
- The Module accepts either gridded or point (or station) data.
- Gridded data are to be provided in a netCDF format:
    - The Module accepts only one input file, so in case time series data are available in multiple files, those must be concatenated into a single file using appropriate software prior to use.
    - The Module accepts netCDF files downloaded from [IRI Data Library]() and will accept any netCDF file that is CF compliant (http://cfconventions.org/).
    - The netCDF file may contain other variables than rainfall – user will be asked to select the variable of interest on selecting the file.
    - The data array for the rainfall variable in the netCDF file needs to have the 'time, longitude (Module recognizes lon, X or x) and latitude (Module recognizes lat, Y or y) dimensions.
    - Spatial extent of the data should be such that the entire region for which forecast is done is covered. If that is not possible – zones for which there is no data will be marked with as "missing data" in output figures.
- Station data are to be supplied in a CFT - CSV format, i.e., format required by the CFT software for production of forecast. An example screenshot of the head of the CSV file is provided in Figure 11. The following must be adhered to for the Module to run successfully.
    - **file extension:** .csv
    - **first line:** names of columns: ID, Lat, Lon, Year and names of 12 months
    - **subsequent lines:** one line per year of data, each line must have:
        - station ID

- station latitude
- station longitude
- year
- 12 values (one value for each month)

- values must be separated by a comma (,)
- **missing values**: marked with -9999, no empty cells are allowed.

```
ID,Lat,Lon,Year,Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sep,Oct,Nov,Dec
PEMBA,-12.983,40.533,1981,52.1,150.9,95.9,41.5,42.5,19.2,5.1,3.6,1.8,11.0,11.6,109.9
PEMBA,-12.983,40.533,1982,90.2,239.6,111.9,71.3,28.4,7.0,6.9,12.0,1.3,35.4,76.1,173.9
PEMBA,-12.983,40.533,1983,221.9,91.4,209.2,73.6,45.5,14.3,5.2,7.9,1.6,7.9,19.4,80.7
PEMBA,-12.983,40.533,1984,165.1,157.1,152.6,101.2,32.3,26.2,14.5,7.8,1.2,13.5,21.4,223.1
PEMBA,-12.983,40.533,1985,114.0,185.5,104.8,140.0,18.2,11.7,19.3,10.5,1.7,8.0,70.2,99.7
PEMBA,-12.983,40.533,1986,189.3,197.3,130.9,102.6,16.9,10.3,9.3,5.9,1.4,23.2,66.6,224.5
PEMBA,-12.983,40.533,1987,130.0,114.0,146.8,45.4,21.1,7.9,9.0,7.8,1.4,7.9,62.0,11.4
PEMBA,-12.983,40.533,1988,152.8,173.6,66.3,77.0,35.3,6.0,5.3,9.8,1.4,6.4,74.0,68.9
PEMBA,-12.983,40.533,1989,244.7,141.7,259.0,82.4,107.5,13.0,13.4,14.2,1.4,5.8,48.6,175.5
PEMBA,-12.983,40.533,1990,81.1,233.9,97.4,144.0,28.9,5.3,22.8,12.8,1.5,12.0,13.8,102.3
PEMBA,-12.983,40.533,1991,117.9,133.4,392.5,138.1,38.2,8.6,22.8,6.5,1.5,7.1,34.8,223.8
PEMBA,-12.983,40.533,1992,107.1,158.2,137.8,129.2,35.0,12.5,18.6,6.3,1.7,11.0,86.1,20.0
PEMBA,-12.983,40.533,1993,201.0,149.8,311.5,101.8,15.3,9.7,13.7,9.8,1.4,5.2,26.7,75.0
PEMBA,-12.983,40.533,1994,194.2,216.0,104.4,61.7,11.8,6.7,6.0,7.0,1.5,7.0,11.5,111.4
PEMBA,-12.983,40.533,1995,198.4,216.7,184.1,73.0,38.7,5.3,5.2,15.4,1.6,6.4,8.9,118.7
PEMBA,-12.983,40.533,1996,174.9,204.4,76.2,41.5,34.0,7.9,11.1,6.0,1.2,9.6,6.7,87.4
```

Figure 11: An example screenshot of the data format for the CSV file, opened in Notepad, required for running as observation in the CFT Verification Module.

Important considerations

- all stations can be in the same file (more stations=more rows of data), or alternatively each station can be stored in a separate file, and all files must be loaded to predictand box in CFT.
- There must not be any empty rows in the file, i.e., lines with commas only and no data in between them at the bottom of the file, this can be checked by opening the file using a text editor, instead of Microsoft Excel.
- All rainfall values must be numerical entries, not strings, otherwise an error may arise.

4.1.3. Map of zones for zonal summary

The Module provides a functionality to generate summary of skill scores for all points (grid points or stations, depending on which input data are used) falling within a set of zones. Those zones can be those that were used to generate the forecast, or alternatively, a different zonation can be used. In the former case – the forecast geoJSON file can be used, in the latter – a geoJSON file with required zones must be provided.

The format of that geoJSON file is like that of the forecast file, with the exception that the forecast attribute does not have to be present. On uploading the file, user will be asked to identify a relevant attribute to be used to label the zones in output figures.

4.2. Input data preparation

4.2.1. Vector file preparation (geoJSONs)

As described in Section 4.1.1, the forecast data needs to be provided in the geoJSON vector format. To create a new geoJSON vector file from an existing ESRI Shapefile vector or edit an existing geoJSON vector file, one needs to have QGIS installed (see Appendix 1, Section 9.1 for installation instructions), and the steps below are to be followed.

1. To launch the QGIS Desktop application, double click on QGIS Desktop 3.xx.xx shortcut from the Desktop (Figure A5) or from the 'Start' menu. A QGIS window must appear will appear on the screen (Figure 12).

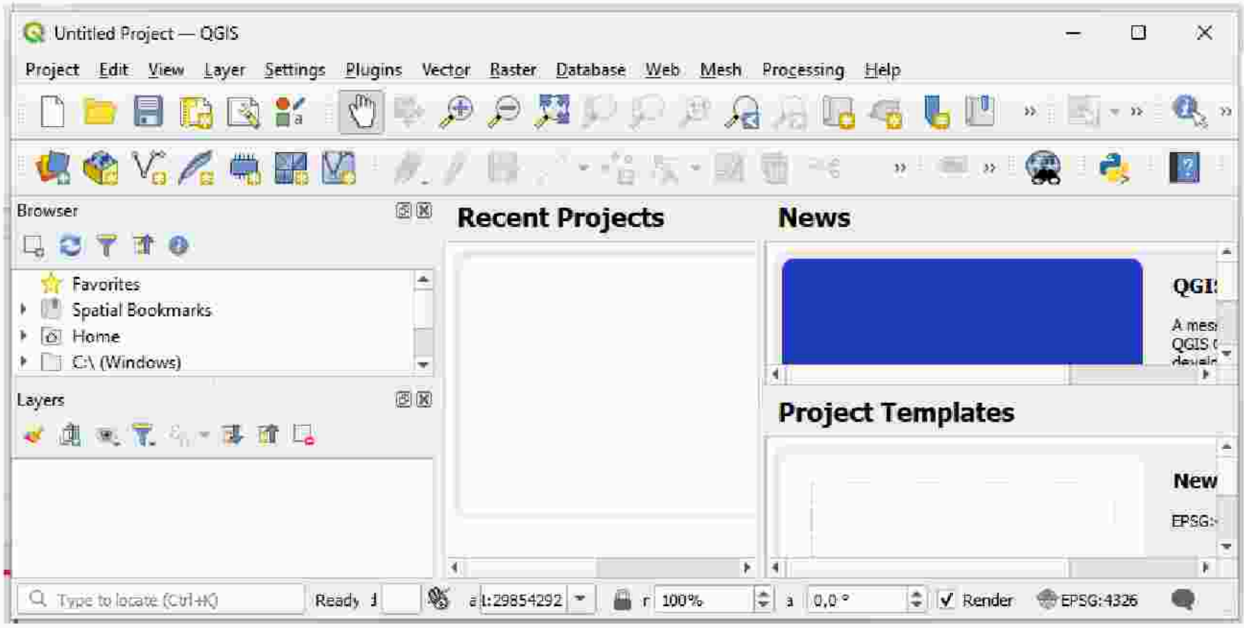


Figure 12: How the QGIS GUI window appears after launching

2. An existing vector file with the forecast 'zones' already defined needs to be available, this can either be an ESRI Shapefile vector or a geoJSON file. The steps to load the vector file to QGIS are summarised in Figure 13 and Figure 14;
    a. Click on the Layer tab on the QGIS menu list (Figure 13 – arrow A)
    b. Move the cursor to 'Add layer' and 'Add vector layer' and click on the selection (Figure 13 – arrow B), a 'Data Source Manager | Vector' window will appear (Figure 13 – right image)
    c. On the window, click on the three dots (Figure 13 – arrow C), this will open another window (Open OGR Supported Vector Dataset(s)) where one needs to navigate to the Folder where the existing vector file is (Figure 14).
    d. Select the existing vector file (Figure 14 – arrow A) and click on the 'Open' button (Figure 14 – arrow B), the window will close, then on the 'Data Source Manager | Vector', click the 'Add' button to load the vector file (Figure 14 – arrow C). The window can be closed.

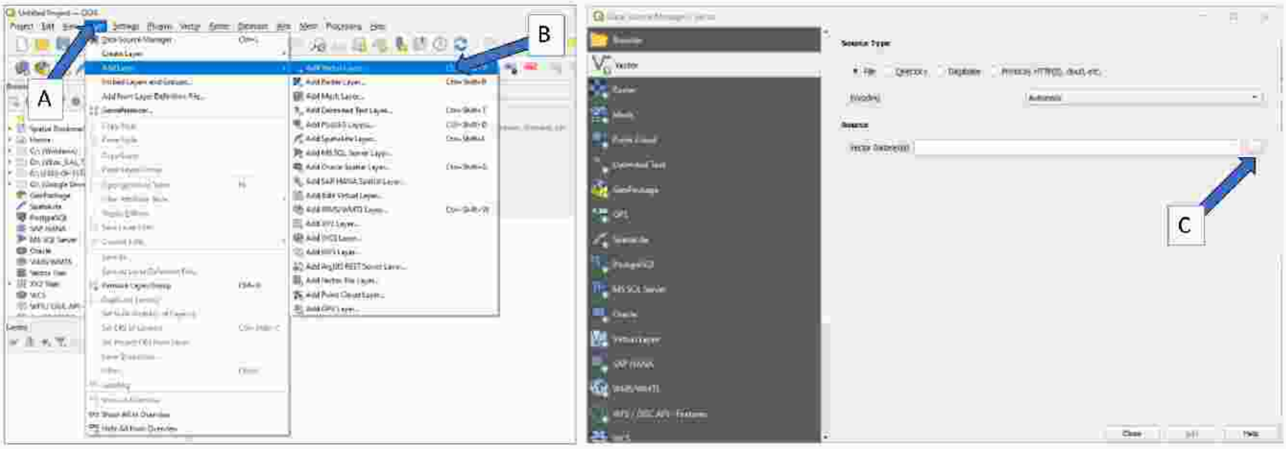


Figure 13: Steps to open a vector file in QGIS.

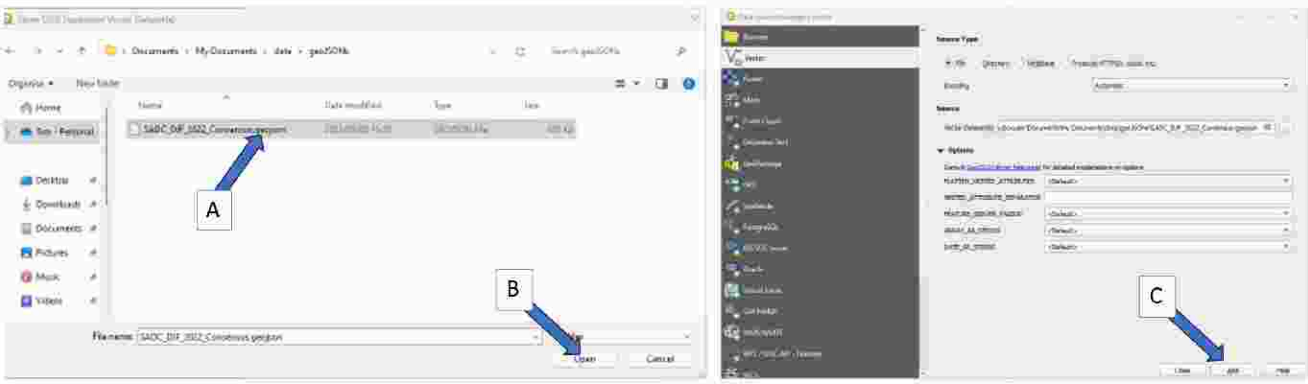


Figure 14: Steps to open vector file in QGIS continued.

3. Once the vector layer is loaded, it must appear on the QGIS window, and listed to the ‘Layers’ sub-window, with a matching colour (Figure 15). The vector layer then needs to be edited to either modify the existing features or add additional features to the layer. Steps to do this are summarized in Figure 15 and Figure 16.
    a. To open the attribute table, select and right click on the layer to be edited (Figure 15 – arrow A)
    b. Select the ‘Open Attribute Table’ option (Figure 15 – arrow B), and a pop-up window will appear with the name of the vector layer at the top (Figure 15 - right image). On the attribute table, a list of available ‘Features’ can be found, with every column representing a feature.
    c. It is required to have a feature in the layer that is unique to each of the different ‘forecast zones’ (see Section 4.1.1), an ‘identifier’. In our case here, the identifier is the ‘ID’ feature. If the identifier does not exist, it can be added to the vector layer by following the same steps as those for adding a new forecast category feature below.

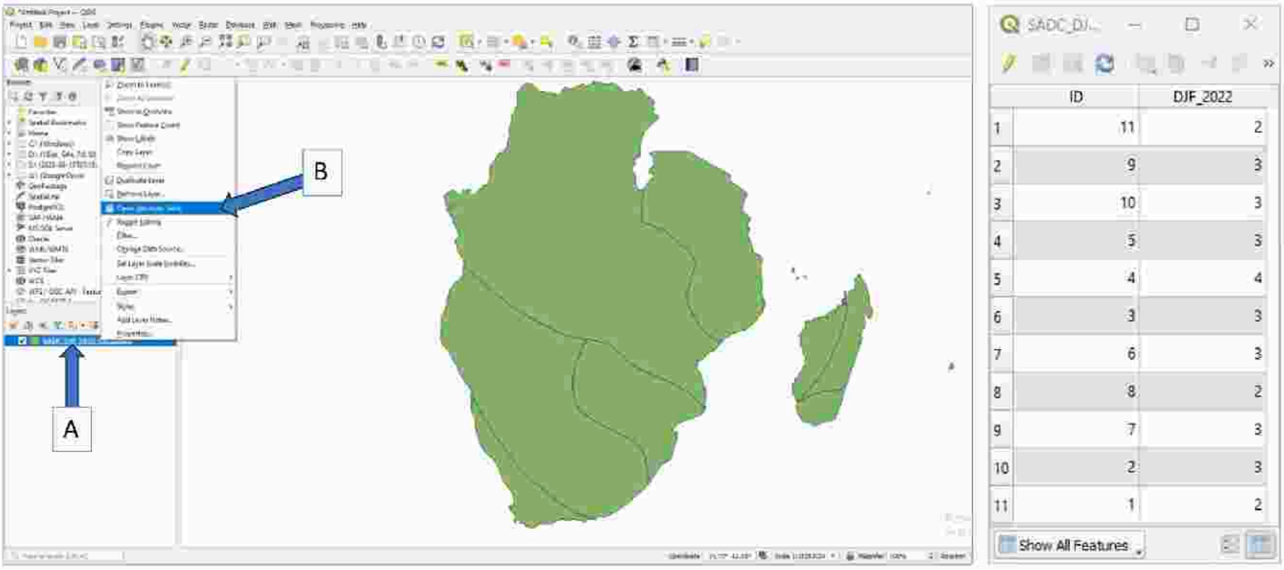


Figure 15: Steps to opening a layer's attribute table in QGIS.

4. To add a new feature to the vector layer, first click on the "Toggle editing mode" pen icon (Figure 16 – arrow A) to enable editing mode. Click on the '>>' icon (Figure 16 – arrow B) to show additional options and select the 'New field' option (Figure 16 – arrow C), this will open an 'Add field' pop-up window, on the window, type the new field name, e.g., MAM_2023 (Figure 16 - arrow D) and the click 'OK' to save (Figure 16 – arrow E). *Note, it is recommended that the underscore '_' character be used as a separator on the name.* An additional column with the provided name will appear on the attribute table (Figure 16 – arrow F) with null values. Change the entries on the column to the corresponding forecast category for each forecast zone (refer to Section 4.1.1 for more information). Once completed, click the "Toggle editing mode" pen icon (Figure 16 – arrow A) again, this will open 'Stop editing' window, click on the "Save" option to save the changes.

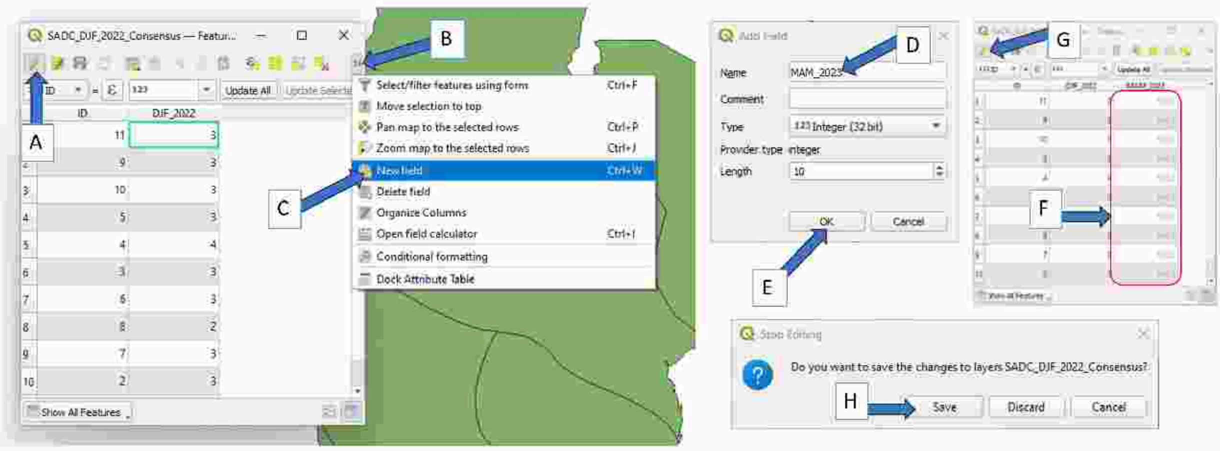


Figure 16: Steps to adding a new feature to a vector layer in QGIS.

5. Once the changes have been saved and a new field added to the layer, the file needs to be saved as a geoJSON vector file. Figure 17 and Figure 18 summarises the steps:
   a. Right click on the name of the layer on the 'Layers' sub-window (Figure 17 – arrow A), and select the 'Export', followed by the 'Save Features as' option (Figure 17 – arrow B). A 'Save vector layer as...' window will appear, click on the 'Format' drop-down option, and scroll down to and select the 'Geojson' option (Figure 17 – arrow C, D). To select the folder to save the file, click on the three dots on the 'File name' option, a 'Save Layer as' window will appear, where one can navigate to the folder where they want to save the file, write the preferred name of the

new file (Figure 18 – arrow A) and click 'Save' (Figure 18 – arrow B). The window will close, on the 'Save vector layer as…' window, click 'Ok' (Figure 17– arrow F), a new layer will be added on the main QGIS window (Figure 18 – arrow C). To confirm that the file has been saved, navigate to the folder where the file was saved, and a new file should be there (Figure 18 – arrow D).

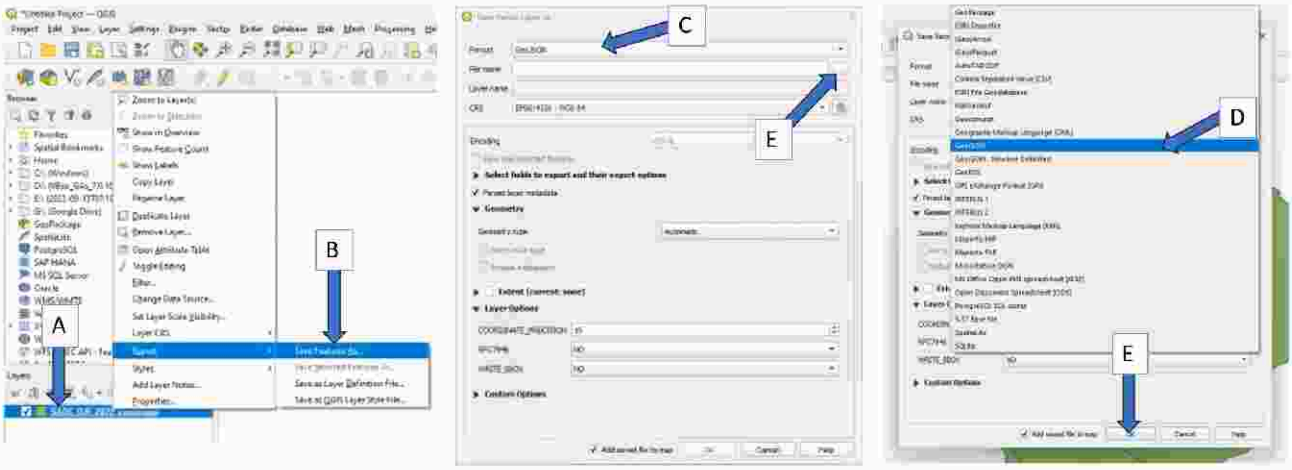


Figure 17: Steps to saving a layer as a geoJSON vector file in QGIS.

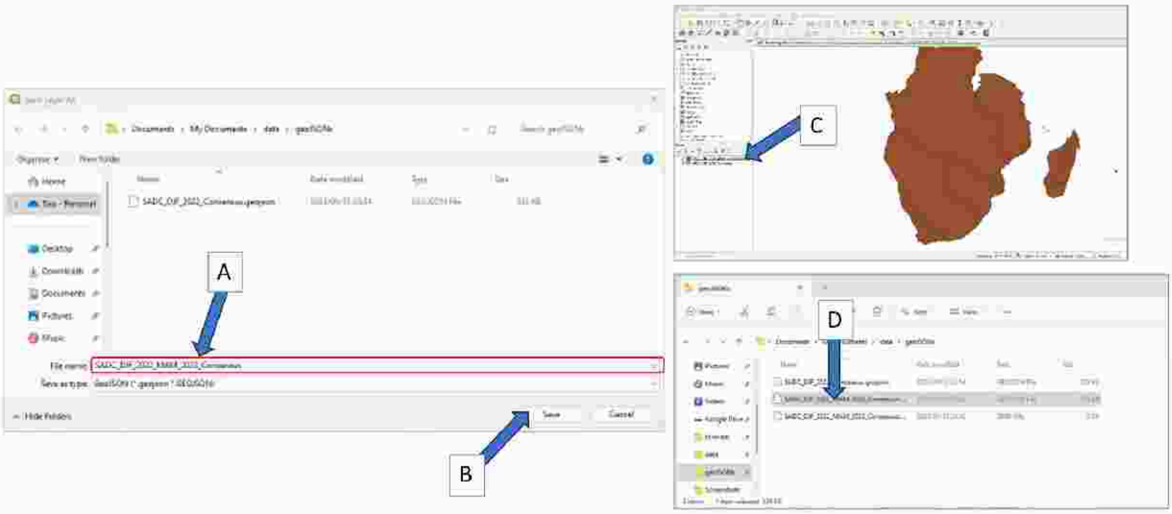


Figure 18: Steps to saving a vector to a geoJSON file in GGIS.

5. How to use CFT Verification Module – Step-by-step instructions

5.1. Step 1 – Launch the Verification Module

5.1.1. Windows (Tested on Windows 11)

To launch the verification Module, there are three options.

1. Once the installation is complete, a new shortcut icon (Figure 19– arrow A) will appear in the CFT Toolkit installation folder, when double clicked, two windows must appear and the Verification Module can be launched by clicking on the 'Verification' button on the 'Climate Forecasting Toolbox' window (Figure 19– arrow B). For additional information on how to use the Verification Module, refer to Section 5.

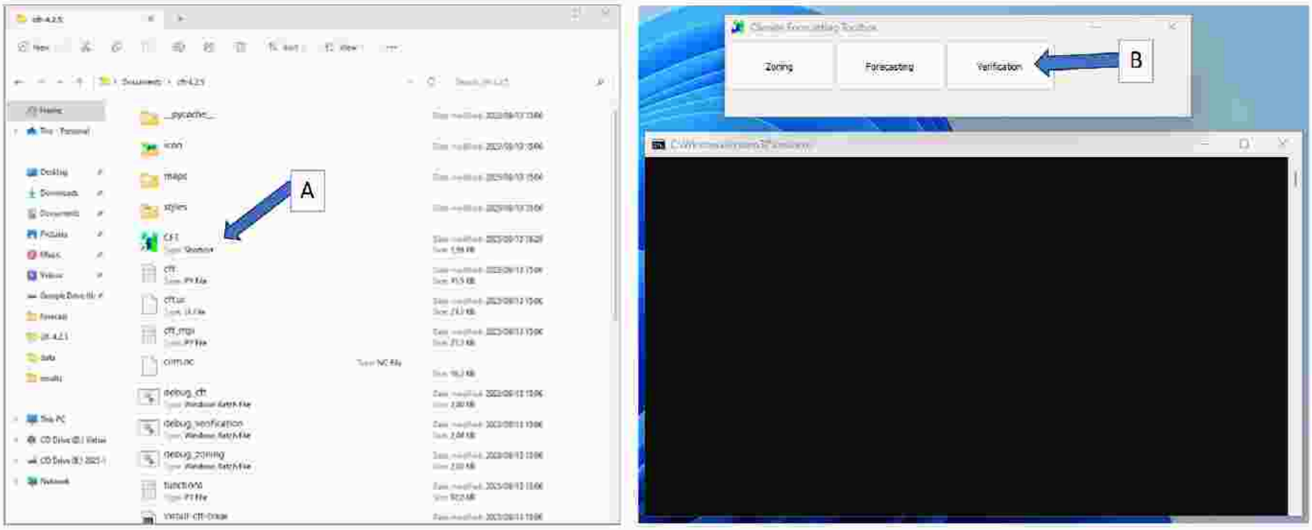


Figure 19: Steps to launch the CFT Toolbox on windows, location of short-cut (left) and windows that appear after launch (right).

2. The Module can be launched be double clicking on the 'start_verification.bat' file. This will open the Module directly without opening the CFT toolbox launch window. ***Note: The Windows Defender protection software may ask for authorization to launch the tool, follow the steps described in Figure 7 to continue.***
3. Th Module can also be opened on 'debug' mode by double clicking on the 'debug_verification.bat' file. The debug mode allows for advanced users to visualize any errors that arise from running the Module from a terminal window. This is also useful for troubleshooting.

5.1.2. Linux (Tested on Ubuntu 22.04 LTS - Jammy)

To be added...

5.1.3. MacOS (Tested on Ventura - Version 13.4)

To be added...

5.2. Step 2 - Familiarize yourself with the GUI (for first time users)

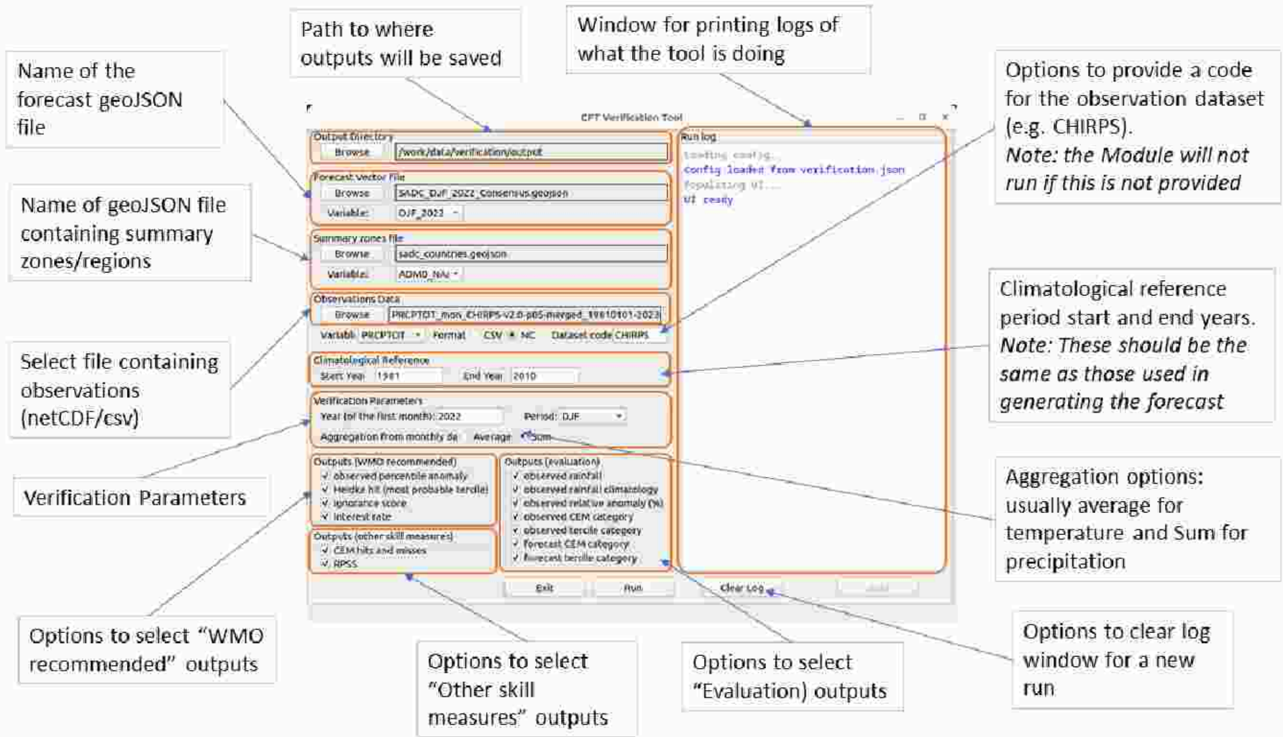


Figure 20: An overview of the GUI for the CFT Verification Module

Note: When the verification tool is launched for the first time, default definitions and paths to files defined in the verification.json file are loaded with the tool. These settings will be replaced by those set by the user when the verification tool is run. It is therefore not recommended to manually edit the verification.json file.

Figure 20 provides an overview of the Graphical User Interface (GUI) of the CFT Verification Module, descriptions of the various components of the GUI are described below:

1. Select inputs.
   - ***Output Directory*** – this is the directory where the outputs from the CFT Verification Module will be stored.
   - ***Forecast Vector File*** – this is the geoJSON file that has the forecast to be verified and evaluated, the file should be formatted according to instructions provided in Section 4.2
   - ***Summary Zones File*** – This is the geoJSON file that has the zones that the forecast was generated for, generally, the Forecast Vector File can be used here, unless the user would like to evaluate the forecast over different regions (e.g., countries). The file should be formatted according to instructions provided in Section 4.2
   - ***Observations Data*** – this is a file that contains the data to be used to evaluate the forecast, it can either be a netCDF or csv file. The file should be formatted according to instructions provided in Section 4.1.2.
2. Selecting the verification parameters
   - ***Forecast period*** – this is the season or months for the forecast to be verified.
   - ***Forecast year*** – this is the year when the last month of the forecast period falls in, for example, when evaluating the January – March (JFM) issued in December 2022 for the 2022-2023 rainfall season, the forecast year should be 2023, the same is the case for December – February (DJF), the forecast year entered must be 2023.

- *Aggregation from monthly data* – here the option of 'sum' is recommended for precipitation and averages for other variables.

5.3. Step 3 – Define output directory and provide input forecast data.

Figure 21 summarises the steps required to define output directory and the options required to load geoJSON vector files for the forecast to be evaluated and the summary zones if the forecast is to be evaluated on regions different from the initial forecast zones, e.g., country level.

1. To define the 'Output Directory', click on the 'Browse' button (Figure 21 – arrow A), this will open a 'Select Folder' window, navigate to and select the desired folder or create a new one (Figure 21 – arrow B) and click 'Select folder' (Figure 21 – arrow C).
2. To add the 'Forecast vector file', click on the 'Browse' button (Figure 21 – arrow D), this will open a 'Select File' window, navigate to the folder where the geoJSON file for the forecast to be evaluated is saved and select the appropriate file (Figure 21 – arrow E), followed by 'Open' (Figure 21 – arrow F) to load the file. Once the file is loaded, the variable layer can be selected from the 'Variable' drop-down menu (Figure 21 – arrow G).
3. For the 'Summary zones file', the same steps as 2 above can be followed (Figure 21 – arrows H, E and F and I) to load the file and select the 'Identifier' variable. ***Note: To evaluate the forecast on the same zones as the forecast zones, the same file has to be loaded twice for the 'Forecast Vector file' and the 'Summary zones file', the only difference being the variable selected for the respective steps (G and I).***

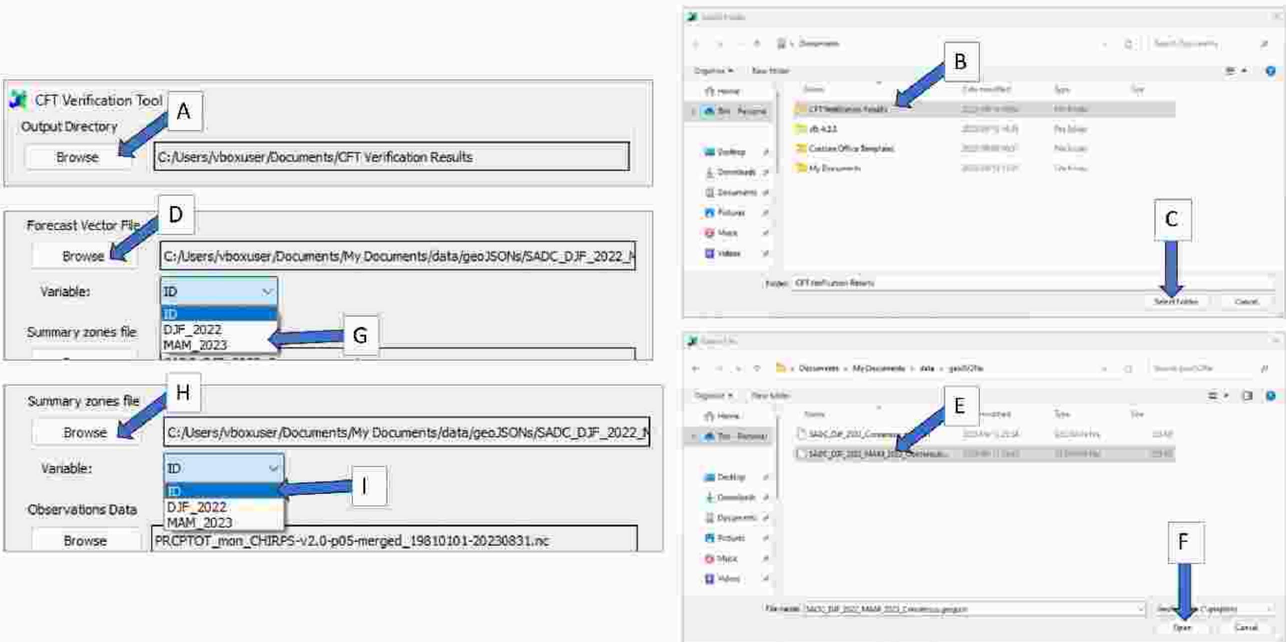


Figure 21: Steps to defining output directory and adding forecast vector files to the CFT verification Module.

5.4. Step 4 – Provide input Observation Data

The next step entails loading the observation dataset needed to evaluate the forecast. The requirements for the data are provided in Section 4.1.2. The Verification Module can accept two data formats, netCDF and CSV formats.

1. To load the data, one needs to first select the data format to be uploaded, i.e., CSV or NC (Figure 22 – arrow A). Click on the 'Browse' button (Figure 22 – arrow B), a 'Select file' window will appear, navigate to the folder containing the observation dataset file, click on the file, then the 'Open' button to load the

file (Figure 22 – arrow C and D). ***Note: If a file with '.nc' for netCDF, or '.csv' for CSV extensions are not available in the folders, then no files will be visible on the 'Select file' window.***

2. For netCDF files, once the file is loaded, the variable name for the precipitation, here 'precip' must be selected (Figure 22 – arrow E).
3. Provide a mandatory 'Dataset Code' (Figure 22 – arrow F), this is an identifier for the dataset that is being used in the verification process, this can be any name, but the name must be able to communicate the origin of the data, for example, if the CHIRPS rainfall estimates are used, using the code 'CHIRPS' will be more appropriate. **Note: This code is also used by the program to annotate the figures produced, as well as create a separate folder for the outputs of the verification based on the dataset.**

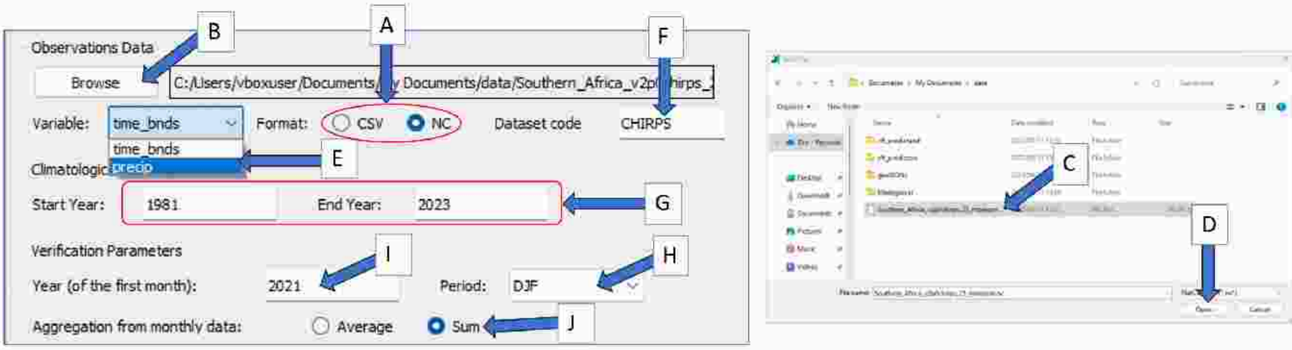


Figure 22: Steps to adding observation data and defining related parameters on the CFT Verification Module.

4. Once the dataset is loaded, the user must input the 'Climatological Reference Period' Start and End years (Figure 22 – arrow G). Ideally, this should be the climatological period used in the generation of the forecast to be evaluated, with a minimum 30-year record length, the Module is however programmed to only allow a minimum 20-year reference period. **Note: The 'End Year' cannot be after the year of the forecast to be evaluated, e.g., one cannot select a reference period ending in 2022 for evaluating a forecast issued for the 2021 season.**
5. The next step is to define 'Verification Parameters' (Figure 22 – arrow I, H and J)., these are parameters for the forecast to be evaluated, i.e., the 'Year' and 'Period' and aggregation function to be used (see Section 5.2 – item 3, for more information). **Note: The Verification Module currently does not have the functionality to cross check whether the parameters provide are the same as those provided in the forecast vector file, users are therefore encouraged to be very diligent.**

5.5. Step 5 – Select output indices and run the Module.

Figure 23 provides a view of the steps to selection of output indices and running the verification Module as well as what the user must expect after a successful run.

1. Outputs can be selected according to the categories described in detail in Section 6 (Figure 23– arrow A). While it is possible to select certain outputs to be calculated, some other outputs are dependent on others and will automatically be calculated but the outputs not saved, for example, to calculate the 'Observed Relative Anomaly', the 'Observed rainfall', and the 'Climatological Mean' are required, but if only the 'observed relative anomaly (%)' option is selected, only that map will be plotted together with a netCDF file containing the values used in plotting.
2. Once the desired outputs are selected, the 'Run' button can be clicked to run the Module (Figure 23– arrow B), as the program runs, the progress is shown on the 'Run log' window. If the run is successful, a 'Finished running verification' message must be printed on the Run log window, indicating the path to where the output files are located (Figure 23– arrow C).
3. When complete, a folder with the naming structure 'verification_$period_$year', with $period representing the season or period of interest (Figure 22 – arrow H) and $year representing the year of the forecast (Figure 22 – arrow I) and sub-folder with the 'Dataset code' (Figure 23– arrow D) will be created in the 'Output Directory' defined in Figure 21. **Note: For periods/seasons that span across**

two years, e.g., DJF, the $year value will have format $year-$(year+1), for example verification_DJF-2022-2023.

4. The verification will have run successfully, the Module can now be closed by clicking on the 'Exit' button. The outputs can now be inspected and interpreted following the descriptions provided in Section 6.

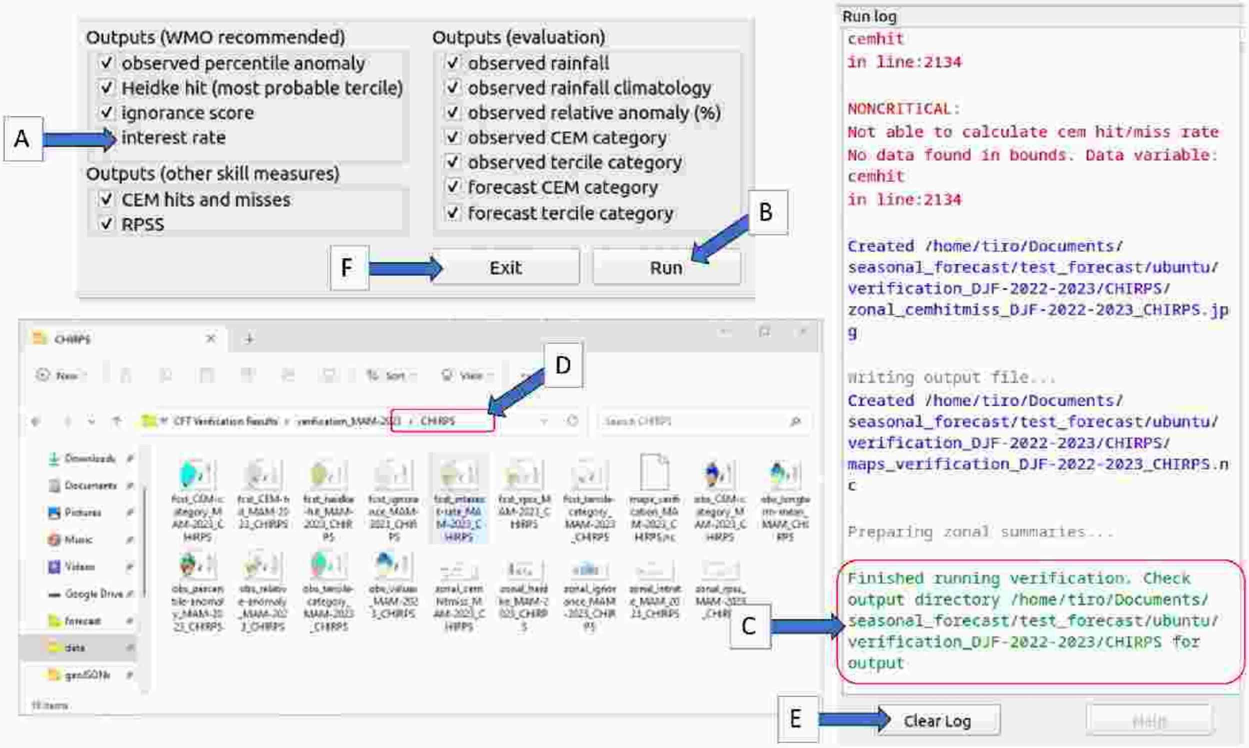


Figure 23: Selecting the Outputs and running the CFT Verification Module, and what to expect if the verification has run successfully.

6. Forecast verification indices implemented in CFT Verification Module

By undertaking forecast verification, information about the quality of the forecasts provided is provided, thereby assisting forecasters to demonstrate the value in generating the forecasts (WMO, 2018). The verification process needs to identify the goodness of the forecast by addressing five main qualities of a good forecast, namely, resolution, discrimination, reliability, sharpness, and skill (Mason, 2015; WMO, 2018). While the landscape of statistical indices that can be used to evaluate forecast qualities is large and complex, the CFT Verification Module utilizes those that are **recommended by WMO (2018)**, summarized in Table 3 below. In addition to these recommended skill indices, the Module also utilizes skill measures developed in the process of evolution of SARCOF methodology and adapted to the nature of the SARCOF forecast. The full set of indices and evaluation outputs/maps currently implemented in CFT Verification Module is presented in Table 4 below. Methodologies behind each of the indices is described in Section 4.

Table 3: Summary of skill indices recommended for individual forecasts, from WMO Guidance on Verification of Operational Seasonal Climate Forecasts (WMO, 2018)

Score	*Questions addressed*	*Key references*
Verification maps as percentiles*	What was the verifying category? How extreme was the observed value?	
Model diagnostics	Various; in general: Did the model reproduce the observed atmospheric conditions responsible for the verifying climate anomalies?	
Hit scores for categories with highest probabilities*	How often did the category with the highest probability occur?	Mason (2012)
Hit scores for categories with second and third highest probabilities	How often did the category with the second highest probability occur? How often did the category with the lowest probability occur?	Mason (2012)
Average interest rate	What is the rate of return if paid fair odds when investing on the forecasts?	Hagedorn and Smith (2008)
Ignorance score*	Given the forecast, how much additional information is needed to determine what the verifying categories were?	Roulston and Smith (2002)

* Indicates procedures that are considered to comprise a minimal set that all operational forecasting centres should strive to calculate.

Table 4: Skill indices and evaluation maps implemented in CFT Verification Module with the naming structure of outputs from the verification process.

	WMO recommendations	Purpose	Output Naming Structure
Forecast category (CEM)	Pre-requisite	Evaluation	fcst_CEM-category_$period-$year_$dataset
Forecast tercile category	Pre-requisite	Evaluation	fcst_tercile-category_$period-$year_$dataset
Observed Rainfall	Pre-requisite	Evaluation	obs_values_$period-$year_$dataset
Observed Rainfall Climatology	Pre-requisite	Evaluation	obs_longterm-mean_$period-$dataset
Observed Percentile Anomaly	WMO required	Evaluation	obs_percentile-anomaly_$period-$year_$dataset
Observed Relative Anomaly (%)	Additional	Evaluation	obs_relative-anomaly_$period-$year_$dataset
Observed tercile	Additional	Evaluation	obs_tercile-category_$period-$year_$dataset
Observed CEM Category	Pre-requisite	Evaluation	obs_CEM-category_$period-$year_$dataset
Heidke skill score	WMO required	Skill	fcst_heidke-hit_$period-$year_$dataset
			zonal_heidke_$period-$year_$dataset
Ignorance Score	WMO required	Skill	fcst_ignorance_$period-$year_$dataset
			zonal_ignorance_$period-$year_$dataset
Average Interest Rate	WMO recommended	Skill	fcst_interest-rate_$period-$year_$dataset
			zonal_intrate_$period-$year_$dataset
CEM Hits and Misses	Tailored	Skill	fcst_CEM-hit_$period-$year_$dataset
			zonal_cemhitmiss_$period-$year_$dataset
Ranked Probability Skill Score	Additional	Skill	fcst_rpss_$period-$year_$dataset
			zonal_rpss_$period-$year_$dataset

6.1. Evaluation indices

6.1.1. Observed Rainfall

The observed rainfall refers to the total accumulated precipitation over a selected period, either month, season, or year (see Equation 1).

$$pr_{tot} = \sum_{t=1}^{n} pr(t) \quad (1)$$

Where pr_{tot} is the total accumulated precipitation pr from n days over the selected period of interest.

Example output from CFT.

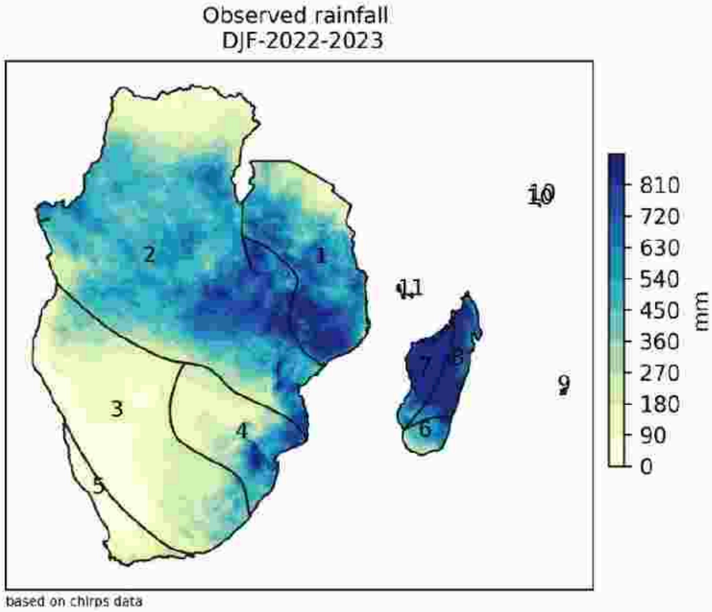


Figure 24: Observed rainfall for the period under evaluation

Interpretation

This output shows the observed precipitation for the season and year of interest based on the selected dataset, in the example above, the accumulated precipitation for the December-January-February 2022-2023 season based on CHIRPS rainfall estimates (Figure 24).

6.1.2. Observed Rainfall Climatology

The observed rainfall climatology refers to the long-term average of the total accumulated precipitation over a selected period, either month, season, or year (see Equation 2).

$$pr_{clim} = \frac{1}{N} \sum_{t=1}^{N} pr_{tot} \quad (2)$$

Where pr_{clim} is the long-term average total accumulated precipitation, pr_{tot} is the total rainfall for year t and N the total number of years over the climatological period.

Example output from CFT.

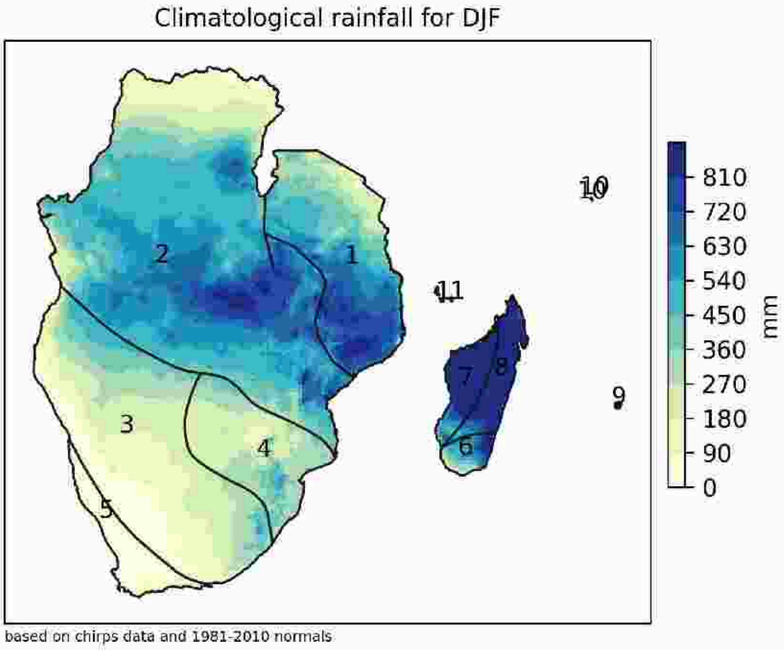


Figure 25: Climatology

Interpretation

This output is the long-term average of accumulated precipitation for the season or period of interest, in this example, for the December-January-February season calculated over the 1981-2010 climatological period (Figure 25).

6.1.3. Observed Percentile Anomaly

To calculate the observed percentage anomaly, the observed value for a given season is ranked against percentiles of the empirical distribution of values in the climatological base period.

Example output from CFT.

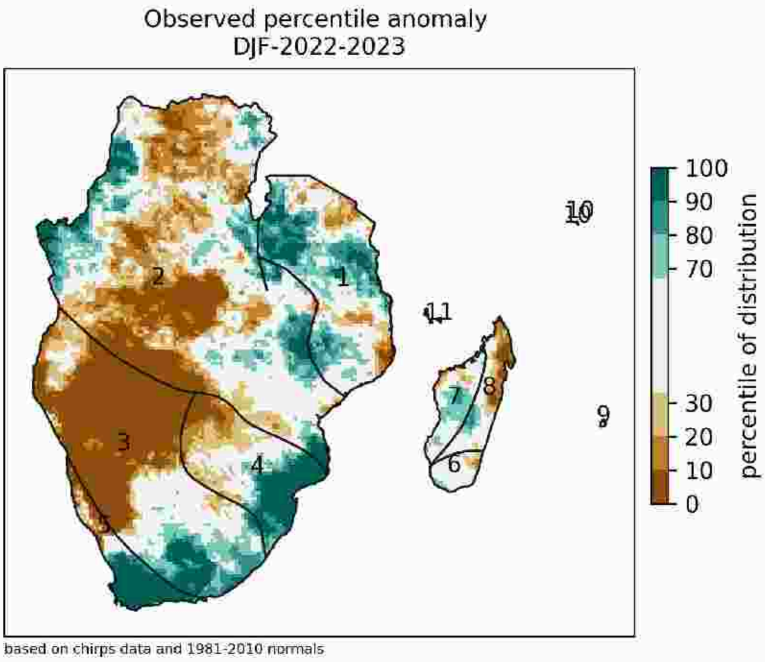


Figure 26: Percentile anomaly

Interpretation

Relative to the climatological record (here 1981-2010), the brown shaded areas in Figure 26 indicate where the accumulated precipitation is generally below normal (defined by the 33-66 percentiles). Values of 0 and 100 represents the values that a lower and higher than values that exist in the climatological record respectively.

Example Use

https://www.ncei.noaa.gov/access/monitoring/dyk/global-mntp-percentiles

https://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/prcp.shtml#

6.1.4. Observed Relative Anomaly (%)

The observed relative anomaly refers to the difference between the observed value of the variable of interest for a particular year/season and the long-term average (climatology) relative to the long-term average, presented as a percentage (see Equation 2)

$$relanom_{obs} = \left(\frac{seas_{tot} - longterm_{mean}}{longterm_{mean}}\right) * 100 \qquad 2$$

Where $seas_{tot}$ is the total precipitation of the season of interest, $longterm_{mean}$ is the long-term average (climatological mean) for the season of interest. The relative anomaly is used to indicate whether in a particular year, the observed value is in the normal range, above or below normal.

Example output from CFT.

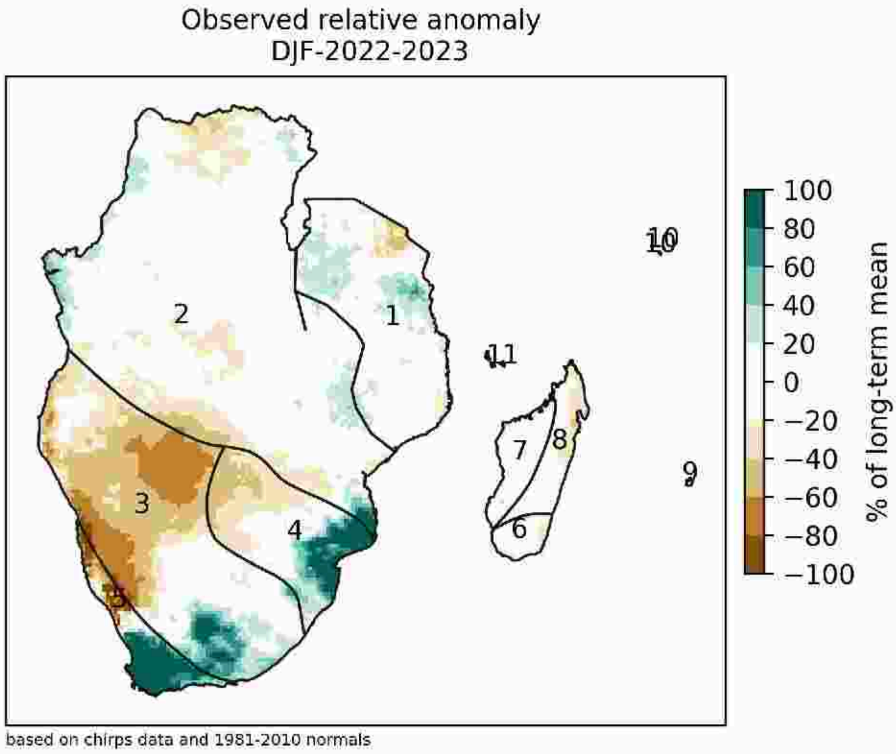


Figure 27: Relative anomaly

Interpretation

In Figure 27, the brown and green shadings indicate areas of lower-than and greater-than average precipitation respectively. It should be noted that one cannot infer how much rainfall was received without looking at the actual long-term average (Figure 25) for a given location or grid-point.

Example Use

https://www.efas.eu/en/meteorology?field_month_value=02&field_year_value=2020

http://iridl.ldeo.columbia.edu/maproom/Global/Precipitation/Anomaly.html

6.1.5. Observed CEM Category

The observed values of a variable of interest for a given season are relative to the long-term average categorized into the four classes of Above-Normal (AN), Normal to Above-Normal (N-AN), Normal to Below-Normal (N-BN) and Below-Normal (BN). The classes and period of long-term normal are the same as those used in generating the forecast.

Example output from CFT.

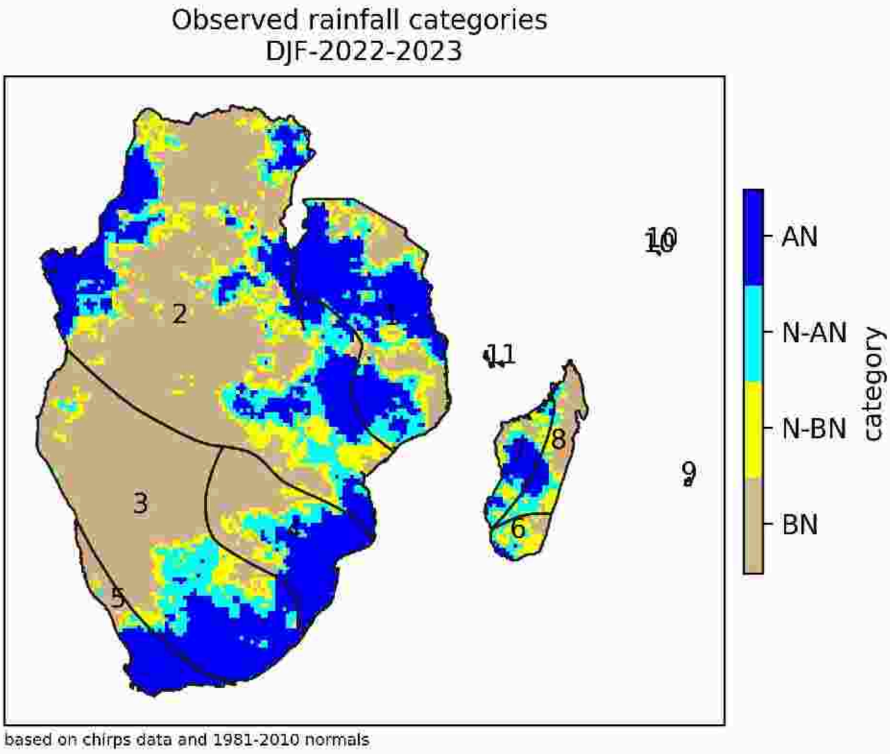


Figure 28: Observed CEM categories

Example Use

No examples available.

6.2. Skill indices recommended by WMO.

6.2.1. Heidke Skill Score (Most Probable Tercile)

The Heidke Skill Score (HSS) compares how often the forecast category correctly matches the observed category, over and above the number of correct "hits" expected by chance alone. This score utilizes the number of correct and incorrect category hits. The equation for the score is:

$$HSS = \frac{H-E}{T-E} \quad 3$$

where H is the number of correct forecasts, E are the expected number of correct forecasts (1/3 of total), and T is the total number of valid forecast-observation pairs. (WMO, 2018 -24). The score measures the fraction of correct forecasts after eliminating those forecasts which would be correct due purely to random chance. This is a form of the generalized skill score, where the *score* in the numerator is the number of correct forecasts, and the reference forecast in this case is random chance. In meteorology, at least, random chance is usually not the best forecast to compare to - it may be better to use climatology (long-term average value) or persistence (forecast = most recent observation, i.e., no change) or some other standard.

Example output from CFT.

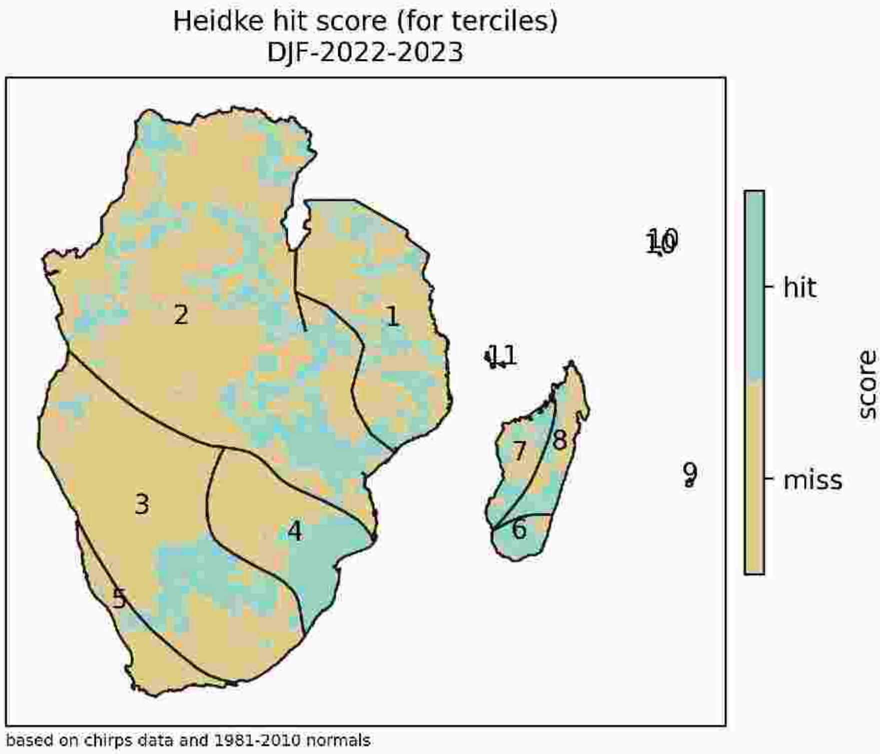


Figure 29: Heidke Hit Skill Score

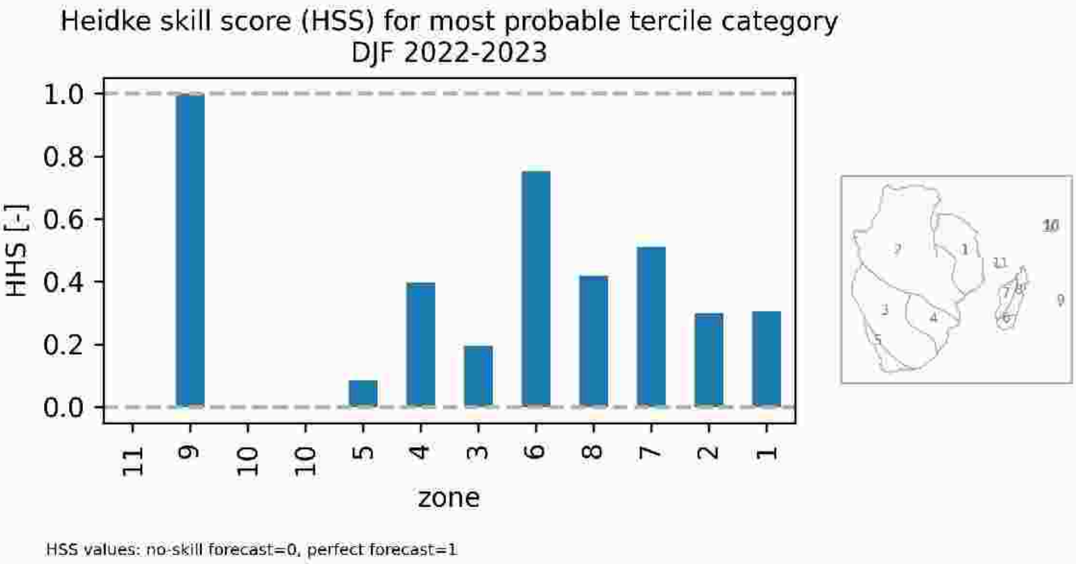


Figure 30: Heidke skill scores averaged over the region/zone of interest.

Interpretation

The HSS answers the question '*What was the accuracy of the forecast relative to that of random chance?*'. The score values range from -1 to 1, with a score of 1 indicating a perfect forecast and a score of -1 indicating a perfectly incorrect forecast. Scores greater than 0 indicate improvement compared to a random forecast and indicate skill. Therefore, whenever a positive score value is found, then the forecast was better that random chance. In Figure 29, areas where the score is greater than zero is considered a hit and a miss otherwise. Figure 30 provides a zonal average of the score, therefore the closer the score is to one, the better the forecast performance for the zone.

Example Use

https://wwa.colorado.edu/sites/default/files/2021-09/IWCS_2005_May_feature.pdf

https://iri.columbia.edu/our-expertise/climate/forecasts/verification/

https://journals.ametsoc.org/view/journals/mwre/138/4/2009mwr3214.1.xml

https://www.climate.gov/news-features/blogs/enso/seasonal-verification-part-2-electric-boogaloo

https://ggweather.com/cpc/verify/cpc_winter.htm

6.2.2. Ignorance score

According to WMO (2018), the ignorance score, first proposed by Roulston and Smith (2002) is defined as:

$$Ignorancescore = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m} y_{j,i} log_2\left[p_{j,i}\right] \quad 4$$

where n is the total number of forecasts, m is the number of categories, $y_{j,i}$ is 1 if the i-th observation is in category$j$, and is 0 otherwise, and $p_{j,i}$ is the corresponding forecast probability. The score ranges from 0.0 for a perfect set of forecasts, to infinity for a perfectly bad set of forecasts. This score for the perfectly bad forecasts may seem unduly harsh but could be considered appropriate given that a 0% probability implies that the category in question is an absolute impossibility. The relative skill of the ignorance score, can be interpreted as the mean bits of information gained from using one forecasting system over some reference forecasting system (say, the climatological distribution) (Wheatcroft, 2019).

Example output from CFT

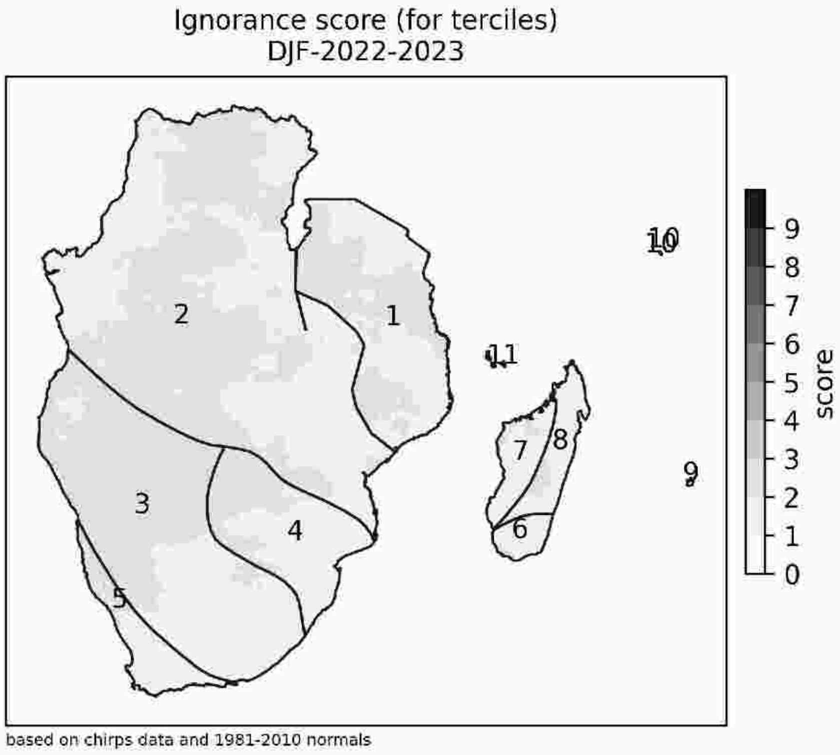


Figure 31: Ignorance score

Interpretation

As in Figure 31, The expected values range between 0 and infinity, where a 0 value indicates a perfect forecast and a the larger the value, the worse the forecast.

Example Use

https://www.sciencedirect.com/science/article/pii/S0169207019300093

6.2.3. Average Interest Rate

The effective interest rate is a transformation of the Ignorance score to enable easy interpretation. It is represented by Equation 5.

$$EffectiveInterestRate = \left(2^{Ign(ref)-Ign} - 1\right) \quad 5$$

where $Ign(ref)$ is the ignorance score for the reference (climatological forecasts), and Ign is the score for the forecasts. The effective interest rate provides an indication of the average returns an investor would make if she/he invested on the forecasts and was paid out against odds based on the climatological probabilities (WMO, 2018).

Example output from CFT.

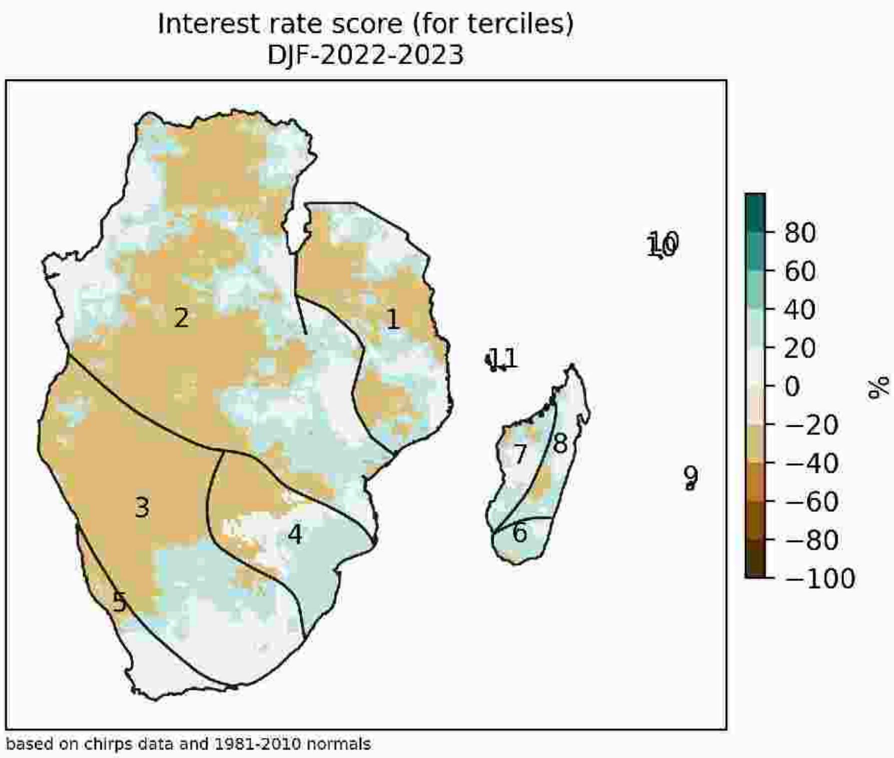


Figure 32: Interest rate

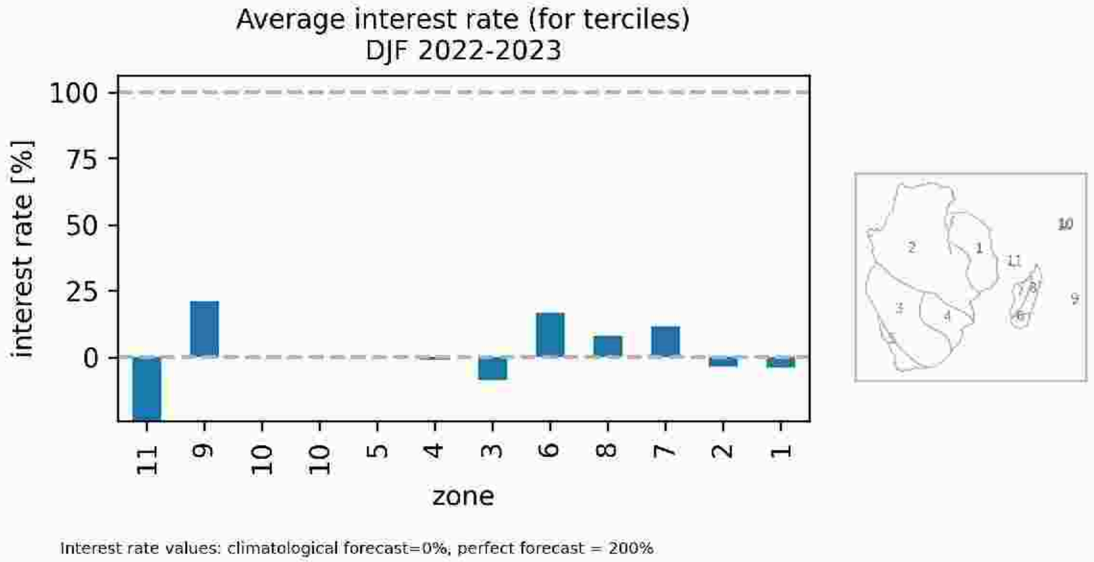


Figure 33: Interest rate scores averaged over the region/zone of interest.

Interpretation

'The effective interest rate measures a number of attributes, but it has a simpler interpretation because of its relationship to investment strategies. Specifically, if a user were to invest on the forecasts and received fair odds (calculated using the climatological probabilities), and to carry losses and profits forwards each time, the effective interest rate indicates the profit or loss that would be made. (WMO, 2018 – 52)'. In Figure 32, shades of brown indicate areas where the forecast would have resulted in a loss, while shades of green indicate profits. Zonal averages for the interest rates are provided in Figure 33.

Example Use

6.3. Tailored skill indices

6.3.1. CEM Hits and Misses

The CEM hits and misses compares the tercile categories forecasted against the tercile categories that have been observed at a given location (grid-point or station). A hit refers to when the forecasted tercile coincides with that observed, a half-hit when the forecasted tercile is one category away from the observed tercile. A half miss refers to when the forecasted tercile is two categories away from the observed tercile and an error when the forecasted tercile is 3 categories away from the observed. It should be noted that an error can only be obtained when the extreme terciles are forecasted, i.e., the above normal and the below normal.

Example output from CFT

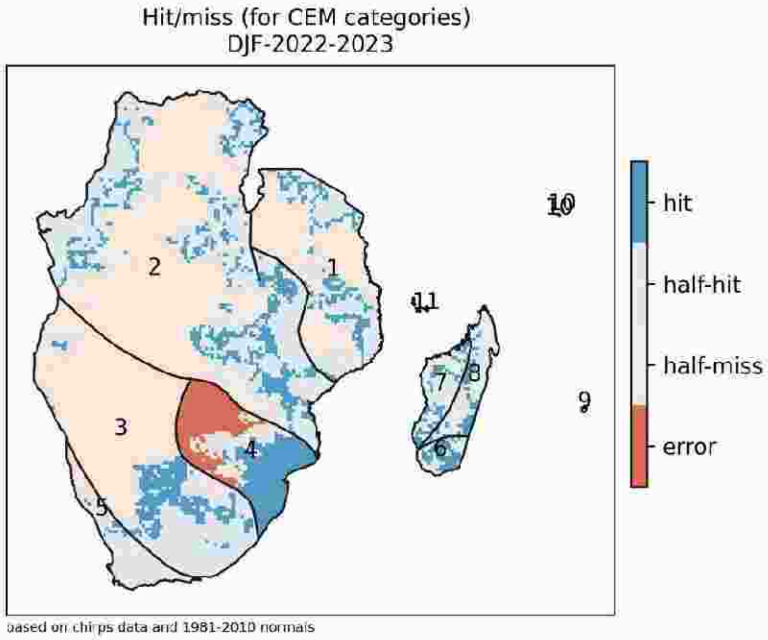


Figure 34: Hit and Misses for CEM categories.

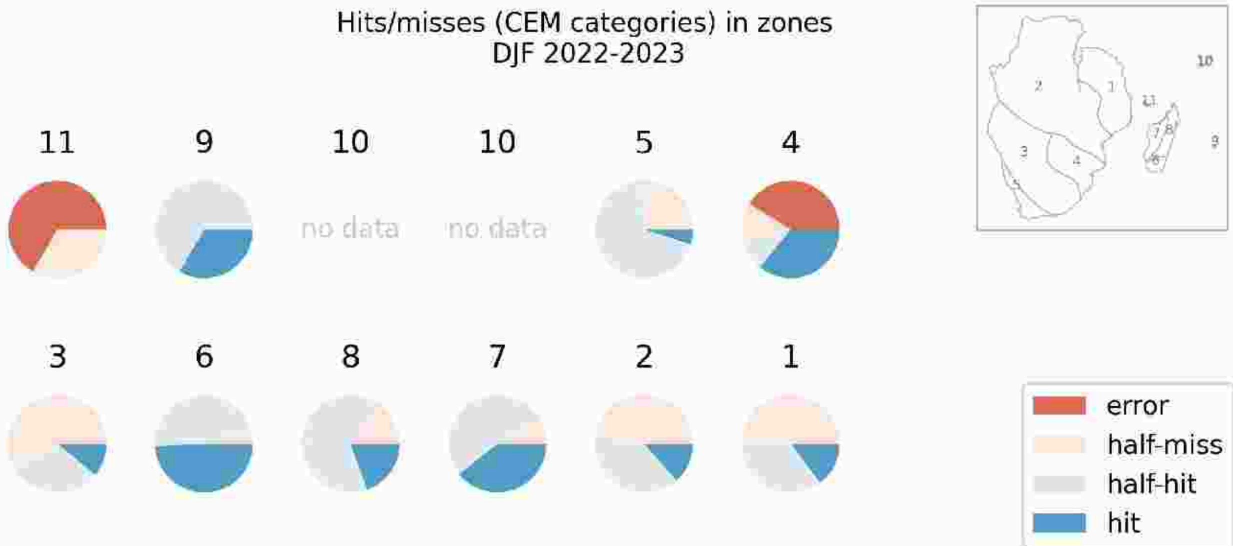


Figure 35: Summary of hits and misses according to the zones in the form of pie charts.

Interpretation

Looking at Figure 34, areas shaded blue is where the forecast performed relatively well while the 'reds' are regions that the forecast was generally poor. One needs to note that this verification metric does not take into account the inclination of the forecast (i.e., whether it was normal – to – above normal or above normal – to – normal). Figure

Example Use

https://collab.sadc.int/s/wnExNJEZ7i8qcnZ?dir=undefined&path=%2F&openfile=113656

6.3.2. Rank Probability Skill Score (RPSS)

As defined by CAWCR (2017), the Rank Probability Skill Score (RPSS) measures the improvement of multi-category forecasts relative to a reference forecast and takes into account the probability for each category by measuring the cumulative squared error between categorical forecast probabilities and the observed categorical probabilities relative to a reference (or standard baseline) forecast.

The Ranked Probability Skill Score (RPSS) measures the improvement of the multi-category forecast relative to a reference forecast (the sample climatology). RPSS values range from -Infinity to 1. Forecasts made with higher probabilities are penalized heavily if they are wrong, and forecasts made with lower probabilities are penalized less severely if they are wrong, since they aren't expected to be correct as often. Conversely, forecasts made with higher probabilities are rewarded more heavily if they are correct, and forecasts made with lower probabilities are rewarded less heavily if they are correct.

EC forecasts for monthly and seasonal forecasts *are* included in scores.

The equation for the score is:

$$RPSS = 1 - \frac{RPS_{forecast}}{RPS_{reference}} \qquad 6$$

Where the RPS is the Ranked Probability Score, a squared error score with respect to the cumulative probabilities for multi-category forecasts that measures whether or not the event occurred. The RPS representing a collection of forecasts in space or time is estimated by:

$$RPS = \frac{1}{n}\sum_{k=0}^{n}\left[\left(probB_k - obsB_k\right)^2 + \left(probN_k - obsN_k\right)^2 + \left(probA_k - obsA_k\right)^2\right] \qquad 7$$

where n is the total number of valid forecast-observation pairs. For the chart, each forecast data point in space is evaluated and represents each k_{th} value. $probB_k$, $probN_k$, $probA_k$ are the probabilities of the below normal, near normal, and above normal forecast categories respectively at each point k, and $obsB_k$, $obsN_k$, $obsA_k$ are either 0 if that category was observed, or 1 if that category was not observed at each point k.

The score is the sum of the squares of the difference between the forecast probability of each category and either "0" or "1" for the category observed at that point over all forecast points, divided by the total number of forecast points used. To get $RPS_{forecast}$, the forecast probabilities are used. To get $RPS_{reference}$, cumulative probabilities starting at 1/3 are used for each category.

Example output from CFT.

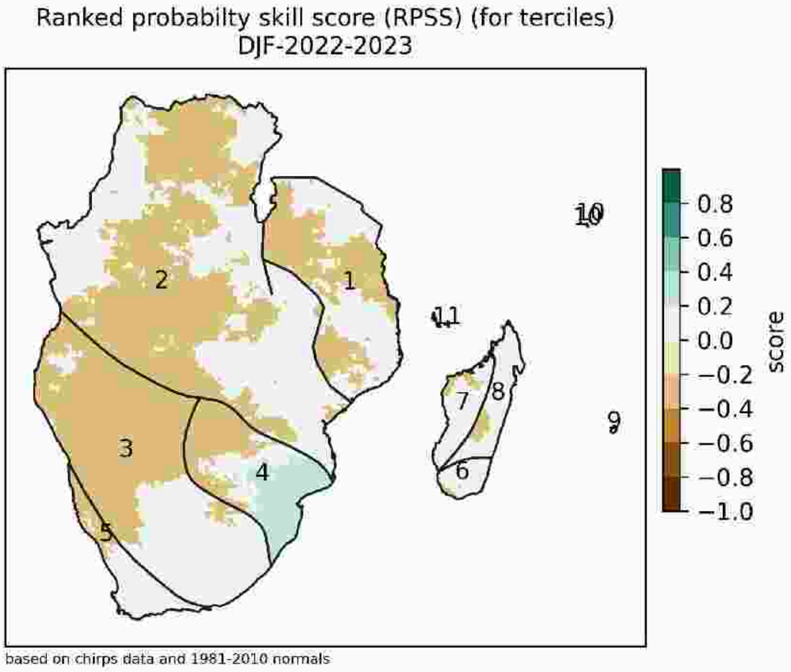


Figure 36: Ranked probability skill score

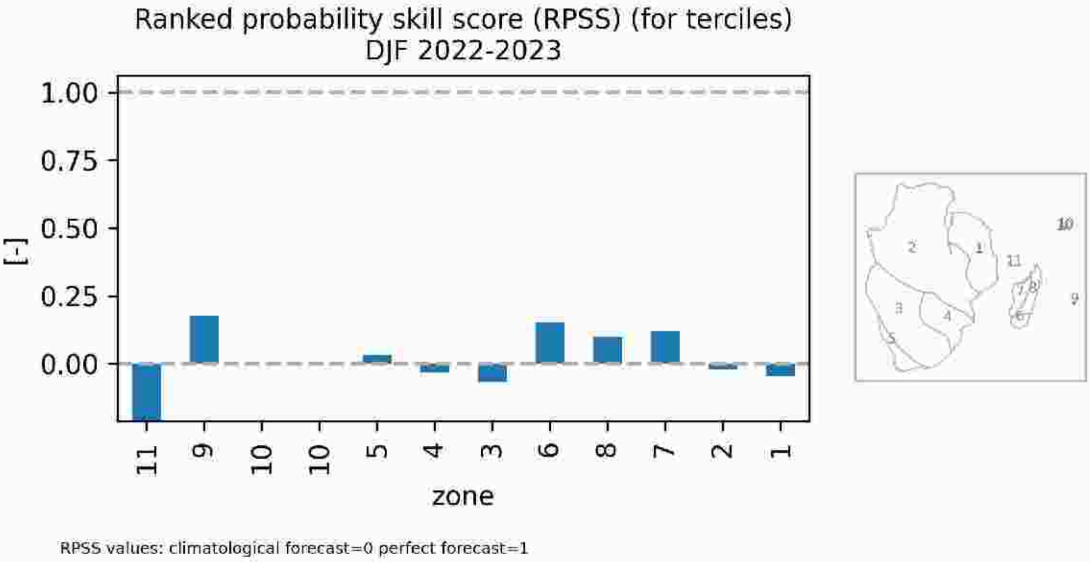


Figure 37: Zonal averages of RPSS scores

Interpretation

The RPSS answers to the question '*How well did the probability forecast predict the category that the observation fell into?'* RPSS values less than zero indicate that the forecast is worse than having taken a random chance or equal probabilities (brown shades in Figure 1), and positive when the forecast is better than if equal probabilities are assumed across the forecast categories (brown shades in Figure 36).

Example Use

https://journals.ametsoc.org/view/journals/apme/49/3/2009jamc2325.1.xml

https://www.climate.gov/news-features/blogs/enso/seasonal-verification-part-3-verify-vengeancethis-time-its-probabilistic

6.4. Additional resources on forecast verification

https://www.cawcr.gov.au/projects/verification/

https://www.cpc.ncep.noaa.gov/products/verification/summary/index.php?page=tutorial

https://iri.columbia.edu/wp-content/uploads/2013/07/scoredescriptions.pdf

https://indico.ictp.it/event/a09161/session/29/contribution/17/material/0/0.pdf

https://iri.columbia.edu/wp-content/uploads/2016/12/CCI-verification-recommendations-final.pdf

https://library.wmo.int/doc_num.php?explnum_id=4886

https://academiccommons.columbia.edu/doi/10.7916/d8-gh4a-ex60 (Alternative source of the WMO (2018) document)

https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1580

7. Feedback and reporting of errors.

7.1. The SADC-CSC CFT GitHub Repository

An issue can be created on the SADC CFT GitHub account (https://github.com/sadccsc/cft/issues), specifying the errors encountered and specifying that the issue is with the Verification Module.

7.2. Frequently Asked Questions

1. The Verification Module runs but hangs and does not show any outputs or notification that the Module has run successfully.
    a. The Verification may have run into an error and failed. Close the Module and run on debug mode, take a screenshot of the error, and send to the developers for them to fix the issue.

8. References

CAWCR. (2017). *Forecast Verification methods Across Time and Space Scales.* https://www.cawcr.gov.au/projects/verification/

Mason, S. J. (2015). *Guidance on Verification of Operational Seasonal Climate Forecasts.* https://iri.columbia.edu/wp-content/uploads/2016/12/CCl-verification-recommendations-final.pdf

Roulston, M. S., & Smith, L. A. (2002). Evaluating Probabilistic Forecasts Using Information Theory. *Monthly Weather Review*, *130*, 1653–1660.

Wheatcroft, E. (2019). Interpreting the skill score form of forecast performance metrics. *International Journal of Forecasting*, *35*(2). https://doi.org/10.1016/j.ijforecast.2018.11.010

WMO. (2018). *Guidance on Verification of Operational Seasonal Climate Forecasts* (Simon J. Mason, Ed.). World Meteorological Organization. http://public.wmo.int/en/

WMO. (2020). *Guidance on Operational Practices for Objective Seasonal Forecasting 2020* (Issue 1246). World Meteorological Organization. https://library.wmo.int/doc_num.php?explnum_id=10314

9. Appendices

9.1. Appendix 1: Step-by-step instructions for Installing QGIS on Windows 11.

1. QGIS can be downloaded from https://www.qgis.org/en/site/forusers/download.html# (see Figure A1)

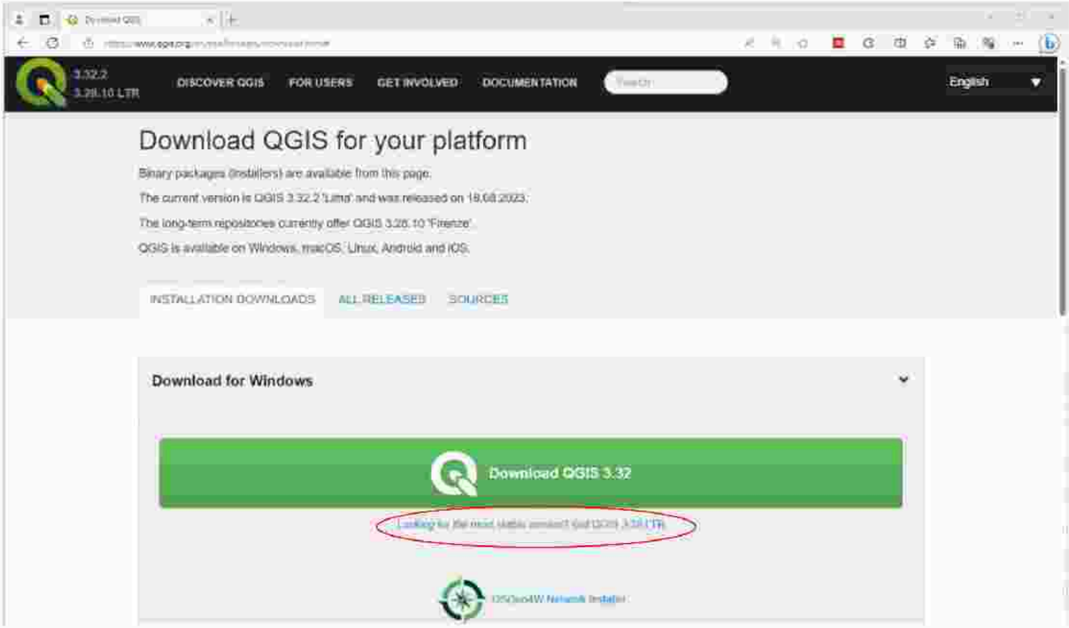


Figure A1: Webpage view of the site to download the QGIS software.

2. To install QGIS, find the installation executable file in the Downloads Folder, double click on the file (Figure A2, Figure A3, and Figure A4) and follow the prompts until the software is installed. The arrows on the figures indicate the selections that need to be made following the letter orders in each figure, except for Figure A2 – A, where the user need to double click on the file to launch the installation process.

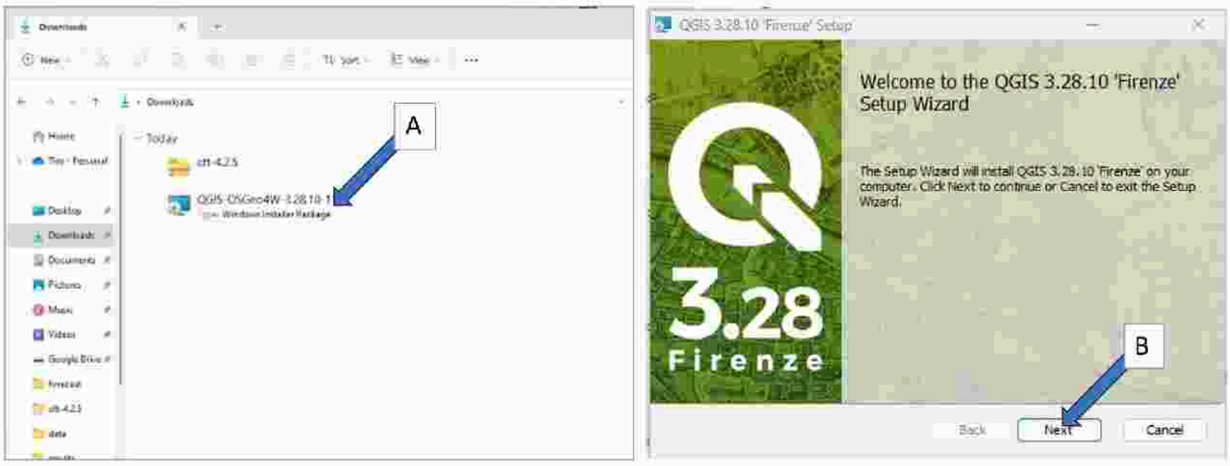


Figure A2: Steps to installing QGIS on windows.

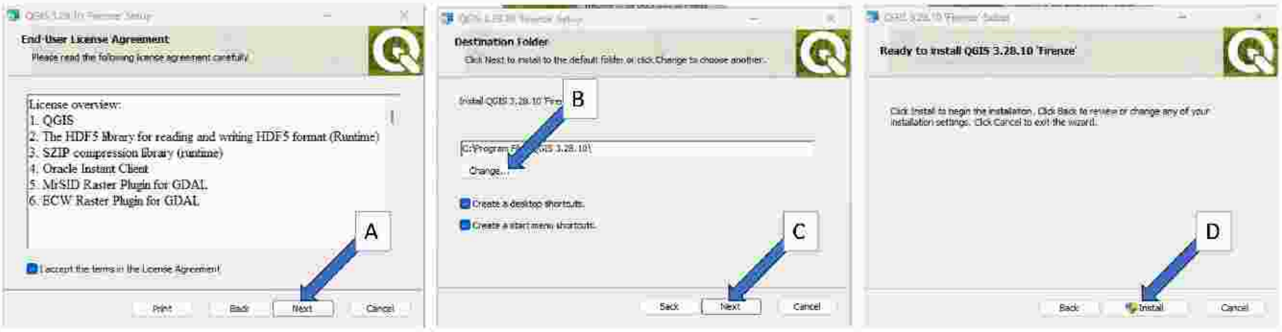


Figure A3: Steps to installing QGIS on Windows 11 continued.

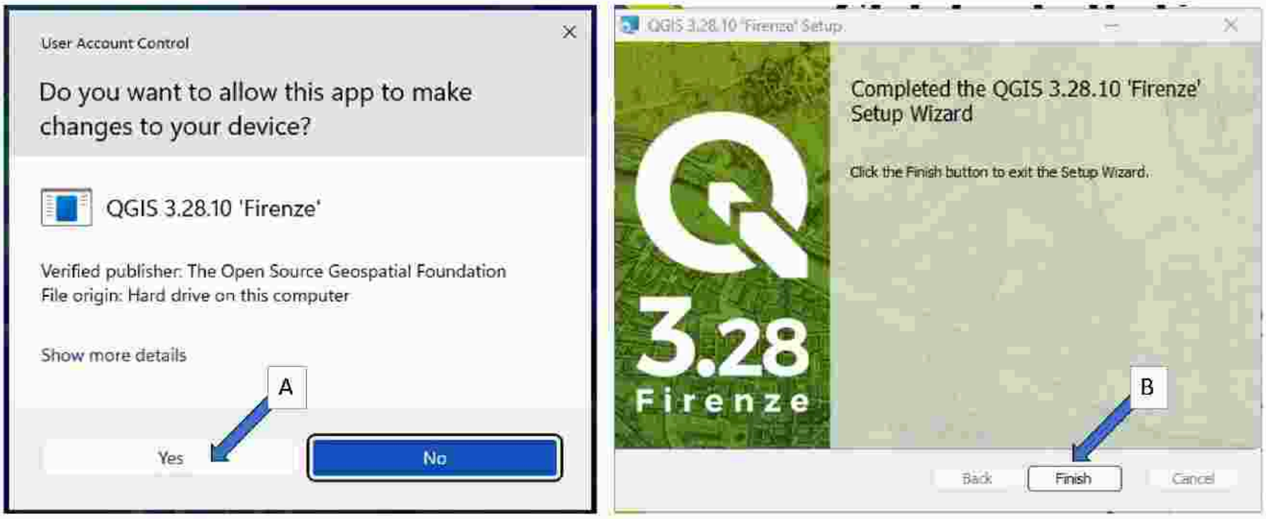


Figure A4: Steps to install QGIS on Windows 11 continued.

3. Once completed, a folder should be created on the Desktop with shortcuts to the software installation (Figure A5). One can launch the QGIS application by double-clicking on the QGIS-Desktop 3.xx.xx shortcut (Figure A5 – arrow B), if the QGIS application GUI is opens, the software has been installed successfully.

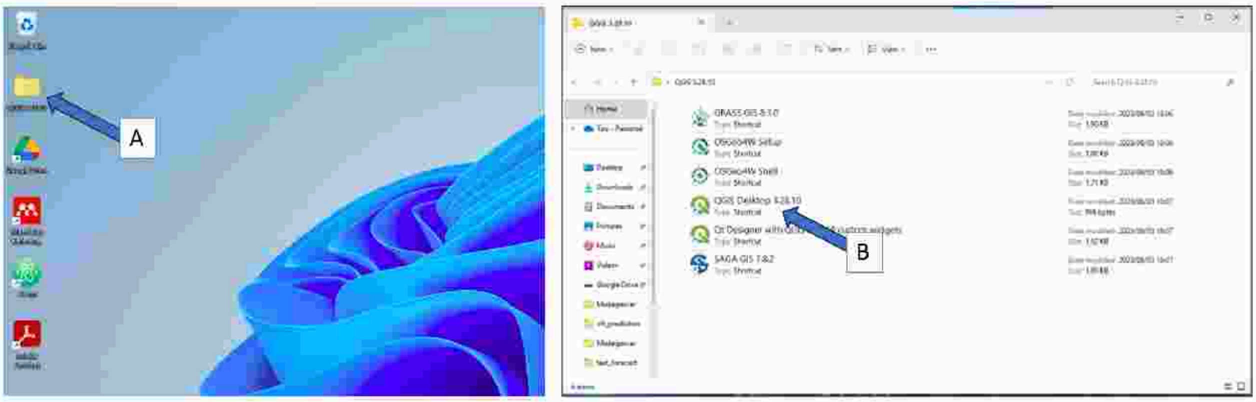


Figure A5: Where to find shortcuts to launch QGIS on Windows 11.