International Center for Integrated Water Resources Management (ICIWaRM)
Institute for Water Resources (IWR)
United States Army Corps of Engineers (USACE)

ICI-RAFT
Regional Analysis of Frequency Tool

Quick Start Guide

Version 1.1

February 2013

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Regional Analysis of Frequency Tool, ICI-RAFT, Quick Start Guide (2013)

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CHAPTER 1: INTRODUCTION

The hydrologic cycle begins and ends with precipitation; therefore, knowledge of the amount and distribution of rainfall over an area is a prerequisite to any attempt at efficient water resources management in developing countries. In addition, in the face of a changing global climate, knowledge of the distribution of rainfall reveals regions that are most vulnerable to an increase in extreme events, whether it be floods or droughts. Such knowledge may help to determine what type of climate adaptation measures need to be taken for a particular community with regard to more intense extreme events, whether it be building more flood control measures, relocating the inhabitants, etc. Researchers also seek to develop robust, defensible, low-error methods for frequency analysis so that users, such as decision makers tasked with addressing recurring physical events, can make estimates with as much certainty, transparency, and consistency as possible.

The International Center for Integrated Water Resources Management (ICIWaRM) Regional Analysis of Frequency Tool (ICI-RAFT) is the result of work performed in order to support the overall mission of ICIWaRM to aid developing countries in water resource management in terms of climate change adaptation with a focus on extreme events and to contribute to the development of non-propriety analytical tools. In order to further accomplish the mission of ICIWaRM as a Category II UNESCO center and in the spirit of UNESCO, the software is offered at no cost; the only costs associated with the software involve expenses associated with the additional programs that are required to fully utilize ICI-RAFT, such as Microsoft Excel and ESRI ArcGIS or other similar GIS software.

ICI-RAFT was developed from scratch with much of the inspiration coming from the book by Hosking & Wallis titled "Regional Frequency Analysis using L-moments", while some of the code used to develop the software was taken from the FORTRAN code provided by Hosking & Wallis and rewritten in order to accommodate Visual Basic 2010. The method of L-moments is preferred over using regular moments due to the fact that L-moment statistics are more robust in terms of accommodating extreme values and characterizing a greater number of frequency distributions. In addition, L-moments are less susceptible to bias in their estimation.

RFA is preferred due to the fact that it helps to alleviate the issue of insufficient rainfall data at a particular site. Insufficient data does not allow the user to make accurate estimates of rainfall intensity at that location; this is especially true in arid and semi-arid regions where rain gauges sites are few and far between and where the measurements taken at those sites where rain gauges do exist may contain numerous and/or long periods of missing data. RFA is used on the assumption that if the frequencies of rainfall events are similar at several nearby locations within a "region", a statistical analysis of all observations at all sites within the "region" will result in a more accurate frequency distribution at each location compared to limiting the analysis to the individual at-site data.

Using RFA and L-moments, ICI-RAFT is able to estimate the frequency/intensity of a rainfall event of a particular duration using rainfall observations on the ground, and the goal is to be able to answer such questions as:

1) "What is the probability that the current drought will end in X months?"
2) "How long a drought should we prepare for?"
3) "What is the frequency of maximum drought intensity observed?"

Chapter 2 of this document lays out the RFA-LM method, explaining why regionalization increases accuracy of quantile estimates, how regions are constructed and evaluated, why linear moments are used in the method, and the fitting of distributions and evaluation of goodness of fit. Chapter 3 consists of a walkthrough of the user interface in which a basic analysis is performed on a large dataset. Chapter 4 contains a table of the global climate indices that are included in ICI-RAFT as well as a short description of each. Finally, Chapter 5 reiterates the terms and conditions for using ICI-RAFT.

CHAPTER 2: OVERVIEW OF THE RFA-LM METHOD

Why *Regional* frequency analysis? How is regional quality measured?

The principles of regional frequency analysis can be summarized as "trading space for time" – lumping together spatially disparate data so that the resultant *increase* in error of estimation is less than the *decrease* in error brought about by increasing sample size. Hosking and Wallis' RFA-LM method preserves the at-site mean, normalizes all at-site data before regionalization, and conducts the entire analysis on normalized data before multiplying the regional 'growth curve' (normalized quantile function) by that at-site mean at the very end to output at-site quantile estimates.

The RFA-LM method is designed with hydrological variables, specifically precipitation and streamflow quantile estimation, in mind. However the method is potentially applicable to the estimation of quantiles for many physical parameters – the data records of precipitation gauges, stream flow monitors, thermometers, anemometers, and so on. If a physical parameter can be measured across space and time, it is possible that RFA-LM provides a responsible framework in which the one can be traded for the other.

The key to keeping the increase in 'space' error lower in magnitude than the decrease in 'time' error is in grouping gauges or at-site data records, referred to hereafter as sites, which appear to share a common underlying distribution frequency. If a region is perfectly *homogeneous*, observed differences between sites reflect only randomness. In other words, we extend the above assumption – instead of each site being N iterations of a Monte Carlo simulation off of a unique distribution, a region with pooled sample size N* is modeled as N* Monte Carlo iterations drawn from one shared distribution. The degree to which a putative region fits this assumption is a quantifiable measure of homogeneity. Hosking and Wallis evaluated several different quantifications and developed a metric called the *heterogeneity statistic* or **H**. The statistic is constructed so that an H of less than 2 indicates acceptable homogeneity, but Hosking and Wallis showed that mildly heterogeneous regions can still achieve overall error reduction. Another statistic called **D** for discordancy measures how much each site's first three L-moment ratios differ from the regional average; sites with D higher than a threshold are discordant.

How are regions constructed?

It might seem easy to construct regions – simply find the sites with similar probability distribution functions and group them. However, one-site statistics are unreliable – that is the motivation behind regionalization in the first place – and it is possible that multiple sites appear identical through random variance but have different underlying distributions. Better results are achieved by grouping sites using at-site characteristics such as location (latitude/longitude), elevation, mean annual precipitation, monthly totals, and so on. A clustering algorithm is built into ICI-RAFT, as described below, which can organize sites into regions based on any number of these statistics multiplied by analyst-selected

weights. Hosking and Wallis recommend trying many different numbers of regions – they find that a point of diminishing returns is reached at around 20 sites per region – and making ad hoc adjustments by hand to lower the H score and increase the physical reasonableness of the candidate regions. This process is subjective and will involve trial and error on the part of the analyst.

Why linear moments?

While the theoretical derivation of linear moments is beyond the scope of this guide, they take the form of summations of the linearly sorted data values in a site or regional record, weighted in such a way as to mimic the conventional moments and their ratios (e.g. mean, coefficient of variation, skewness, kurtosis) but with favorable algebraic characteristics so that distributions fitted to a dataset using Linear or L-moments have lower error than distributions fitted using that dataset's conventional moments. The first linear moment is identical to the mean. The ratio of the second to the first L-moment is known as the linear coefficient of variation or L-CV; the ratio of the third L-moment to the second is L-skewness and the ratio of the fourth to the second is L-kurtosis.

How is goodness of fit measured?

Hosking and Wallis provide an appendix of fitting equations from L-moments for many different distributions. Which one should be used? Two-parameter distributions such as the Normal and Exponential, which consider only the mean and L-CV and have pre-set values of L-skewness and L-kurtosis, are rarely the best choice. Four- and even five-parameter distributions, the Kappa and Wakeby respectively, can also be fitted to the mean, L-CV, L-skewness, L-kurtosis, and the unnamed fifth L-moment ratio, but this raises the threat of overfitting the data.

Hosking and Wallis prefer several three-parameter distributions, which take L-skewness as a parameter but output L-kurtosis values as a function of L-skewness. This function can be graphed as a curve on a graph of L-skewness and L-kurtosis. Hosking and Wallis' **Z** statistic, for goodness of fit, is calculated for three-parameter distributions only. It is based on the difference between each distribution's predicted L-kurtosis and the value in the data; plotting regional averages as dots on the same L-skewness/L-kurtosis graph gives a graphical analogue of this statistic. Other considerations, such as what distributions were used in similar analyses in the past, also play a large role in selection of a distribution.

CHAPTER 3: USER INTERFACE

Title Screen

When the program is first opened, the title screen appears. Aside from the help menu, the 'File' menu is the only un-grayed item; the other menus, 'Data', 'Sites', and 'Regions', will open up as the walkthrough progresses. Under file, 'Load Data' opens the Load Data screen, which allows the user to first 'Browse' for a file, then 'Open' it once selected. After 'Open' is clicked the 'Display Data' screen is opened, showing all the monthly data in the input file. 'Save File' creates a .txt file containing all the information necessary to re-do the analysis to the current saved step. 'Open File' opens a window for selecting a saved file; when selected, the analysis runs automatically to the point where progress was last saved.
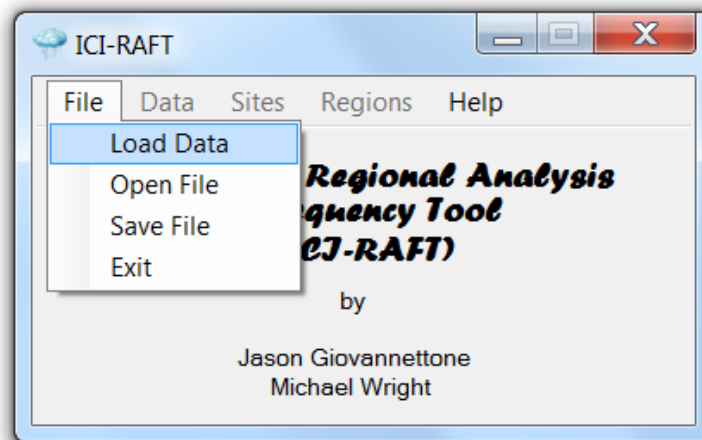

Figure 1: Title Screen with the File menu opened and Load Data option selected.
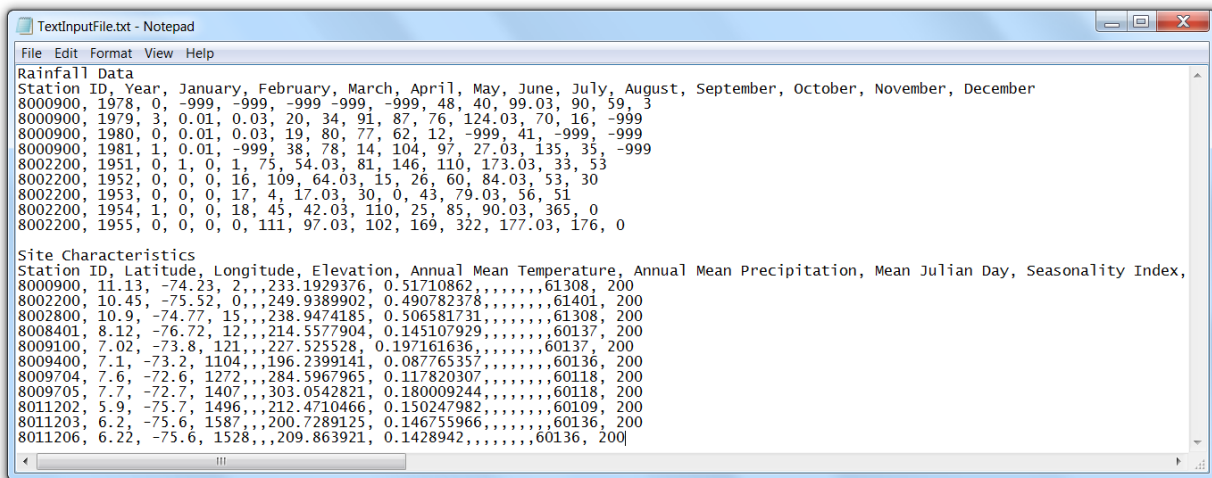
Input File

Prior to loading rainfall data, an input file must be created. This can be accomplished by creating a text file or by using Microsoft Excel. An example of a text input file is shown in Fig. 2. The file is split into two sections, one for the actual rainfall data and one for site characteristics. Rainfall data is organized by site and year, followed by twelve columns for each month of each year. The second section allows the user to provide some of the characteristics for each site, such as latitude, longitude, elevation, temperature, annual precipitation, etc.

The Excel input file (not shown) is similar to the text format, except that the data and site characteristics are split into two separate worksheets titled 'Data' and 'Characteristics'. The first worksheet contains the monthly rainfall data, organized by site and year, with 12 additional columns for each month of each year. Monthly rainfall totals are then placed in the appropriate columns. The second worksheet contains the site characteristics, organized similarly to the text file except that different characteristics are separated by columns rather than by commas.

Site characteristics are necessary in order to perform regionalization of the data. If a particular site characteristic is to be used in regionalization, that site characteristic needs to be known and included in the input file for all sites. The templates for both the text and Excel input files are available on the IWR website (www.iwr.usace.army.mil).

In order to load an input file, choose 'Load Data' from the 'File' menu of the title screen and browse your computer for the file. Once loaded, the rainfall data will be displayed in a separate window.

Figure 2: Text input file format.

Screen Data

Selecting 'Screen Data' from the 'Data' menu on the 'Title Screen' opens a window for the screening of either 'Rainfall' data or 'Drought Index' values (Fig. 3). The difference between the two types of data is that with regard to rainfall, ICI-RAFT sums the months for each period into one value, whereas 'Drought Index' values are averaged for each period. The focus here will be on the 'Rainfall' options.

The user first decides the period they would like to analyze by providing a 'Beginning Month' between 1 and 12 and a 'Duration' in months between 1 and 60. For example, a beginning month of 2 and a duration of 3 would indicate that for each year, the user only wants to analyze the period of February – April. If a particular stations has 50 years of data, the following frequency analysis will be based on 50 values of total precipitation between the months of February and April. If any of those 50 years of data contain a missing value, that year will not be included in the computations. So if 10 years of data contain missing values between February and April, only 40 years can be used in the analysis. The minimum number of years of good data for a particular site to be included in the following analysis is chosen by the user below 'Duration'. This number should always be greater than 4. The final option in the screening process is the 'Climate Index Lag', which will be described later. Clicking 'Filter' proceeds with data screening.

After clicking 'Filter', the user will be able to enter the units for the site characteristics provided in the input file. If there are additional site characteristics included in the input file other than the standard characteristics, these will be indicated in the section titled 'Other Characteristics', and units may also be provided for these characteristics as well. Clicking 'OK' will continue with the screening process and compute the L-moments for all those sites that met the conditions specified by the user in the 'Data Screening' portion of Fig. 3.

Figure 3: Data Screening window.

Site Details

Upon completion of 'Data Screening', the 'Site Details' window opens (Fig. 4), which displays lists of accepted and rejected sites, along with the L-moments associated with the accepted sites to the left. The discordancy value for each site is given below the list of L-moments. Discordancy is a measure of how a particular site's L-moment ratios compare to the site L-moment ratios of the entire data set. Accepted sites with a discordancy above a critical threshold, which is dependent on the total number of sites, are considered discordant and are identified as such by an '*' following their respective 'Site ID' in the list of accepted sites. If the discordancy is high, or for any other reason that the user would like to exclude a particular site from further analysis, they can click the 'Delete Site' button.

A graph is displayed on the right side of the window; this graph allows the user to plot any of the L-moments and site characteristics on either axis. Discordant sites are plotted in red, while the other sites are plotted in blue. The current site highlighted in the column of accepted sites is represented in the graph by a larger dot. The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button; this button is present in multiple locations of ICI-RAFT and opens a window where the user can either specify the image size of the saved graph or choose to save the data in the graph as a table. Click 'Close' when finished.
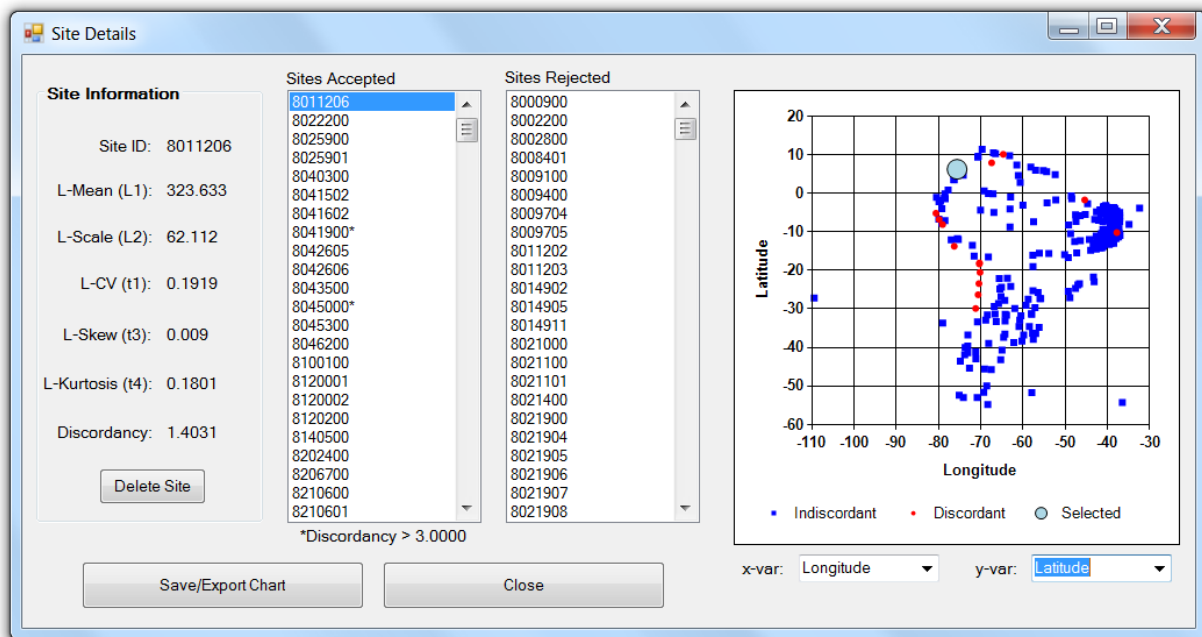

Figure 4: Site Details form showing site accepted and rejected and the L-moments and discordancy for the selected site. Plotted in the graph are latitude on the y-axis and longitude on the x-axis; blue dots represent non-discordant sites while red dots represent discordant sites. The large dot represents the site selected in the column of accepted site.

Site Plots

Selecting 'Plots' in the Title Screen's 'Sites' menu presents the user with two options: 'General' and 'Index Analysis'. The first option, 'General', opens the window 'Site Plots' (Fig. 5). This window allows the user to plot a site's raw data, scaled or normalized data, and a plot of L-Kurtosis vs. L-Skewness. The user can choose the site to display at the top of the window, while also choosing one of the options described by selecting the appropriate radio button below the graph. The graph of L-Kurtosis vs. L-Skewness plots these two L-moments for each site (with the selected site shown as a black dot) and compares them to the relationship of L-Kurtosis to L-Skewness for several standard frequency distributions: two-parameter distributions are plotted as a single point, whereas three-parameter distributions are plotted as lines or curves. This graph may help in determining which standard frequency distribution will best fit the rainfall data for each site.

Near the bottom of the window the user can opt to look at only certain portions or intervals of the data record or they can filter the data record for those years when a global climate index was greater than or less than a certain value. The 'Interval' option can only be used when the t4/t3 graph is displayed, whereas the 'Index' filter option can be used for any of the displays. Intervals are specified by clicking the 'Interval' radio button and choosing an interval size or step in years; the interval drop box is then filled with all intervals of that size for the entire period of record for the selected site. An index filter is set by selecting a global climate index from the drop-down box and then specifying a lower or upper limit or both and clicking 'Set'. Only those years meeting the selected criteria will be highlighted in the 'Raw Data' and 'Rescaled Data' plots for the selected site, while the t4/t3 graph will be recomputed and replotted for all sites in order to take into account these criteria as well.
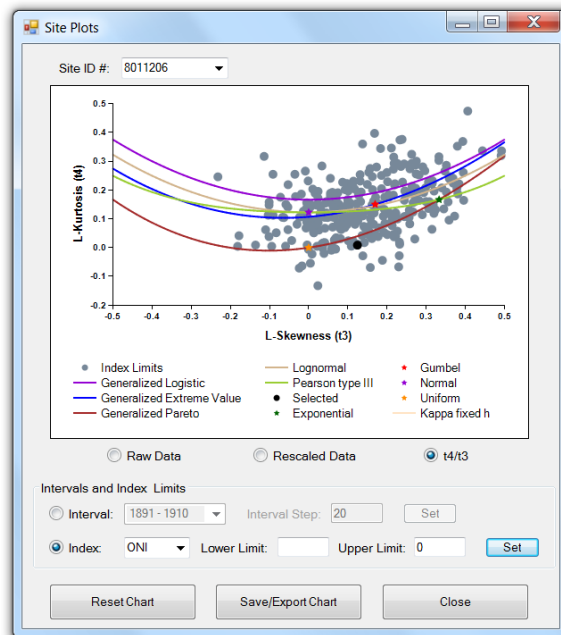

Figure 5: Site Plots window, showing the t4/t3 graph of the data with ONI index of < 0.

Clicking on the second option of the site 'Plots' menu, 'Index Analysis', opens a window similar to the one shown in Fig. 6. ICI-RAFT calculates how well each global climate index correlates with site rainfall using the R^2 statistic, taking into account the lag entered in Fig. 3.   The top five indices with the highest R^2 values compared to the selected site's precipitation data are displayed and clicking one of the buttons on the right side of the list displays a graph of the selected site's precipitation on the y-axis against the corresponding index value on the x-axis. The equation for the plotted trendline is given below the graph.

There are three buttons at the bottom of the window, the first of which allows the user to erase, or reset, the interval and index limits. The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button; this button is present in multiple locations of ICI-RAFT and opens a window where the user can either specify the image size of the saved graph or choose to save the data in the graph as a table. Click 'Close' when finished.
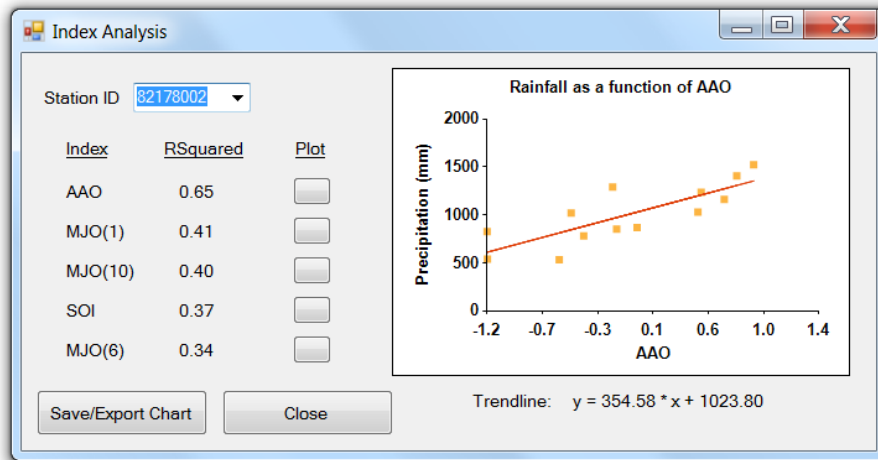

Figure 6: Index Analysis window showing a list of the top 5 global climate indices in terms of their correlation to rainfall at a particular site, one of which is plotted on the right.

Site Frequency Distribution

Selecting 'Frequency Distribution' from the 'Sites' menu of the 'Title Screen' opens a window that displays the first site's data probability density function (PDF) as vertical blue bars (Fig. 7). Any of the accepted sites for analysis can be viewed using the drop-down box below the graph. In addition, fits of any of the fourteen different standard frequency distribution functions (see Table 1) to the L-moments of the site's data can be displayed on the graph by clicking the checkbox next to the desired distribution; the EXP, GLO, and LP3 are compared in Fig. 7. With regard to the KP3 (3-parameter Kappa distribution), it is similar to the commonly-used 4-parameter Kappa distribution except that the fourth parameter (h) is fixed by the user, which can be set near the bottom of the window. In addition, the small unlabelled button next to the KAP distribution allows the user to change the number of iterations used in the four-parameter fitting process; this option should not be used unless the Kappa function is not producing a satisfactory fit to the sample data.

In addition, a site's cumulative distribution function, non-exceedance curve, or exceedance curve can be displayed using the radio buttons below the graph. For each type of graph there is the option of displaying individual data values for a specific period of time or by specifying global climate index limits using the same procedure as was described in the previous section. Specifying and selecting an interval or index limit will display the data within the interval or index limits as blue squares and the mean of that data as a larger black square.

There are four buttons at the bottom of the 'At-Site Distribution Plots' window. The 'Parameters' button displays the parameters for a particular standard frequency distribution estimated from the L-moments of the selected site. The 'Analysis' button will be described in more detail in the following section. The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button; this button is present in multiple locations of ICI-RAFT and opens a window where the user can either specify the image size of the saved graph or choose to save the data in the graph as a table. Click 'Close' when finished.

Table 1: Standard frequency distribution abbreviations.

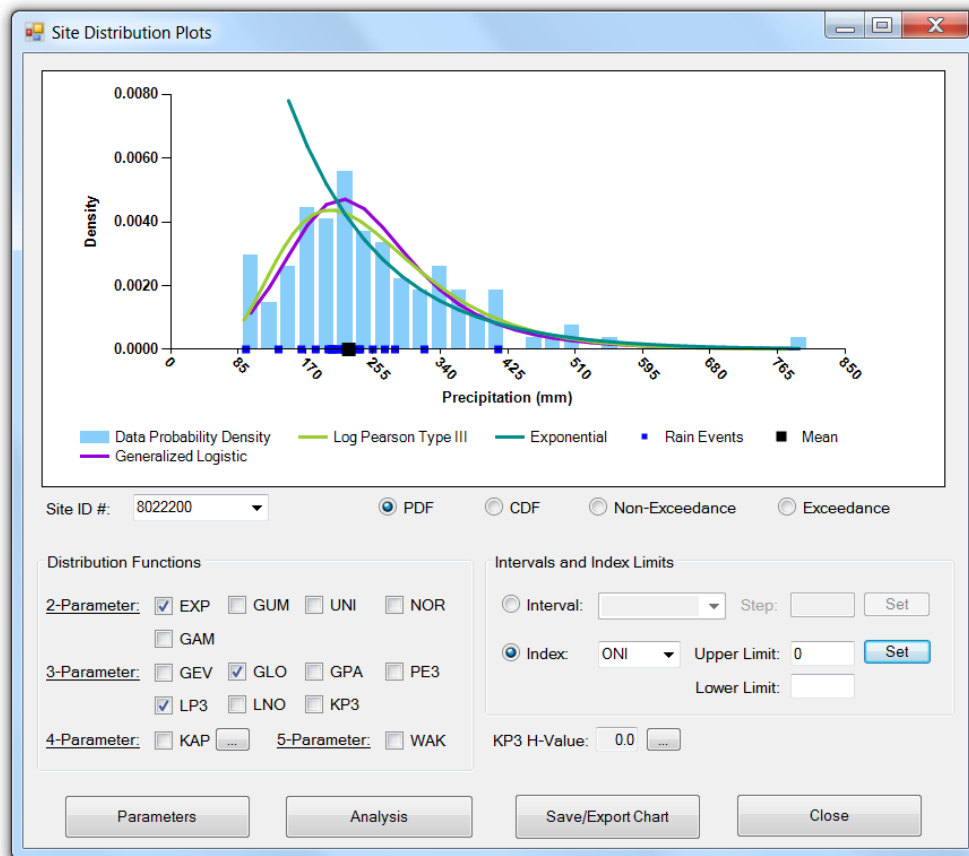| Distribution	Abbreviation
Exponential	EXP
Gumbel	GUM
Uniform	UNI
Normal	NOR
Generalized Extreme Value	GEV
Generalized Logistic	GLO
Generalized Pareto	GPA
Log-normal	LNO
Pearson Type III	PE3
Log-Pearson Type III	LP3
Gamma	GAM
Kappa (3-parameter)	KP3
Kappa (4-parameter)	KAP
Wakeby	WAK

Figure 7: Site Frequency Distribution window showing the PDF for a particular site compared to the PDF's of three standard distribution functions. A global climate index limit has also been set, with individual rainfall events that fall within this limit shown as blue squares and the mean shown as a black square.

Site Frequency Analysis

Selecting 'Analysis' on the previous screen opens the 'Site Frequency Analysis' window. This screen shows a table of rainfall exceedance frequencies and the associated intensities for the site chosen in the drop-down box in the top-left of the window using the selected standard frequency distribution. Information on how well each standard frequency distribution fits the frequency distribution of the selected site is shown to the right of each distribution. The goodness-of-fit statistics shown are the Pearson's R and the z-score, which is only valid for 3-parameter distributions. The Pearson's R is determined by computing the square root of the means of the difference squared between the sample data and the standard distribution. The z-score is computed based on the distance between a site's t4/t3 value displayed on the graph shown in Fig. 5 and that of each 3-parameter distribution. A Pearson's R close to 1 and a z-score close to 0 indicate a good fit.

There is also the option of computing exceedance values for a specific period of time or by specifying global climate index limits using the same procedure as was described in the previous section. The difference here is that when the button to the right of 'Set Index Limit(s)' is clicked, a separate screen appears that allows the user to select an index and set the desired limits. Specifying and selecting an interval or index limit will cause the exceedance values in the table to be recomputed. The user should re-select 'None' when desiring to analyze the entire data set without any index limits or intervals set.

There are three buttons at the bottom of the 'Site Frequency Analysis' window. The first button labeled 'Other Frequencies' opens a separate window that allows the user to compute the rainfall intensity for any exceedance or non-exceedance (flood or drought) frequency. The second button labeled 'Plots', when clicked, plots the exceedance curve for the site selected in Fig. 8 if an interval has not been set. If an interval has been set as in Fig. 8, then the resulting plot will appear as shown in Fig. 9. The rainfall intensity for each interval will be plotted for the selected site over that site's period of record. The event frequency can be changed using the drop-down box on the left below the plot. The light blue dot represents the currently selected interval and can be moved using the interval drop-down box or by clicking one of the arrows on either side of the interval drop-down box. The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button in Fig. 9. Click 'Close' when finished with either window.
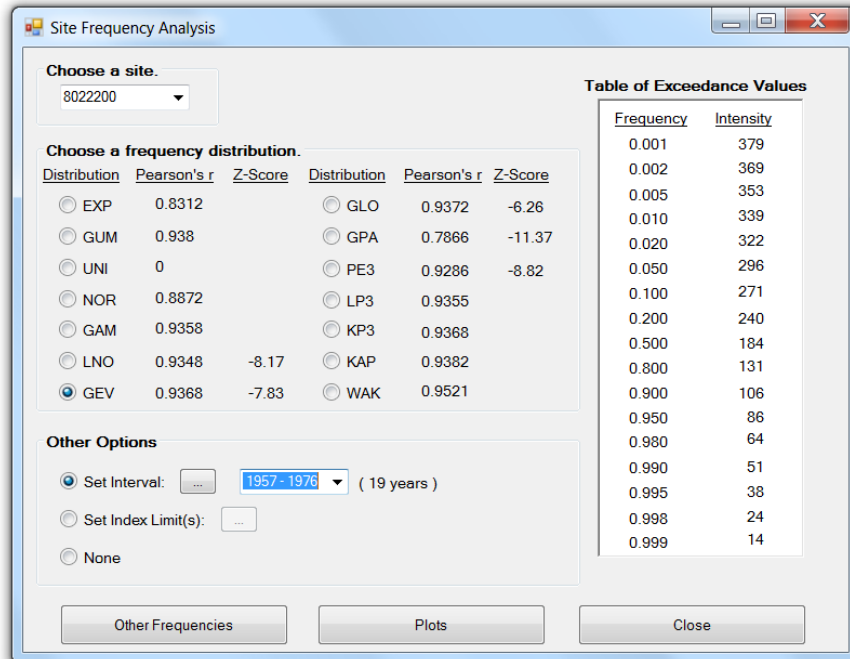
Figure 8: This screen estimates the storm intensity for an event of a particular frequency. Closeness-of-fit statistics (Pearson's R and Z-score). The final results for the selected interval are displayed in the table.
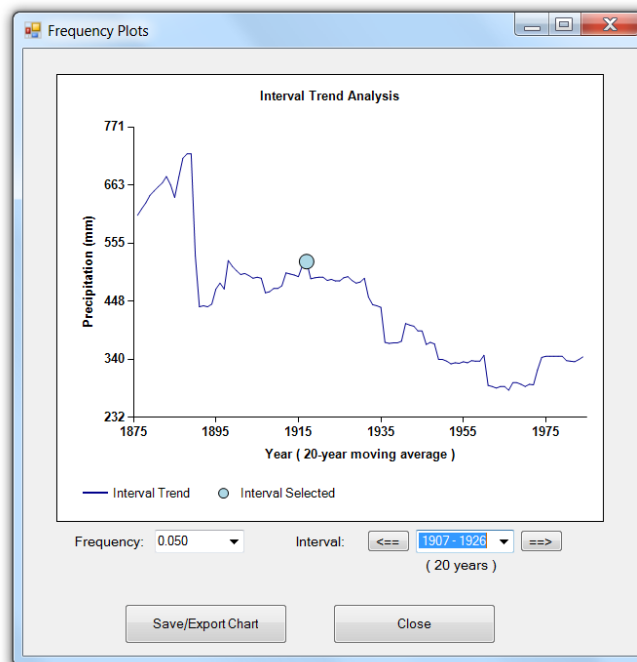

Figure 9: **Frequency Plots** window showing intensities of 20-year events (selected frequency = 0.050) for the entire period of record for a particular site. The dot represents the 20-year event for the selected interval.

Regionalization

The 'Regions' menu on the Title Screen becomes available after the initial data screening. The only item in the 'Regions' menu currently available is 'Regionalization, which opens the window shown in Fig. 10. The first option at the top of the window allows the user to choose one of three methods when creating regions: use the site characteristics for each site in an attempt to create homogenous regions, use eco-regions, or manually specify regions. Prior to choosing the 'Eco-regions/Own regions' option, the regions must be manually identified for each site in the appropriate locations in the input file. If the 'Use Site Characteristics' button is selected, all site characteristics that are provided for all sites in the input file are enabled in the 'Regionalization' window. After choosing a regionalization method, the second option near the top of the window, number of regions, needs to be specified.

The user will next enter weights between 0 and 1 for all site characteristics that are enabled. If the user entered data in the 'Other' columns of the 'Site Characteristics' worksheet of the input file, these will be shown in the bottom three rows of the current window. If the user desires to give equal weights to some of the site characteristics, the checkboxes next to the appropriate site characteristics can be checked after which the 'Equal Weights' button can be selected. Weights for all site characteristics selected will be divided equally to add up to 1.00. The 'Select All' option may be selected if equal weights are desired for all site characteristics, whereas the 'Unselect All' option may be selected to clear all checkboxes and enter each weight manually. The 'Reset Weights' button sets all weights to zero. All weights that are entered must total to one (shown in the bottom left corner of Fig. 10) before continuing. Click the 'OK' button to begin the computation of the regions and the regional L-moments.

Figure 10: Regionalization window.

Regional Details

Upon completion of Regionalization', the 'Regional Details' window opens (Fig. 11), which includes two drop-down boxes containing lists of regions and sites within each region, along with the L-moments associated with each selected region and site below the drop-down boxes. Regional information also includes the number of total sites and the number of discordant sites within the region along with a measure of the homogeneity of the region. In this case, the site discordancy is a measure of how a particular site's L-moment ratios compare to the site L-moment ratios of the other sites within the selected region only. If the discordancy is high, or for any other reason that the user would like to move a site to a different region, they can indicate the new region number below the site L-moments and click the 'Move Site' button; the new region will be highlighted prior to clicking the button. The homogeneity is a measure of the similarity between the frequency distributions of all sites within a region. A graph of latitude vs. longitude is displayed on the right side of the window; this graph allows the user to plot any of the L-moments and site characteristics provided in the input file on either axis. All sites not included in the selected region are shown as gray dots, whereas discordant sites within the selected region are shown as red dots and non-discordant sites are shown as blue dots. Discordant sites are also identified with an asterisk after their site-id within the 'Site ID #' drop-down box. The site that has been selected is identified in the graph by a large dot. Graphing the various L-moments and site characteristics against each other may help to identify why some sites are discordant compared to others within the selected region, which may lead to moving a particular site to a different region.

The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button; this button is present in multiple locations of ICI-RAFT and opens a window where the user can either specify the image size of the saved graph or choose to save the data in the graph as a table. Click 'Close' when finished.
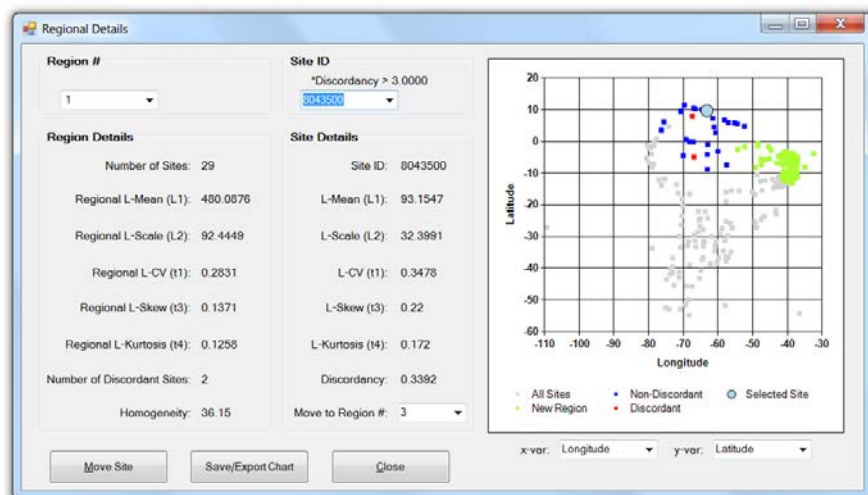

Figure 11: Image of the 'Region Details' window with the graph showing 'Latitude' vs. 'Longitude'. Blue dots represent non-discordant sites, red dots represent discordant sites, and light green sites represent the receiving region chosen for a site move.

Regional Plots

Selecting 'Plots' in the Title Screen's 'Regions' menu opens the window in Fig. 12. This window allows the user to plot all sites' raw data, scaled or normalized data within a region, along with a regional plot of L-Kurtosis (t4) vs. L-Skewness (t3). The user can choose the region (and site when displaying the graph of L-Kurtosis vs. L-Skewness) to display at the top of the window, while also choosing one of the options described by selecting the appropriate radio button below the graph. The graph of L-Kurtosis vs. L-Skewness plots these L-moments for each site (with the selected site of the selected region shown as a black dot) and compares them to the relationship of L-Kurtosis to L-Skewness for several standard frequency distributions: two-parameter distributions are plotted as a single point, whereas three-parameter distributions are plotted as lines or curves. This graph may help in determining which standard frequency distribution will best fit the rainfall data for each region and/or site.

Near the bottom of the window the user can opt to look at only certain portions or intervals of the data record or they can filter the data record for those years when a global climate index was greater than and/or less than a certain value. The 'Interval' option is available when the t4/t3 graph is displayed, whereas the 'Index' filter option can be used for any of the displays. Intervals are specified by clicking the 'Interval' radio button and choosing an interval size or step in years; the interval drop box is then filled with all intervals of that size for the entire period of record for the selected region. An index filter is set by selecting a global climate index from the drop-down box and then specifying a lower or upper limit or both and clicking 'Set'. Only those years meeting the selected criteria will be highlighted in the 'Raw Data' and 'Rescaled Data' plots for the selected region, while the t4/t3 graph will be recomputed and replotted for all sites within the region in order to take into account these criteria as well.
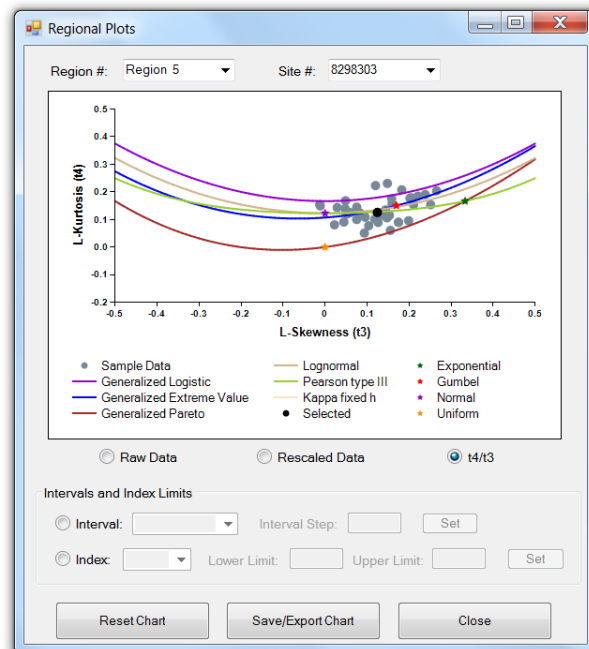

Figure 12: 'Regional Plots' window, showing the t4/t3 graph with ONI index < 0.

Regional Frequency Distribution

Selecting 'Frequency Distribution' from the 'Regions' menu of the 'Title Screen' opens a window that displays the first region's data probability density function (PDF) as vertical blue bars (Fig. 13). Any of the regions can be viewed using the drop-down box below the graph. In addition, fits of any of the fourteen different standard frequency distribution functions (see Table 1) to the regional L-moments can be displayed on the graph by clicking the checkbox next to the desired distribution; the GEV, GLO, and LP3 are compared in Fig. 13. With regard to the KP3 (3-parameter Kappa distribution), it is similar to the commonly-used 4-parameter Kappa distribution except that the fourth parameter (h) is fixed by the user, which can be set near the bottom of the window. In addition, the small button next to the KAP distribution allows the user to change the number of iterations used in the KAP fitting process.

In addition, a region's cumulative distribution function, non-exceedance curve, or exceedance curve can be displayed using the radio buttons below the graph. For each type of graph there is the option of displaying individual data values for a specific period of time or by specifying global climate index limits using the same procedure as was described in the section 'Site Frequency Distribution'. Specifying and selecting an interval or index limit will display the data within the interval or index limits as blue squares and the mean of that data as a larger black square.

There are four buttons at the bottom of the 'Regional Distribution Plots' window. The 'Parameters' button displays the parameters for a particular standard frequency distribution estimated from the L-moments of the selected region. The 'Analysis' button will be described in more detail in the following section. The user can save the graph or export the values in the graph to a text file by clicking the 'Save/Export Chart' button; this button is present in multiple locations of ICI-RAFT and opens a window where the user can either specify the image size of the saved graph or choose to save the data in the graph as a table. Click 'Close' when finished.
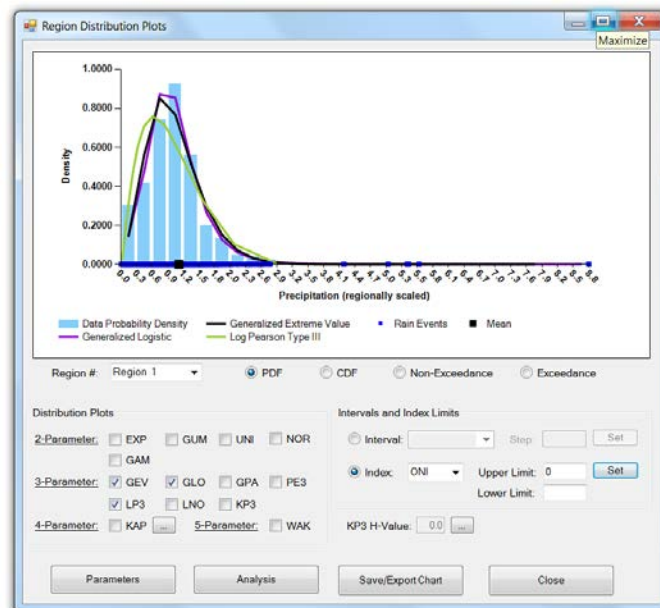

Figure 13: As in Fig. 7 except for regions instead of sites.

Regional Frequency Analysis

Selecting 'Analysis' on the previous screen opens the 'Regional Frequency Analysis' window, which contains two tabs titled 'Onsite Analysis' and 'Offsite Analysis'. This 'Onsite Analysis' screen shows a table of rainfall exceedance frequencies and the associated intensities for the region and site chosen in the drop-down box in the top-left of the window using the selected standard frequency distribution. Information on how well each standard frequency distribution fits the frequency distribution of the selected region is shown to the right of each distribution. The goodness-of-fit statistics shown are the Pearson's R and the z-score, which are described in more detail in the section "Site Frequency Analysis". Once the desired distribution has been selected, the user needs to choose which site averaging method to use to estimate the storm intensity for a particular site. Because the regional distribution was fit to scaled or normalized site data, the resulting regional exceedance curve needs to be multiplied by a mean value representative of the selected site. Two options are available: using the L-Mean (**L1**) computed from the selected site's rainfall data provided in the input file or using an 'Index Flood' value for that site. The 'Index Flood' method uses the 'Mean Precipitation' for the period chosen in Fig. 3 and, if available, needs to be entered by the user in the final column of the 'Site Characteristics' portion of the input file. An external source, such as a Mean Annual Precipitation map or database, is needed to use this option. If this information is not available, then the user must use the 'L1' option.

There is also the option of computing exceedance values for a specific period of time or by specifying global climate index limits using the same procedure as was described in the previous section. This is discuss in detail in the section 'Site Frequency Analysis'.

There are three buttons at the bottom of the 'Regional Frequency Analysis' window. The first button labeled 'Other Frequencies' opens a separate window that allows the user to compute the rainfall intensity for any exceedance or non-exceedance (flood or drought) frequency. The second button labeled 'Plots', when clicked, plots the exceedance curve for the region and site selected in Fig. 14 if an interval has not been set. If an interval has been set as in Fig. 14, then the resulting plot will be similar to what was shown in Fig. 9. The details of this plot were given in the section 'Site Frequency Analysis'.

When the user clicks the 'Offsite Analysis' tab of the 'Regional Frequency Analysis' window, a screen similar to the one in Fig. 15 appears. Offsite analysis is performed when attempting to estimate the intensity of storms of a particular frequency at sites where there are no data. The user first needs to identify the region of interest by entering the range of latitudes (northern and southern limits) and longitudes (eastern and western limits). In addition, the user needs to enter a 'Resolution' in units of degrees and choose a standard frequency distribution, a site averaging method, and a frequency. Clicking OK will allow the user to save a text file that contains information on the number or rows and columns of output data, the x- and y-coordinates of the lower left corner of the region, the resolution in degrees, and the actual offsite data organized into rows and columns.

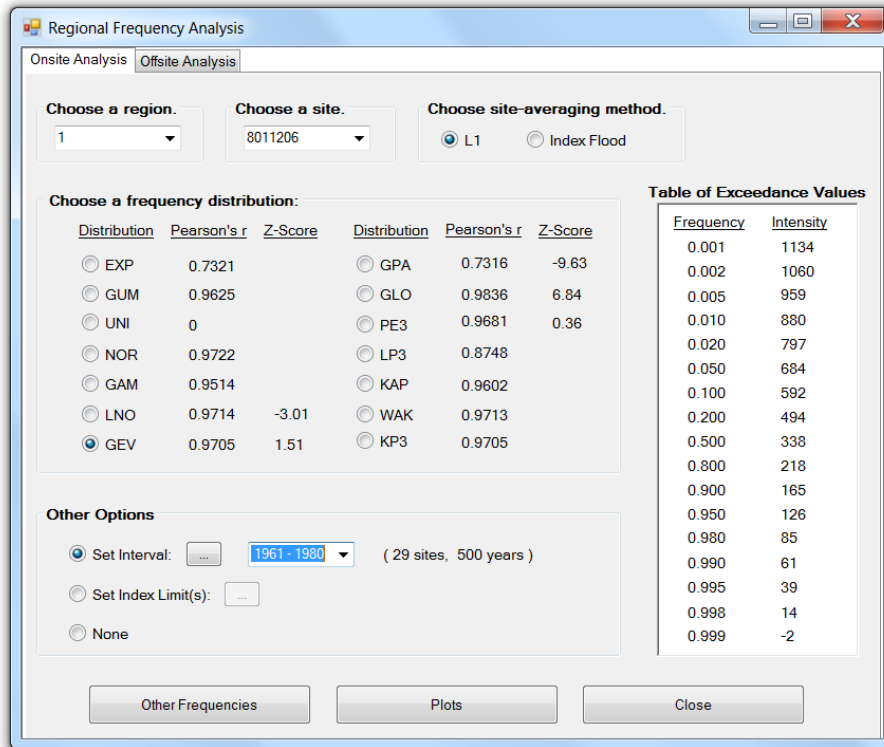Click 'Close' when finished.

Figure 14: Input screen for regional 'Onsite Analysis using data within a specified interval to compute intensities for the frequencies in the table.
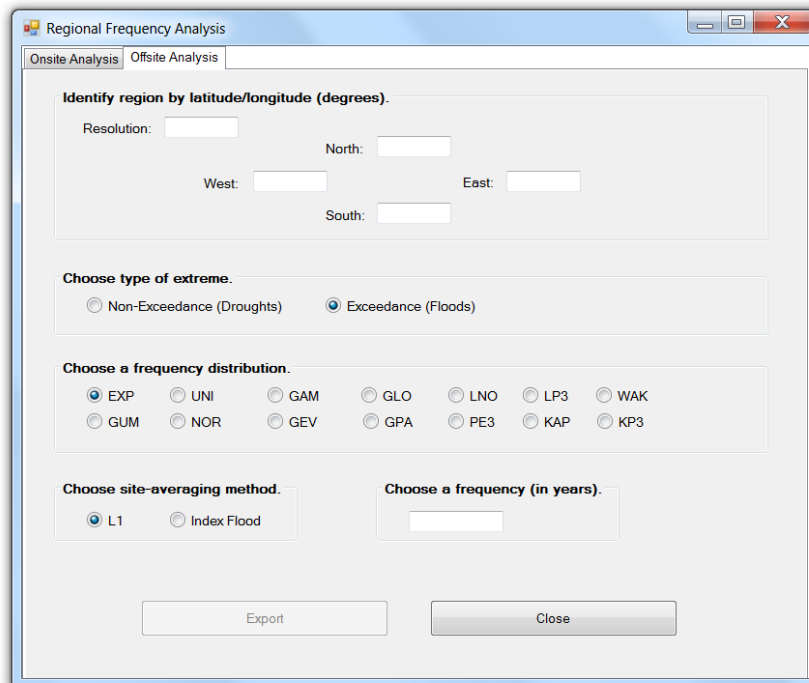

Figure 15: Input screen for regional 'Offsite Frequency Analysis'.

CHAPTER 4: GLOBAL CLIMATE INDICES

There is contained within ICI-RAFT a database of various climate indices that may help the user to identify modes of climate variability that can affect a particular region of interest. Short descriptions of each index are given below, while general ranges for each index are provided in Table 1.

Table 2: List of indices and their abbreviations and ranges since 1948.

Abbreviation	Full Name	Range since 1948
AAO	Antarctic Oscillation	-3.01 to 2.69
AO	Arctic Oscillation	-4.27 to 3.50
EA	East Atlantic Index	-3.33 to 2.68
EA/WR	Eastern Atlantic/Western Russia Index	-4.17 to 3.68
EP/NP	East Pacific/North Pacific Index	-2.96 to 3.88
MJO	Madden-Julian Oscillation	-2.02 to 2.01
NAO	North Atlantic Oscillation	-3.14 to 3.06
NOI	Northern Oscillation Index	-12.20 to 8.68
NP	North Pacific Index	996.44 to 1020.99
ONI	Oceanic Nino Index	-2.10 to 2.50
PDO	Pacific Decadal Oscillation	-3.60 to 3.51
PNA	Pacific/North American Index	-3.65 to 2.87
POL	Polar/Eurasia Index	-3.44 to 3.53
SCA	Scandinavian Index	-2.44 to 3.15
SOI	Southern Oscillation Index	-3.60 to 2.90
WP	West Pacific Index	-3.45 to 3.39

Antarctic Oscillation (AAO)
The AAO is estimated based on mean height anomalies at 700 mb from latitude 20°S to 90°S. Positive values appear to drive cooling in East Antarctica and warming on the Antarctic Peninsula; a trend toward extreme values of this index has been linked to stratospheric cooling driven by ozone loss.

Arctic Oscillation (AO)
The AO is estimated based on mean height anomalies at 1000 mb from latitude 20°N to 90°N. Positive values indicate cold, wet weather at higher latitudes and warm/dry conditions at lower latitudes, with the reverse holding true for negative values.

East Atlantic Index (EA)
The EA is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20°N to 90°N. The EA's anomaly centers are displaced southeastward compared to the NAO pattern; positive index values are associated with warmer temperatures in Europe and colder temperatures in the USA.

Eastern Atlantic/Western Russian Index (EA/WR)
The EA/WR is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20°N to 90°N. Positive height anomalies in Europe and China counterbalance lows in the Atlantic and north of the Caspian Sea. The effects of a positive cycle are warmer/wetter weather in East Asia and colder/dryer weather in Europe and surrounding regions.

East Pacific/North Pacific Index (EP/NP)
The EP/NP is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20 N to 90 N. Positive values feature a high anomaly over Alaska and low anomalies over the north Pacific and the eastern USA, pushing the jet stream southward. Temperatures drop on the American east coast in this scenario, while Canada's Pacific coast is dry.

Madden-Julian Oscillation (MJO)
Unlike other indices, the MJO is characterized by convective rainfall anomalies that are in motion during the course of its cycle, propagating from the Indian Ocean east into the Pacific Ocean. The anomalies are modeled using ten separate indices centered on lines of longitude around the globe, with seven in the eastern hemisphere and three in the western. Indices 1-4 and 10 model the zone through which MJO events move; each of the other five strongly anti-correlate with one of the first set and indicate the worldwide effects of MJO, from facilitating El Niño dynamics to influencing high-latitude rainfall. The longitudes each index represents are given: (1)80E, (2)100E, (3)120E, (4)140E, (5)160E, (6)120W, (7)40W, (8)10W, (9)20E, (10)70E.

North Atlantic Oscillation (NAO)
Key features of the NAO are centers of low pressure near Iceland and high pressure near the Azores, both of which are strong for positive values of the NAO. One important effect of a positive NAO is a wetter and stormier winter season in the eastern USA, with negative values corresponding to a dry, cold winter.

Northern Oscillation Index (NOI)
The NOI represents the surface-level pressure difference between the North Pacific High near North America and Darwin (in Australia's Northern Territory), normalized by the long-term average and standard deviation. Built as a rough north Pacific equivalent of the SOI, it represents the influence of a wide variety of global-scale climatic forces on the North Pacific and North America. A 14-year cycle in the value of this index has been noted.

North Pacific Index (NP)
According to NASA's website, the NP Index is the area-weighted sea level pressure (SLP) over the region 30N-65N, 160E-140W and is used to measure decadal variations linked to El Nino (ENSO) and La Nina events.

Oceanic Niño Index (ONI)
According to the website of NOAA's Climate Prediction Center, the ONI represents the 3-month running mean of ERSST.v3b sea-surface temperature (SST) anomalies in the Niño 3.4 region (5^oN-5^oS, 120°-170^oW), based on centered 30-year base periods updated every 5 years. Warm (El Niño) and cold (La Niña) episodes are based on a threshold of +/- 0.5^oC ONI; for historical purposes cold and warm episodes are defined when the threshold is met for a minimum of 5 consecutive over-lapping seasons.

Pacific Decadal Oscillation (PDO)
The PDO is a major cycle sometimes compared to El Niño, but of a longer time period (20-30 years) and with stronger effects in the North Pacific than in the tropics. The index is based on North Pacific monthly sea surface temperature variability. Warm PDO regimes tend to increase coastal ocean biological productivity off Alaska and decrease it further south, while cold PDO regimes have the reverse effect.

Pacific/North American Index (PNA)
The PNA is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20 N to 90 N. Key features of the PNA are a low center near the Rockies and a high center near the Aleutian Islands, both of which are strong for positive values; high positive values correlate with warm/dry weather in the west USA and wet/cold weather in the east USA, with negative values corresponding to the opposite effects.

Polar/Eurasia Index (POL)
The POL is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20 N to 90 N. Its main temperature effects are in Siberia (hotter) and China (colder). An oscillation in this index has been noted on the half-decadal scale.

Scandinavian Index (SCA)
The SCA is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20 N to 90 N. A positive value drives positive height anomalies over western Russia and Scandinavia, with cooling effects in central Russia and western Europe and increased precipitation for central and southern Europe.

Southern Oscillation Index (SOI)
The SOI represents the normalized surface-level pressure difference between Tahiti and Darwin (in Australia's Northern Territory). Negative values of the SOI during the southern hemisphere's summer season indicate an El Niño event; positive values indicate a strong Walker Circulation pattern.

West Pacific Index (WP)
The WP is estimated based on the analysis of monthly height anomalies at 500 mb from latitude 20 N to 90 N. The WP has anomaly centers over the Kamchatka Peninsula and a broad swath of ocean adjacent to Southeast Asia, which are associated with the entrance region of the Pacific jet stream, as well as another center over the southwest USA. Positive values correlate with cooler/wetter weather in the North Pacific and eastern Siberia and drier weather further south.

CHAPTER 5: TERMS AND CONDITIONS FOR USE

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