

UNCLASSIFIED

**THE ICI-WARM NON-PROPRIETARY REGIONAL FREQUENCY ANALYSIS
TOOL USING THE METHOD OF L-MOMENTS**

J. P. Giovannettone*
Institute for Water Resources, Alexandria, VA 22315
Telephone: 703-428-8565
Email: jason.p.giovannettone@usace.army.mil

M. J. Wright, Institute for Water Resources, Alexandria, VA 22315

EXTENDED ABSTRACT

Introduction

When it comes to setting policy, making water use plans, designing infrastructure, and making operational water management decisions, it is important to be informed concerning the frequency, severity, and duration of droughts (and floods) in the region. Questions posed by water planners, managers, and decision-makers that should be answered include the following: “How rare is the current drought?”, “How likely is it that the drought will end in X months?”, “How large a drought should we plan for?”, and “How rare is the drought of record?”. These questions can be answered by performing a frequency analysis of rainfall and using the results to compute statistics for the various sites in question.

Most tools that have been developed for this purpose require a license to use or are made specifically for a particular group’s interests. The International Center for Integrated Water Resources Management (ICIWaRM) is currently developing a non-proprietary and comprehensive Regional Frequency Analysis (RFA) tool (which has recently been renamed the ICIWaRM Regional Analysis of Frequency Tool or ICI-RAFT) that can be used in general to answer the questions above; the title screen is shown in Fig. 1. ICI-RAFT uses the method of L-moments, which provides the means for estimating the shape of the rainfall frequency distribution for an entire homogeneous region. L-moments are analogous to regular moments (mean, standard deviation, skewness and kurtosis) except that they are calculated using equations that represent linear combinations of the sample or population data elements, hence the name Linear-moments or L-moments. The resulting statistics are referred to as L-location (or mean), L-scale, L-CV (Coefficient of Variability), L-skewness, and L-kurtosis. The advantage of L-moments over regular moments is that using linear statistics makes the procedure more robust with respect to outliers. L-moments are also able to characterize a wider range of frequency distributions and are less subject to bias in their calculations than regular moments.

Another advantage of ICI-RAFT is that, as the name implies, it estimates site L-moments by first estimating the L-moments and the associated frequency analysis curves for multiple homogeneous regions that each contain multiple sites. Advantages of

Distribution Statement A -- Approved for public release; distribution is unlimited.

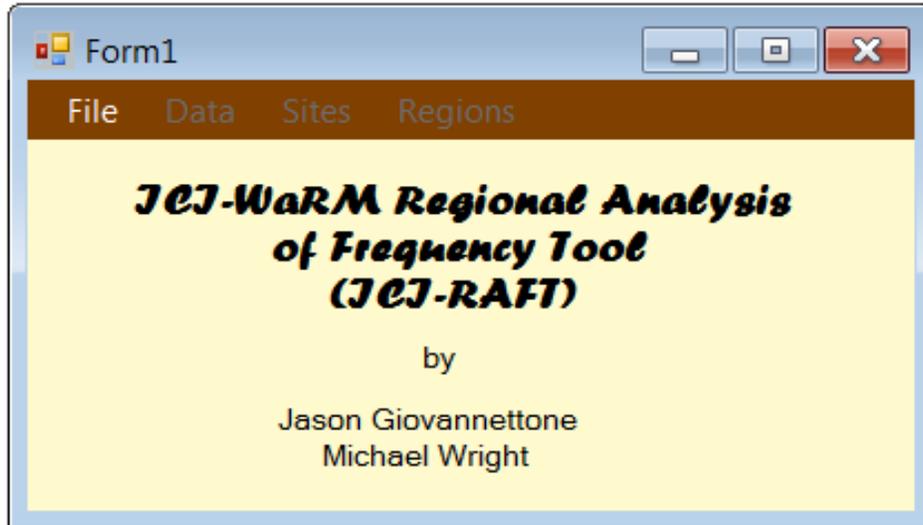


Figure 1: ICI-RAFT Title Screen.

performing a regional frequency analysis instead of using each individual site's data separately is that it allows the inclusion of sites with short record lengths, few rain gage stations, a substantial amount of missing data, or station data with a higher variability due to the presence of mountain ranges and/or multiple precipitation sources. In addition, it is difficult to find frequency distributions that fit an individual site's rainfall data well. A regional analysis that combines the data from all sites can obtain a closer fit. These advantages especially make this tool ideal for use in arid and semi-arid regions where other methods fall short.

Input Files

The first step when using ICI-RAFT is to enter quality-controlled data into the input file, which ICI-RAFT requires to be an Excel worksheet. The input file must contain two sheets: **moxyrData** (Fig. 2a) contains the monthly total precipitation values to be analyzed, while **OtherData** (Fig. 2b) holds the site characteristics, e.g. mean annual precipitation, elevation, longitude and latitude; this information will assist the user when creating homogenous regions. In **moxyrData** (Fig. 2a) Column A contains each Site ID, whereas Column B contains each year for each site. As the user moves along a single row for a particular site and year, monthly values of total precipitation are entered. If a particular monthly total is not known or is known to be incorrect, then "-999" is entered.

In **OtherData** (Fig. 2b), each column represents a particular site characteristic that can be used when creating homogenous regions if such data are available. Only variables that are known for all sites and years will be used during regionalization; therefore not all columns are required to be filled in. The user should remember that the more data that are available, the more efficient the regionalization process will be. In addition to the site characteristics shown in Fig. 2b, the user is welcomed to add up to three of their own site characteristics in the **Other** columns. Within the **Other** columns, the name of the site characteristic is required in Row 2, and the units are required in Row 3. An alternative to

UNCLASSIFIED

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Site	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	8000900	1952	-999	-999	-999	-999	-999	3	2	3	84.03	4.03	0	1
3	8000900	1953	0	0.01	0.03	0	0	2	0	2	1.03	9.03	0	0
4	8000900	1954	0	0.01	0.03	0	4	22	1	2	61.03	3.03	27	0
5	8000900	1955	0	0.01	0.03	0	2	0	13	25	4.03	-999	0	0
6	8000900	1956	0	0.01	0.03	0	1	1	0	1	0.03	1	1	0
7	8000900	1957	0	0.01	1.03	0	53	9	8	13	57.03	22	0	0
8	8000900	1958	0	0.01	0.03	0	121	7	50	36	0.03	16	0	0
9	8000900	1959	0	0.01	0.03	0	6	26	2	1	5.03	21	0	0
10	8000900	1960	0	0.01	0.03	8	16	54	50	-999	31.03	55	34	3
11	8000900	1961	0	0.01	0.03	4	0	67	78	5	30.03	-999	-999	-999
12	8000900	1962	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
13	8000900	1963	0	18.01	0.03	0	0	1	13	1	25.03	72	82	0
14	8000900	1964	0	0.01	0.03	25	2	51	204.01	60	144.03	71	83	0
15	8000900	1965	-999	-999	-999	-999	-999	3	0	40	43.03	75	110	0
16	8000900	1966	0	0.01	5.03	1	18	104	40	8	21.03	89	26	27.02
17	8000900	1967	0	0.01	0.03	0	1	67	31	6	75.03	38	38	0
18	8000900	1968	0	0.01	0.03	5	11	94	17	17	4.03	-999	9	0
19	8000900	1969	0	0.01	6.03	36	1	79	1	107	62.03	33	96	0
20	8000900	1970	59.01	0.01	2.03	26	124	115	161	73	95.03	14	109	9.02
21	8000900	1971	15	0.01	0.03	4	36	30	6	-999	-999	-999	-999	0
22	8000900	1972	0	0.01	0.03	0	0	45	0	15	43.03	111	4	0
23	8000900	1973	0	1	0.03	5	16	23	166	81	97.03	295	56	0
24	8000900	1974	0	1	1.03	0	101	130	57	32	103.03	150	69	1
25	8000900	1975	0	0.01	6.03	0	3	51	144	54	59.03	153	60	24.02
26	8000900	1976	0	0.01	0.03	1	2	42	2	75	23.03	68	40	0
27	8000900	1977	24.01	0.01	0.03	0	73	127	6	63	147.03	31	12	0
28	8000900	1978	0	-999	-999	-999	-999	-999	48	40	99.03	90	59	3
29	8000900	1979	3	0.01	0.03	20	34	91	87	76	124.03	70	16	-999
30	8000900	1980	0	0.01	0.03	19	80	77	62	12	-999	41	-999	-999
31	8000900	1981	1	0.01	-999	38	78	14	104	97	27.03	135	35	-999
32	8002200	1951	0	1	0	1	75	54.03	81	146	110	173.03	33	53
33	8002200	1952	0	0	0	16	109	64.03	15	26	60	84.03	53	30
34	8002200	1953	0	0	0	17	4	17.03	20	0	43	70.03	56	54

(a)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Site ID	Latitude	Longitude	Elevation	Annual Mean Temperature	Annual Mean Precipitation	Mean Julian Day	Seasonality Index	Mean Precipitation (Winter)	Mean Precipitation (Spring)	Mean Precipitation (Summer)	Mean Precipitation (Autumn)	Other (1)	Other (2)	Other (3)	Eco-Region/ Open Region	Mean Precipitation (Selected Period)
3																	
4	8000900	11.13	-74.23	2			233.1929176	0.51710882								61308	200
5	8002200	10.45	-75.52	12			249.9389902	0.49070338								61401	200
6	8002800	10.9	-74.77	15			238.9474185	0.506081731								61308	200
7	8008401	8.12	-76.72	12			214.5577904	0.145107929								60137	200
8	8009100	7.02	-73.8	121			227.525228	0.197161836								60137	200
9	8009400	7.1	-73.2	1104			196.2399141	0.587765357								60136	200
10	8009704	7.6	-72.6	1272			284.5967965	0.117820207								60118	200
11	8009705	7.7	-72.7	1407			303.0542821	0.180009244								60118	200
12	8011202	5.9	-75.7	1496			212.4710466	0.150247982								60109	200
13	8011203	6.2	-75.6	1587			200.7289125	0.146753966								60136	200
14	8011206	6.22	-75.6	1528			208.863921	0.1428942								60136	200
15	8014902	5	-75.6	1295			184.9718123	0.020626212								60109	200
16	8014905	4.9	-75.1	2141			146.9336935	0.00787214								60136	200
17	8014911	4.98	-75.58	1463			228.3568478	0.018161971								60109	200
18	8021000	4.82	-75.8	1188			307.7937521	0.034361705								60109	200
19	8021100	4.5	-75.72	1302			15.43389255	0.073857996								60109	200
20	8021101	4.5	-75.6	2151			325.8450427	0.081081388								60109	200
21	8021400	4.43	-75.15	960			162.8213581	0.030195232								60221	200
22	8021900	4.28	-74.8	284			107.0949758	0.018964508								60221	200
23	8021904	4	-75	326			87.660313	0.045268756								60221	200
24	8021905	3.8	-75	326			344.6226573	0.122110602								60221	200
25	8021906	4.2	-74.9	330			129.0709464	0.036956398								60221	200
26	8021907	4	-75	326			90.82839864	0.016099432								60221	200
27	8021908	4.3	-74.4	1573			360.5438278	0.140739016								60136	200
28	8022200	4.7	-74.13	2550			354.5516666	0.037475064								60136	200
29	8024100	4.55	-70.92	184			186.0963571	0.392823215								60709	200
30	8025900	3.55	-76.38	962			52.00408303	0.080219823								60207	200
31	8025901	3.5	-76.3	991			43.36627263	0.09678166								60207	200
32	8025902	3.8	-76.5	1516			212.2094601	0.017724094								60145	200
33	8025903	3.5	-76.3	991			68.41840873	0.082110351								60207	200
34	8025905	3.4	-76.4	960			69.58678996	0.094160165								60207	200
35	8030800	2.47	-76.6	1737			357.7628545	0.255447306								60109	200
36	8030801	2.45	-76.58	1809			361.545847	0.223939096								60109	200
37	8031500	2.97	-75.1	425			3.958842076	0.268871208								60221	200
38	8031502	3.6	-75.1	322			360.6683265	0.1688805494								60221	200
39	8031503	3.7	-75.5	869			356.3201274	0.106873071								60221	200
40	8033700	1.57	-78.68	17			109.0627878	0.255417627								60178	200
41	8034200	1.42	-77.27	1915			18.40227923	0.13853878								60145	200
42	8034204	1.27	-77.47	1873			5.236239721	0.118449082								60145	200
43	8037000	0.82	-77.83	2851			11.24678114	0.119242509								60145	200
44	8037001	1.2	-78	1948			19.64737385	0.104583111								60145	200

(b)

Figure 2: Example input file, showing the (a) rainfall data and (b) site characteristics worksheets.

UNCLASSIFIED

regionalization is to use **Eco-regions**, as defined by the World Wildlife Federation, the U.S. Environmental Protection Agency, or other groups, or to choose to manually set your own region for each site; this can be done using Column P. The final column will be discussed later in this document.

In terms of climate variability, a database of indices from various types of multi-decadal meteorological events such as the El Nino/Southern Oscillation, the North Atlantic Oscillation, the Pacific Decadal Oscillation, and others has been included. Using this database, only rainfall data from a particular phase of any one of these phenomena can be analyzed and compared to the opposite phase. This should give an indication of the effects of that phenomenon on climate variability in terms of the frequency of certain rainfall intensities. This feature will be ready in a future version of ICI-RAFT.

Data Screening

Once the input file is completed and loaded into ICI-RAFT, the next step is to choose the period for analysis. Upon selection of **Screen Data** within ICI-RAFT, a window appears (Fig. 3) that allows the user to determine the time period over which analysis is to be performed. A **Beginning Month** and **Duration in Months** must be entered to define this time frame; individual monthly values within the period chosen are totaled in order to obtain one value for each period; the length of the period analyzed can be from 1 month to 60 months or 5 years. If there are any missing or bad data during a particular year (represented by a -999 in the input file), that year is not used in the analysis for that

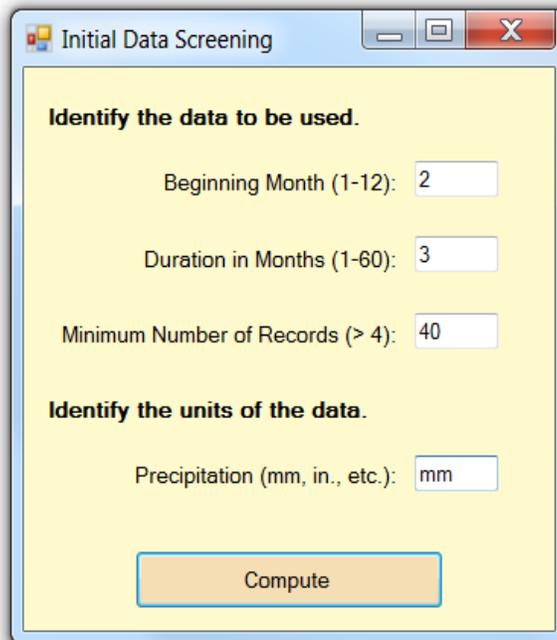


Figure 3: **Initial Screening** window.

UNCLASSIFIED

particular data site. Fewer years of data available for a particular site means that that particular site will contribute less to the overall regionalization process. A threshold for the number of valid years for a particular site can be set in the **Screen Data** window next to the caption **Minimum number of records**. Any sites having fewer than the specified number of annual records with good data will not be used in the regionalization process. This threshold must be more than four so that all of the program's statistics are calculable for all sites. Finally, the user enters the **Data Units** of the monthly precipitation data.

Site Analysis

Upon completion of the **Initial Screening** form, the **Site Details** form appears (Fig. 4); this window can also be accessed through the **Sites** menu on the title screen. The **Site Details** form contains two lists of sites, one each for accepted and rejected sites based on the number of years of data they contained with no missing or bad data (-999's) compared to the minimum numbers of years specified by the user in the **Initial Screening** window. Sites listed in the **Sites Accepted** column may be selected, which causes their L-moment statistics to be displayed in the left column of the form along with the **Site ID** and the **Discordance** of that site. In this case, the discordance is a measure of how a particular site's L-moment ratios compare to the site L-moment ratios of the entire data set. High discordance could indicate that a site's data may contain some type of measurement error, which may include, for example, an error related to data entry.

The right side of the **Site Details** window in Fig. 4 contains a graph of Latitude vs. Longitude. Discordant sites are shown on the graph as red dots, whereas the blue dots represent non-discordant sites. Discordant sites are also identified with an asterisk after their site-id in the **Sites Accepted** column. The site that has been selected in the **Sites Accepted** column to the left is identified in the graph by a large dot, which is either light blue or red depending whether it is discordant or non-discordant. Drop-down menus allow the user to display L_1 , t_1 , t_3 , t_4 , t_5 , or any of the at-site information from the **OtherData** input sheet as the x- or y-variables on the graph. Graphing the various L-moments and site characteristics against each other may help to identify why some sites are discordant compared to others. For example, as can be seen in Fig. 4, many of the discordant sites seem to be located on the West Coast of South America on the windward side of the Andes Mountains, which reveals a different precipitation regime than the remainder of South America.

Any site in the **Accepted** list may be eliminated from the analysis by clicking the **Delete Site** button. A confirmation box (not shown) will appear; clicking **OK** will remove the site from your analysis. The site can only be added back to the analysis by repeating the initial screening procedure from the previous step.

Plots

Choosing **Plots** in the **Sites** menu within the **Title Screen** opens a window allowing the user to view graphs of the data for any individual site. Any site can be chosen using the drop-down box at the top of the window. Radio buttons below the chart window allow the user to view **Raw Data**, **Rescaled Data**, or a **t4/t3** (L-Kurtosis vs. L-Skewness) plot.

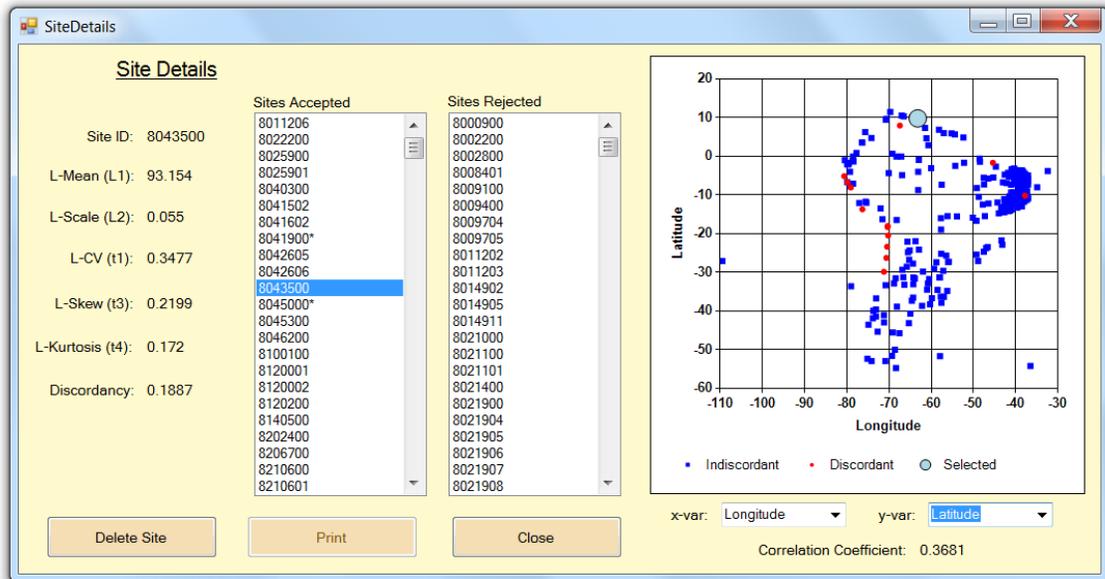


Figure 4: **Site Details** window showing **Longitude** vs. **Latitude**. Blue dots represent non-discordant sites, while red dots represent discordant sites.

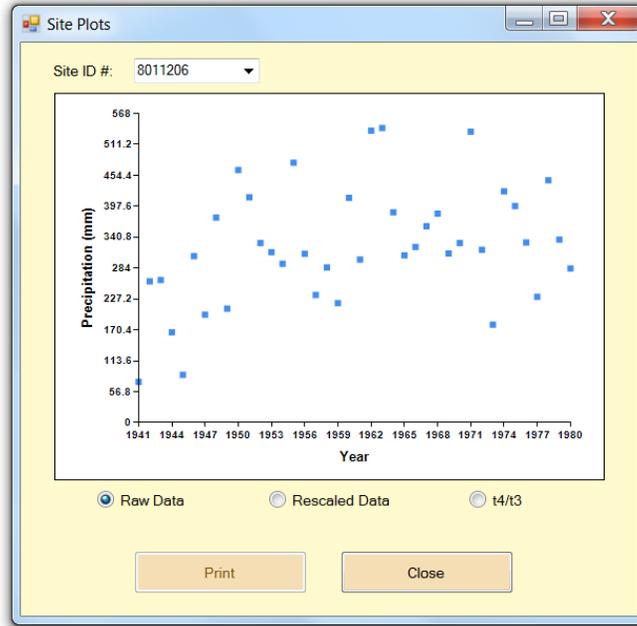
Selecting **Raw Data** will allow the user to see a graph of the raw data for the selected site (Fig. 5a), whereas selecting the **Rescaled Data** option produces a graph of the raw data divided by the mean of that dataset (not shown). The value of rescaling the data will be seen in the regionalization portion of the analysis.

The graph of L-Kurtosis vs. L-Skewness (Fig. 5b) illustrates how each individual site's L-moments compare to the other sites (represented by the gray circles) and to the possible L-skew and L-kurtosis values representative of various frequency distributions. The black dot represents the L-Kurtosis and L-Skew for the site selected in the drop-down box. The colored stars represent the L-Kurtosis and L-Skew for the two-parameter frequency distributions that are available within this program, while the curves represent the range of possible values of L-Kurtosis vs. L-Skew for each of the three-parameter distributions, as indicated in the legend on the graph. This graph provides an initial indication of which frequency distribution may best represent the data for a particular site based on the proximity of the sites value of $t4/t3$ compared to each distribution. It should be noted that this provides only one clue as to which distribution to use and should never be used alone when making a final decision.

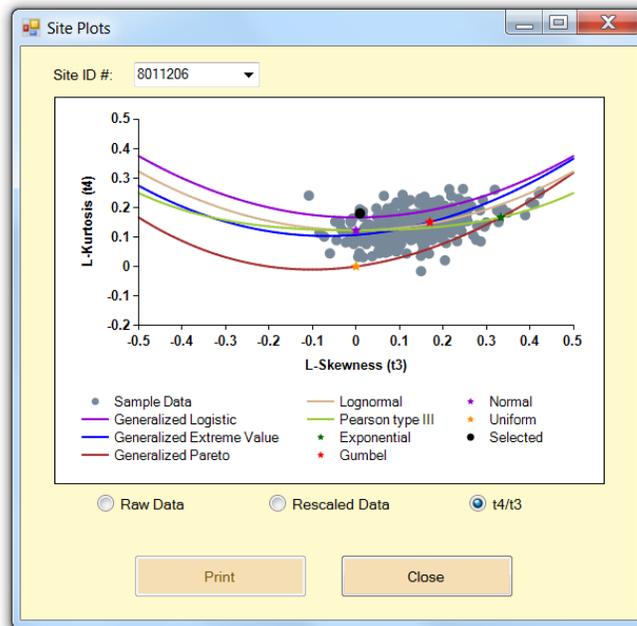
Frequency Analysis

The final option in the **Sites** menu on the **Title Screen** is **Frequency Distribution**. Once clicked, a window opens that displays the first site's data probability density function (**PDF**) as vertical blue bars (Fig. 6a). 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 thirteen 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 box next to the

UNCLASSIFIED



(a)



(b)

Figure 5: **Site Plots** window, showing (a) the raw data for a particular site and (b) the **t4/t3** graph, which includes all sites as gray dots, the selected site as a black dot, two-parameter distributions as colored stars, and the three-parameter distributions as colored curves. All distributions are identified in the legend.

UNCLASSIFIED

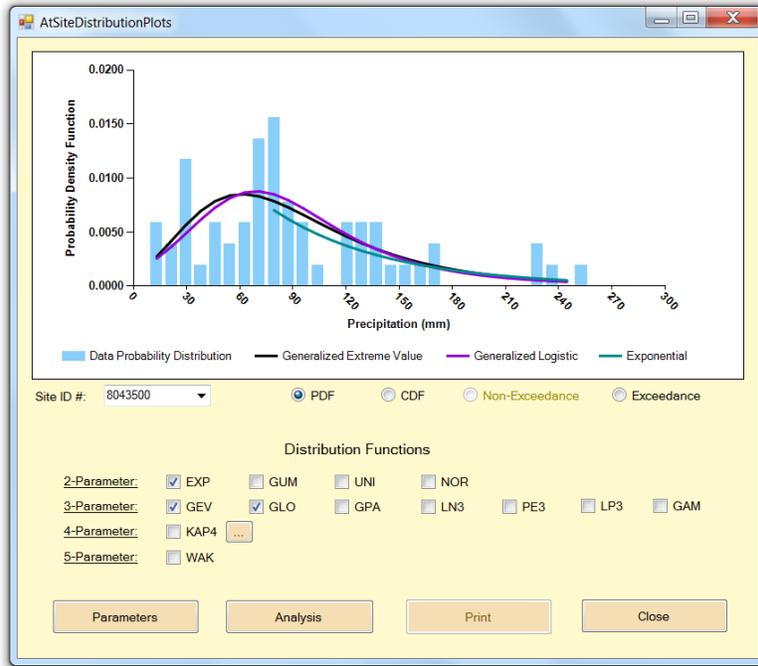
Table 1: Standard frequency distribution abbreviations.

Distribution	Abbreviation
Exponential	EXP
Gumbel	GUM
Uniform	UNI
Normal	NOR
Generalized Extreme Value	GEV
Generalized Logistic	GLO
Generalized Pareto	GPA
Log-normal	LN3
Pearson Type III	PE3
Log-Pearson Type III	LP3
Gamma	GAM
Kappa (4-parameter)	KAP
Wakeby	WAK

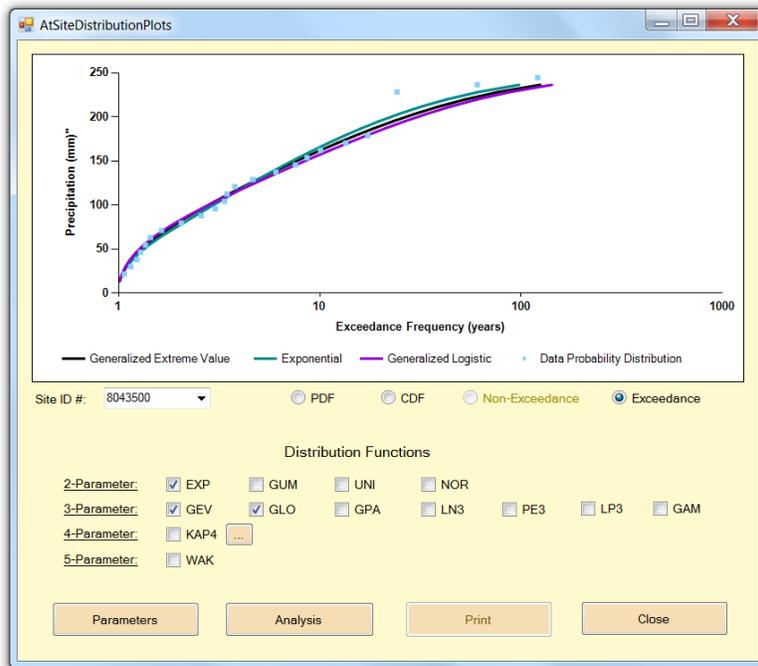
desired distribution. Distributions are divided based on the number of parameters required. This graph provides a way to visually determine how well each standard frequency distribution fits the site’s sample data and offers another clue in determining which distribution may be best for a particular site. In addition, a site’s cumulative distribution function or **CDF** (not shown) and **Exceedance** curve (Fig. 6b) can also be displayed. The **exceedance** graph is shown on a logarithmic scale and provides the user with information on the intensity of a storm for a particular frequency. The estimated exceedance curve of the sample data is represented by the blue dots, and the distributions are represented as colored lines. Each of these graphs can be used to make a visual comparison between how well each standard distribution fits the site data. As in the previous screen, these graphs should not be used alone in finally determining which distribution to use to characterize a particular site’s distribution curve.

At the bottom of the **At-site Distribution Plots** window there are buttons that allow one to view the parameters for a particular standard frequency distribution estimated from the L-moments of the site selected. In addition, there is also a button titled **Analysis**, and once clicked, the screen shown in Fig. 7 appears. All calculations performed within this window relate to the site selected in the **At-Site Distribution Plots** window shown in Fig. 6. The **Analysis** window is used to make a quantitative estimate of the intensity of an event for a particular frequency. This can be accomplished using any of the thirteen standard frequency distributions mentioned earlier. Once the desired distribution has been selected and the desired frequency entered, clicking the **Update** button will give the associated intensity. Also shown in this window are the **R-squared** values and **z-scores** for each distribution, which give an indication of the closeness of fit of each standard distribution to the sample data of the site being analyzed. The R-squared value 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 on the graph shown in Fig. 5b and that of each 3-

UNCLASSIFIED



(a)



(b)

Figure 6: **At-Site Distribution Plots** screen, showing (a) the probability density function (**PDF**) and (b) the **exceedance** curve for the sample data of the selected site as blue bars (**PDF**) and blue dots (exceedance curve). Also included are the estimations for each curve using three different standard frequency distributions: **EXP** (blue), **GEV** (black), and **GLO** (violet).

Distribution	R-Squared	Z-Score	Distribution	R-Squared	Z-Score
<input type="radio"/> EXP	0.767		<input type="radio"/> GPA	0.7218	-5.07
<input type="radio"/> GUM	0.6615		<input type="radio"/> LN3	0.6551	-2.92
<input type="radio"/> UNI	0.0354		<input type="radio"/> PE3	0.6485	-2.36
<input type="radio"/> NOR	0.5692		<input type="radio"/> LP3	0.6332	
<input type="radio"/> GAM	0.6508		<input type="radio"/> KAP4	0.6582	
<input type="radio"/> GEV	0.6582	-2.59	<input type="radio"/> WAK	0.6365	
<input checked="" type="radio"/> GLO	0.669	-3.95			

Enter event frequency in years:

Resulting Event Intensity: **215 mm**

Figure 7: This screen estimates the storm intensity for an event of a particular frequency using one of 13 standard frequency distributions. Closeness-of-fit statistics (R-Squared and z-score) are shown for each distribution compared to the sample data of the site selected in the **At-Site Distribution Plots** window.

parameter distribution; the z-score is only applicable for 3-parameter distributions. An R-Squared value close to 1 and a z-score close to 0 indicate a good fit. These statistics, along with the graph in Fig. 5b and the visual fits of the PDF, CDF, and exceedance curves should be used together to determine the preferable standard frequency distribution to use for a particular site.

Regional Analysis

Once the user is finished with site analysis, they can move on to creating homogenous regions and regional analysis. Creating regions that are as homogenous as possible can be a difficult and time-consuming process; therefore, ICI-RAFT attempts to facilitate this process as much as possible through its visual features. In order to create regions, the **Regionalization** option should be selected under the **Regions** menu on the **Title Screen**; the window that appears is shown in Fig. 8. Regions may be created using the site characteristics in the input file, by using standard eco-regions, or by entering the region numbers manually. Prior to choosing the **Eco-regions/Own regions** option, the user must enter the eco-region or specify their own region number for each site in the final column of the **OtherData** worksheet of the input file. If the final column of the **OtherData** worksheet is not complete for all sites, the user will be unable to use this option and will be required to use site characteristics to create regions.

UNCLASSIFIED

The screenshot shows a software window titled "Regionalization". It contains the following elements:

- Choose method for regionalization:** Two radio buttons: "Use Site Characteristics" (selected) and "Use Own/Eco-Regions".
- Number of Clusters:** Input field with value 8.
- Number of "H" Simulations (>350):** Input field with value 500.
- Enter Weight for Each Site Characteristic:** A checkbox labeled "Equal Weights" is currently unchecked.
- Site Characteristics:** A grid of input fields for various characteristics:
 - Latitude: 0.33
 - Longitude: 0.33
 - Elevation: 0.34
 - Mean Temp: 0
 - Mean Precip (Annual): 0
 - Mean Precip (Winter): 0
 - Mean Precip (Spring): 0
 - Mean Precip (Summer): 0
 - Mean Precip (Autumn): 0
 - Mean Julian Day: 0
 - Seasonality Index: 0
- Other Characteristics:** Three rows labeled "Other (1)", "Other (2)", and "Other (3)". Each row has three input fields: "name", "units", and a weight value (all set to 0).
- Total Weight:** Input field with value 1. Below it, the text "Total Weight is Equal to 1!" is displayed.
- Buttons:** "Reset Weights" and "OK".

Figure 8: The **Regionalization** window.

When using site characteristics to create regions, only those site characteristics that are completely filled in the **OtherData** worksheet of the input file are enabled in the **Regionalization** window. The user will enter the number of regions desired and the weights for each site characteristic as numbers between 0 and 1, making sure that all weights sum to 1. If the user entered data in the **Other** columns of the **OtherData** worksheet of the input file, these will also be enabled in the **Regionalization** window along with the name and units of the added site characteristic as specified in the input file; the name and units can be edited in the **Regionalization** window if desired. It is also possible to set all weights back to zero by clicking the **Reset Weights** button. The user can also make all weights for enabled site characteristics equal by clicking the box next to **Equal Weights**.

Details

After regionalization is completed, the **Regional Details** window (Fig. 9) will appear. The regional L-moments and **homogeneity** for a particular region are shown, while the L-moment statistics and **discordance** of a selected site within that region are also shown. In this case, the site discordance 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. The homogeneity statistic gives an idea of how close the frequency distributions of all sites

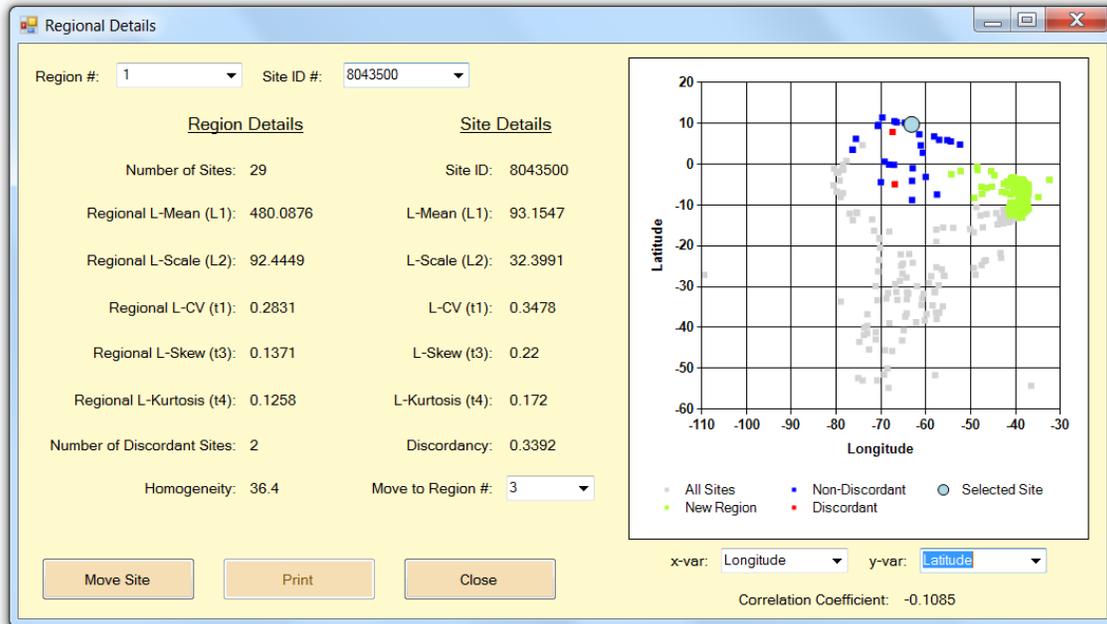


Figure 9: Images of the **Region Details** window with the graph showing Latitude vs. Longitude. Blue dots represent non-discordant sites, red dots represent discordant sites, and light green sites represent the receiving region chosen for a site move. The large light blue dot represents the selected site.

within the region are to each other. Also displayed in this window is a graph similar to that shown in Fig. 4 during the site analysis. All sites not included in the selected region are shown as gray dots, whereas the blue and red dots are the same as before. The drop-down menus also allow the user to graph the same variables against each other as in the site analysis. 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. When the **Move to Region** box is clicked, a list of the other region numbers is shown, from which a new region can be selected. The selected region appears in light green as illustrated in Fig. 9. This is a prime example of how ICI-RAFT visually facilitates the difficult process of regionalization.

Plots

Choosing the option to view **Regional Plots** is very similar to the corresponding option in the site analysis except that you can view data only from one particular region at a time. One interesting point that should be made here involves the resulting regional **t4/t3** (L-kurtosis vs. L-skewness) plot (Fig. 10). Similar to what was stated before, this graph provides an initial indication of which frequency distribution may best represent the data for a particular region based on the proximity of the sites' values of **t4/t3** compared to each distribution. Compared to the site analysis, it is much easier to identify the sites of a region with a particular standard frequency distribution. As shown in Fig. 10, some of the sites within the region tend to follow the **t4/t3** curve of the **Generalized**

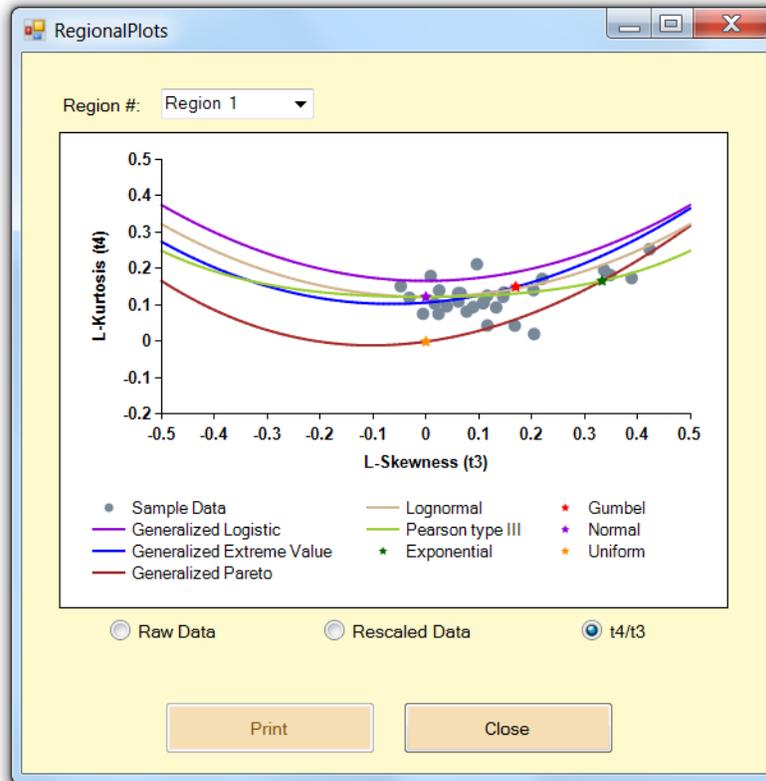


Figure 10: **Regional Plots** window displaying the t_4/t_3 graph, which includes all sites within the selected region as gray dots, two-parameter distributions as colored stars, and the three-parameter distributions as colored curves. All standard distributions are shown in the legend.

Pareto distribution, while the other sites seem to follow one of the other distributions. This observation may lead the user to separate these two sets of sites into different regions.

Frequency Analysis

The final product or objective of ICI-RAFT is to be able to estimate the intensity of a storm of a particular duration and frequency for a particular site using regional frequency analysis. This is finally accomplished using the final option under the **Regions** menu on the **Title Screen**. The window that opens displays all of the first region's site data as a probability density function (**PDF**), which is represented by the vertical blue bars. The resulting PDF for Region #3 is shown in Fig. 11a. As during site analysis, fits of any of the thirteen different standard frequency distribution functions (see Table 1) to the L-moments of the region's data can be displayed on the graph. This graph provides a way to visually determine how well each standard frequency distribution fits the region's sample data and offers another clue in determining which distribution may be best for a particular region. In addition, a region's cumulative distribution function or **CDF** (not shown) and **exceedance** curve (Fig. 11b) can also be displayed. Each of these graphs can

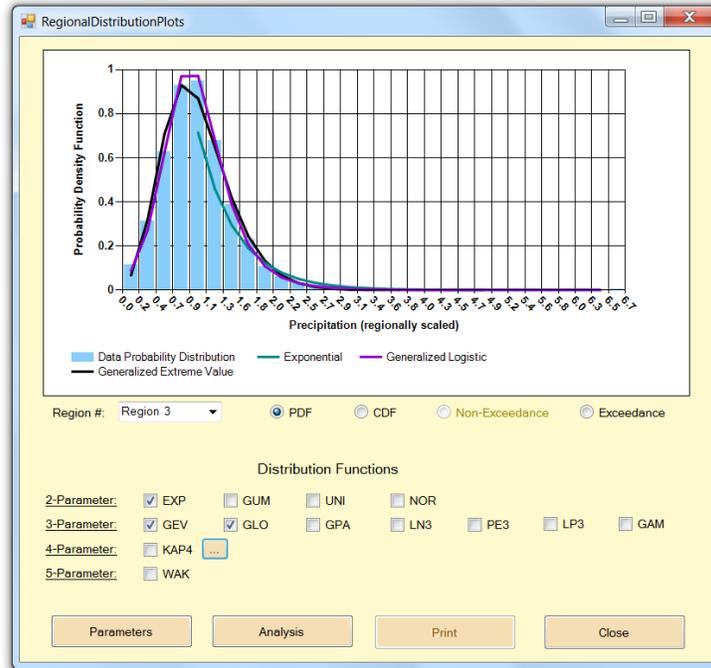
UNCLASSIFIED

be used to make a visual comparison between how well each standard distribution fits the data of a region.

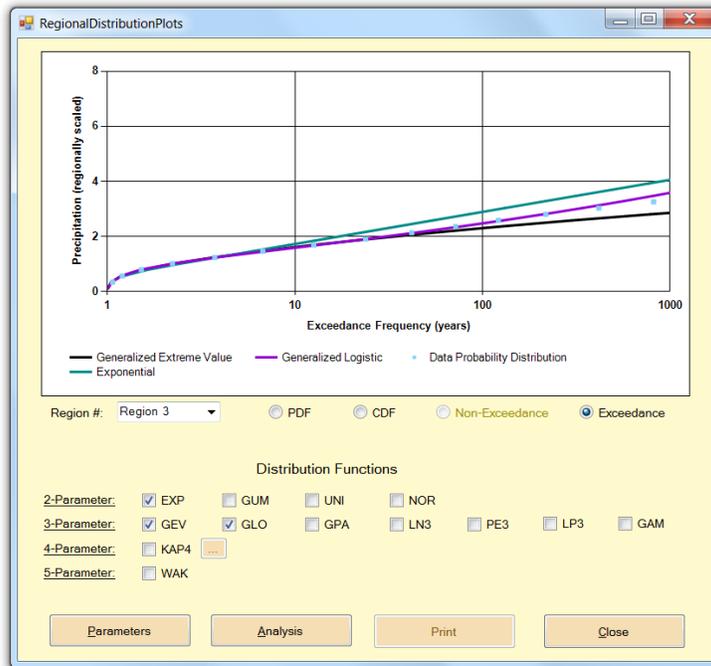
There are buttons at the bottom of the **Regional Distribution Plots** window that allow one to view the parameters for a particular standard frequency distribution estimated from the L-moments of the region selected. In addition, there is also a button titled **Analysis**, and once clicked, the screen shown in Fig. 12 appears. The window in Fig. 12 is divided into two tabs titled **Onsite Analysis** and **Offsite Analysis**. Onsite analysis (Fig. 12a) refers to estimating the magnitude of a storm event of a particular frequency for a specific site where data is available. This is similar to what was done in the **Site Frequency Analysis** window described earlier. A desired region and a site within that region can be selected from the two drop-down boxes at the top of the window. As was also done in the **Site Frequency Analysis** window, any of the thirteen standard frequency distributions mentioned earlier can be used to estimate the event intensity for a particular site. Additionally, the user needs to choose which site averaging method to use in order to convert the result from a regionally scaled or normalized regional quantile to a site-specific quantile. 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 entered in the **Initial Screening** window; the mean precipitation for this period needs to be entered by the user in the final column of the **OtherData** worksheet at the data entry phase, if available. An external source, such as a Mean Annual Precipitation map or database will be needed in order to use this option. If this information is not available, then the user must use the **L1** option. Once the site averaging method has been chosen, the associated intensity can be found in the same units as the sample data. This method of computing the at-site estimate of the x-year storm event should be an improvement over direct at-site estimates as was performed earlier.

Also shown in this window are the R-squared values and z-scores for each distribution, and as stated before, these statistics, along with the graph in Fig. 10 and the visual fits of the **PDF**, **CDF**, and **exceedance** curves should be used together to determine the preferable standard frequency distribution to use for a particular region.

When the user clicks the **Offsite Analysis** tab of the **Regional Frequency Analysis** window, the screen in Fig. 12b appears. Offsite analysis is performed when attempting to estimate the intensity of storms of a particular frequency at sites where there are no data. This is accomplished using the sites that do contain data and some sort of interpolation scheme to estimate the values between these sites. The first step in this process is to identify the region over which the user would like to estimate storm intensities. This is accomplished by entering the range of **latitudes** (northern and southern limits) and **longitudes** (eastern and western limits) that the region is to cover. In addition the user needs to enter a **resolution** in units of degrees; the resolution entered must be less than the lesser of the latitude and longitude ranges. As before, the desired standard frequency distribution, site averaging method and rainfall frequency are required prior to completing the analysis. After all of the required information is provided, the user can



(a)



(b)

Figure 11: **Regional Distribution Plots** screen, showing (a) the probability density function (**PDF**) and (b) the **exceedance** curve for the sample data of all sites within the selected region as blue bars (**PDF**) and blue dots (**exceedance** curve). Also included are the estimations for each curve using three different standard frequency distributions: **EXP**, **GEV**, and **GLO** (see Table 1 for explanations of the distribution function abbreviations).

UNCLASSIFIED

Frequency Analysis

Onsite Analysis Offsite Analysis

Choose a region. Choose a site from Region 1:

1 8043500

Choose a frequency distribution:

Distribution	R-Squared	Z-Score	Distribution	R-Squared	Z-Score
<input type="radio"/> EXP	0.9894		<input type="radio"/> GPA	0.9219	-9.66
<input type="radio"/> GUM	0.9631		<input type="radio"/> LN3	0.972	1.44
<input type="radio"/> UNI	0.0177		<input type="radio"/> PE3	0.9688	7.1
<input type="radio"/> NOR	0.973		<input type="radio"/> LP3	0.8791	
<input type="radio"/> GAM	0.952		<input type="radio"/> KAP	0.9614	
<input type="radio"/> GEV	0.9714	1.55	<input type="radio"/> WAK	0.9708	
<input checked="" type="radio"/> GLO	0.984	6.84			

Enter event frequency in years: 50

Choose site averaging method: L1 Index Flood

Resulting event intensity: 221 mm

Update Result Close

(a)

Frequency Analysis

Onsite Analysis Offsite Analysis

Identify region by latitude/longitude (degrees).

North: -20

West: -90 East: -70

South: -40

Resolution: 5

Choose a frequency distribution.

Distribution

EXP NOR GLO PE3 WAK

GUM GAM GPA LP3

UNI GEV LN3 KAP

Choose site averaging method: L1 Index Flood

Choose a frequency (in years): 50

Export Create Map Close

(b)

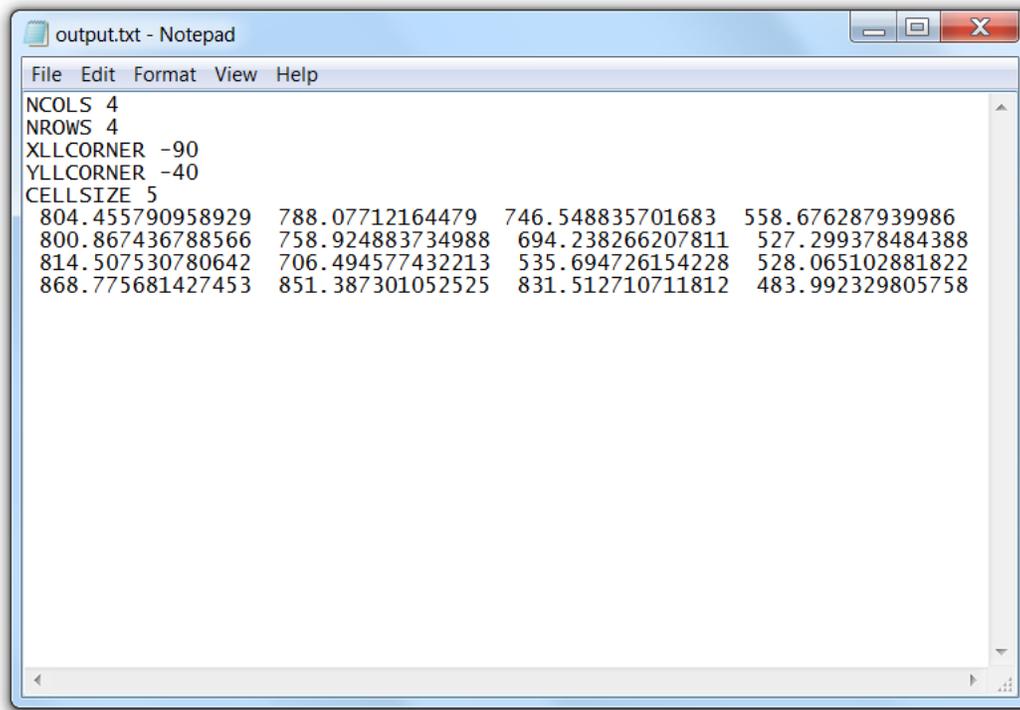
Figure 12: Shown are the input screens for regional (a) **Onsite Analysis** and (b) **Offsite Analysis** as described in the text.

export the results to a text file that can be imported into a GIS program for further analysis. Figure 13 shows an example of the text file along with information that is included.

Deliverables & Training

Using the process described above, the end products of ICI-RAFT include estimations of the intensity of rainfall events for individual sites and rainfall probably maps for a particular region for any rain event frequency, duration, and starting month. When looking at multiple maps of extreme low-rainfall events, the collection of maps is called a Drought Atlas.

The fact that this software will be free facilitates capacity building through training experts from other nations in its use. Initially this training will be focused in South and Central America as a step towards creating one drought atlas for the entire Latin American continental region. Other future applications include a regional analysis of precipitation frequency in the country of Rwanda in Africa and as a mechanism to compare the effects of climate variability and climate change. ICI-RAFT can facilitate a simple climate change induced analysis by looking at rainfall data over a region for a particular range of years using different starting years. Trends over the entire period can then be identified. Being able to differentiate between the effects of climate change and climate variability on regional rainfall using a simple, non-proprietary program is what will make ICI-RAFT a novel and useful tool for multiple user-types, including universities, water managers, and government agencies.



```

output.txt - Notepad
File Edit Format View Help
NCOLS 4
NROWS 4
XLLCORNER -90
YLLCORNER -40
CELLSIZE 5
804.455790958929 788.07712164479 746.548835701683 558.676287939986
800.867436788566 758.924883734988 694.238266207811 527.299378484388
814.507530780642 706.494577432213 535.694726154228 528.065102881822
868.775681427453 851.387301052525 831.512710711812 483.992329805758

```

Figure 13: Resulting output file when performing **offsite analysis**.