PEER REVIEW COMMENTS AND RESPONSES ON DEPTH-DURATION FREQUENCY ANALYSIS FOR FLORIDA

I. Overview and Methodology Documentation

Comment 1:		
I am concerned that it be made crystal clear in the report + on the final maps that the return period is left in terms of the annual maximum series (AMS). Precipitation frequency estimates have traditionally been published in terms of the partial duration series (as in TP-40 and HYDRO-35). Leaving in terms of the AMS is fine (if that is what the sponsor wants) but regardless this should be indicated on all maps with a brief statement.		
Response	**X** Agree	Disagree
We are adding the term Annual Maximum Series in the report and on final maps.		

Comment 2:		
Scientific support - Other techniques used are sound and acceptable practice.		
Response	**X** Agree	Disagree
As noted the techniques are sound and useful.		

Comment 3:		
There was a mention of partial duration series (PDS) to be analyzed in the initial project/study proposal documents. However, it is not clear from the documents from the project web site if any PDS was considered.		
Response	**X** Agree	Disagree
A decision was made early in the research to limit the work to Annual Series. This was done partly because there is no acceptable criteria for the "cut off" value for PDS, and thus to determine it was not within the scope of this work. It could be however done and with the valid data base we now have, it could be done in a cost effective way.		

Comment 4:		
A detailed report summarizing the procedures is required as one stand-alone document explaining exhaustive details of: 1) selection of fitted distribution, 2) quantitative performance evaluation of goodness-of-fit and residual analysis of regression equations for IDF curves and 3) spatial interpolation process. All other issues raised in the previous section need to be addressed in that report. The document should also address issues such a missing data and the locations in space where the missing data is dominant.		
Response	**X** Agree	Disagree
We have added to the report to help explain details.		

II. List of Sites

Comment 1:

The data sets used contain rainfall data from frontal weather systems as well as tropical systems. A statistical analysis was not done to determine whether the combination of these two systems in the frequency analysis is acceptable from a statistical perspective. Although previous work has indicated that in some cases the two types of systems can be considered as part of a homogeneous set, this analysis was not performed on the Florida data.

Response | Agree | **X** Disagree

For the frequency analyses, a double response (hump) on the frequency curves was not evident. The dual responses would indicate two distinct physical reasons or two distinct distributions. Thus all the data were used and the response frequency distribution presented for all stations. There does not appear to be a way we could have separated or factored out the meteorological reasons behind each event and then to determine their return frequencies within the time available. In discussion with the project managers, the factoring may be done if there was only interest in a particular duration and frequency, but the results needed all durations and frequencies common to design criteria within the State. Furthermore, regulations would have to change to accommodate time of year.

Comment 2:

The procedures for quality control of the data and the statistical analyses follow accepted practices and are sound.

Response | **X** Agree | Disagree

These are commonly acceptable methods and significant time was spent on the quality of the data base.

Comment 3:

In reference to #1 above, the analysis used data from several hurricanes that occurred during the period of record. The likelihood of recurrence of these extreme events is not included in the analyses. The likelihood of hurricane recurrence, including landfall location, path, and magnitude can significantly impact the results. The inclusion of hurricane data may cause extremely large rainfall depths in areas along the hurricane path, whose likelihood of recurrence may be very small. This will impact stormwater management systems that rely on more frequent events in their design. The question is: do we want a hurricane event that passes through a certain location to impact all future designs? By the same token, are we comfortable with not including the likelihood of hurricanes passing though a certain part of the state? It is important to evaluate the sensitivity of including hurricane data and how they impact the isohyets. If nothing else, one should determine whether the annual maxima (for the all durations) were dominated by hurricane rainfall.

Response | Agree | **X** Disagree

All data on all causative factors have been included in the analyses. Frontal passages that remain for extended times in one part of the State may also stay for extended periods in another part. The same is true for hurricanes that in

some time period impact one part of the state and not another. It is presumptive to assume that all loner duration frontal passages and hurricanes will affect all parts of the State equally. The historical data has been used without bias to extending the analyses from one part of the State to all parts or other portions of the State.

Comment 4:

It is not clear from the documents available on the web about the requirements set for the minimum number of sample data (minimum number of annual extreme rainfall depths) used for analysis. Data length is always a contentious issue in statistical analysis. It was indicated that 11 years of data was used as threshold minimum in the teleconference meeting. It is important to provide references and proper justification for the use of minimum 11 years of data for the analysis. Validity of this assumption of minimum data sample size needs to be thoroughly checked against similar studies available from literature. A minimum of 25 years of data is generally accepted length of the record for statistical analysis of extreme values (Gupta, 2008). Methods are available (e.g., Sokolov, 1976) to confirm the adequacy of data length. Comparison of summary statistics of observations from a gage with incomplete data set can be compared with a nearby gage with complete data.

Response	**X** Agree	Disagree

The use of 11 years was made based on the relationship of one station to adjacent ones. There must be consistency in the comparisons. Thus we used adjacent station confirmation since there were many stations available for the analyses. We however disagree that 25 years of data is needed.

Comment 5:

Stationarity of annual extreme time series was not discussed in the report or any documents. This is an important element of the statistical analysis conducted after the initial phase of the data collection. Trend analyses conducted by this reviewer for all the available annual extreme data for all durations suggests that stationarity is preserved as only very few time series data sets indicated statistically significant trends based on Mann-Kendall tests. Have the contractors performed any trend analyses of the rainfall time series data sets? If so, please report them.

Response	**X** Agree	Disagree

No Trend analyses were performed, but we agree that this would be an indication of changing conditions. This was not within our scope because of the regulatory implications of changing criteria based on trends that may change from one time period to another. This is a dissertation in itself and not without controversy. We would find this work irresistible and would be keen to partner with someone to do it.

Comment 6:

It is important to associate different rainfall producing mechanisms (slow moving frontal systems, hurricane events and summer convective storms) to rainfall depths in specific years for specific durations. Spatial summary statistics for all stations should be provided at one place to appreciate the regional or global variability of rainfall in Florida. This analysis will help to establish or confirm if the storm events produced by meteorological processes are

similar in nature. This will also strictly satisfy the homogeneity requirement of statistical analysis of extreme events		
Response	**X** Agree	Disagree
There is agreement on the variability in space and the meteorological forces causing the changes. Nevertheless the data base does take into account these events. A better way of referencing the spatial statistics is now included in the report.		

Comment 7:		
Atlantic Multi-decadal Oscillation (AMO) cycles have influence on rainfall patterns in Florida. AMO warm phase (one phase starting in 1970s) has been attributed to higher precipitation totals (especially for long temporal durations [greater than 24 hours]). Missing data in AMO phases at some stations will heavily influence the fitted distributions for observations at these stations and finally the iso-pluvial curves. Temporal (year-wise) details of missing data are provided in individual excel files on the web site. However, a summary of missing data at all the stations is required.		
Response	**X** Agree	Disagree
The missing data for each station is in the report and more direct reference to them was added.		

Comment 8:		
Quality Control / Station Selection: Okay, stations were vetted appropriately.		
Response	**X** Agree	Disagree
This is support for the station selection procedures used.		

III. Return Period Analysis Results

Comment 1:		
GEV: Appropriate Distribution, Okay. Gumbel (EV Type 1) used in TP-40 and HYDRO-35. GEV is a 3-parameter version of the Gumbel distribution and makes good sense for this study. Weiss Factors: Okay, these are theoretical sampling adjustment factors assuming constant rainfall rate (on/off). The theoretical values match well with empirical data by Young and McEnroe 2003 (http://cedb.asce.org/cgi/WWWdisplay.cgi?137566).		
Response	**X** Agree	Disagree
Thanks for the support.		

Comment 2:

Performing frequency analysis at multiple durations will lead to inconsistencies in rainfall depth across durations for one return period. This effect is exaggerated at higher recurrence intervals. The authors used a curve fit to smooth out the results for each station for each recurrence interval. This is appropriate and appears to have been done carefully.

Another approach would be to use the Weiss-adjusted GEV values directly in the spatial interpolation, allowing the interpolation method to smooth out uncertainties in the data (instead of curve fitting, then interpolating). The potential downside to this approach would be that stations on the edge of the analysis (coastal) could skew the interpolation. I believe the approach taken by the authors is appropriate; the curve fitting equation is appropriate and fits the data well.

Response	**X** Agree	Disagree

Yes, this statement is a validation and observation in that we had to use a curve fit procedure. The curve fit provides a quantitative way to smooth the data without biased input.

Comment 3:

I spot checked five stations for frequency analysis results. I fit a Gumbel and a GEV distribution to the data using product and L-moments (L-moments only for the GEV). This approach differs from that used by the authors (maximum likelihood, MLE). I agree that MLE is a better approach overall. L-moments were used here as a cross-check (and because they are easier to implement).

My results agreed well for four of the five stations checked. The exception was Grady, at the 2-hour duration. I will attach an appendix with more detail on this comment.

Response	**X** Agree	Disagree

Grady was the only station for which the distribution fits were not the same as the others. The data however could not be eliminated from the analyses because telephone contact was made and no reason found for the unusual site conditions. The kriging for space differential results should smooth out the effects of Grady data.

Comment 4:

Frequency analysis results were checked for five stations, selected at random. The duration evaluated for each station was also selected at random.

Please see additional information regarding the Spot Check of Frequency Analysis on the following pages.

Response	**X** Agree	Disagree

The additional information supports the analyses performed.

Comment 5:			
Soundness of selected Return Periods: They are sound.			
Response	**X**	Agree	Disagree
A supporting comment.			

Comment 6:

A detailed data analysis of available data (from the web site: 87 stations for 9 temporal durations) was conducted by this reviewer to evaluate the validity of assumptions and methodologies adopted in the study. The analyses are available for download from the web links provided below. Several distributions were fitted and statistical inference tests were carried out. The distributions tested are: extreme value, generalized extreme value, normal, log-normal, 3 parameter log-normal, Pearson and log-Pearson. The distribution parameters are estimated using maximum likelihood estimation (MLE) and L-moment based methods. Two goodness-of-fit tests are used and they are: chi-square and Kolmogorov-Smirnov tests. Trend analyses to assess the stationarity of the rainfall depth time series was carried out using Mann-Kendall Tau-b with Sen Slope method. Quantile-quantile (QQ) plots were also generated to evaluate the theoretical and observed quantiles for assessment of the fitted distributions. The theoretical quantiles are generated using distribution-specific random samples using the fitted distribution parameters based on MLE approach.

1. Analysis for 87, 7 distributions, Maximum Likelihood Estimates for all durations. Hypothesis (Ho=null, Ha=Alternative) Chi-Square goodness-of-fit test tests

   http://www.civil.fau.edu/~ramesh/rainfall/rainfallanalysisMLE.pdf

2. Analysis for 87, 2 distributions, L-moment-based Estimates for all durations. Hypothesis(Ho=null, Ha=Alternative) Chi-Square goodness-of-fit test tests

   http://www.civil.fau.edu/~ramesh/rainfall/rainfallanalysisL-moments.pdf

3. Analysis for 87, Trend Analysis, Sen-Slope Hypothesis (Ho=null, Ha=Alternative) Chi-Square goodness-of-fit test tests

   http://www.civil.fau.edu/~ramesh/rainfall/trendanalysis.pdf

4. Analysis for 87, 7 distributions, Maximum Likelihood Estimates for all durations. Hypothesis (Ho=null, Ha=Alternative) Kolmogorov-Smirnov goodness-of-fit test tests

   http://www.civil.fau.edu/~ramesh/rainfall/mle-ks.pdf

5. Analysis for 87, 7 distributions, Q-Q Plots.

   http://www.civil.fau.edu/~ramesh/rainfall/qqplots.pdf

It is essential to know the correlation structure for the rainfall extremes at different durations. A correlation matrix (average values based on 87 rain gage stations) created by this reviewer is presented below.

	R(1 hr)	R(2 hr)	R (6 hr)	R (12 hr)	R (24 hr)	R (48 hr)	R(72 hr)	R (96 hr)	R (120 hr)
R(1 hr)	1.000	0.816	0.579	0.464	0.388	0.345	0.334	0.325	0.333
R(2 hr)	0.816	1.000	0.776	0.622	0.523	0.476	0.460	0.449	0.447
R (6 hr)	0.579	0.776	1.000	0.907	0.795	0.719	0.679	0.651	0.635
R (12 hr)	0.464	0.622	0.907	1.000	0.919	0.831	0.784	0.747	0.725
R (24 hr)	0.388	0.523	0.795	0.919	1.000	0.921	0.870	0.831	0.806
R (48 hr)	0.345	0.476	0.719	0.831	0.921	1.000	0.961	0.920	0.891
R(72 hr)	0.334	0.460	0.679	0.784	0.870	0.961	1.000	0.964	0.934
R (96 hr)	0.325	0.449	0.651	0.747	0.831	0.920	0.964	1.000	0.973
R (120 hr)	0.333	0.447	0.635	0.725	0.806	0.891	0.934	0.973	1.000

Summary:
Based on the comprehensive statistical analysis completed by this reviewer, it can be concluded that the methodology adopted by the contractors is robust and accurate. The data analysis and reporting of the analyses through a web site are extremely beneficial. The methods adopted are conceptually accurate, reliable and repeatable. However, there are several issues that need to be addressed before the final results (i.e., isopluvial curves) study can be approved and used for hydrologic design within the state of Florida.

Response	**X**	Agree	Disagree

A supporting comment and the isopluvials were redone using a different spatial or Kriging method.

Comment 7:

The details of the analyses conducted for the development of IDF curves and also iso-pluvial curves for Florida were provided as several documents on the web site (*ucf-rainfall.pbworks.com/)* created by the contractors. Detailed analysis of results for each station was presented. Iso-pluvial contours based on different spatial interpolation methods were also presented. A document briefly explaining all the steps was also provided. Based on the analysis completed by this reviewer, GEV (generalized extreme value) distribution provided a better fit (visually) to annual extreme rainfall data compared to all other distributions evaluated. A similar conclusion was reached by the contractors who completed the study. This reviewer conducted chi-square (with varying bins/cells) and Kolmogov-Smironov goodness-of-fit tests in their original forms. Visual evaluations based on the empirical and fitted cumulative density functions indicated two other distributions are strong competitors for the GEV. It was indicated in the conference call that modified goodness-of-fit tests were developed by the contractors. These methods need to be discussed, elaborated and documented. Quantitative performance measures used for the selection of best fit statistical distributions for rainfall annual extreme values should be provided. Modifications made to the traditional goodness-of-fit tests or any other tools developed should be thoroughly explained.

Response	**X**	Agree	Disagree

Additional explanations were added to the website along with the new kriging results.

Comment 8:

It is clear from the analyses that the parameters for the fitted distributions were estimated using maximum likelihood estimation method. L-moments and L-moment ratios were also provided for all the stations. However, it is not clear if L-moments approach was used by contractors for estimating the distribution parameters. The analyses conducted by this reviewer supports the work completed by contractors and confirms that MLE (maximum likelihood estimates) provided equally good estimates of the parameters of the fitted distributions compared to those from L-moment based approaches.

Response **X** Agree Disagree

We agree with the statement and add that at the time of the analyses, MLE was considered as the approved method. We would have preferred to use the L-moment because of their ease of use. It is also noted in the comment that the results would not have been different.

Comment 9:

Regional statistical analysis of rainfall extrema needs to be analyzed by using the concept of meteorologically homogeneous rainfall areas (refer to recent work of SFWMD 2009 in development of meteorologically homogeneous rainfall areas for south Florida) to avoid the artifacts associated with spatial interpolation. Tent-pole effects (local or regionally high values within a specific distance from observation location) seem to dominate the spatially interpolation surfaces. While, the existence of these effects is not completely avoidable, regional analysis is expected to benefit. Regional analysis can be done by forming rain gage clusters identified by homogeneous rainfall areas.

Response **X** Agree Disagree

The spatial analyses were done to more flatten the tent pole effects. The use of all the data and with consideration of adjacent rainfall station effects was the approach taken to eliminate another factoring of the data set into what may or may not be homogeneous rainfall areas. All the variability in the data sets was preserved for carry over into the spatial analyses.

Comment 10:

Results related to residual analysis for best fit equations for the IDF curves need to be provided for assessment of regression fits for the GEV data at each station.

Response Agree **X** Disagree

The best fit and raw data are available in the data set for each station. Providing another calculation of the residuals was felt to not add any more validity to the analyses and adds more pages to the report.

IV. Kriging Analysis Results

Comment 1:

The interpolated rainfall maps in the study are too heavily influenced by individual station data. I agree that kriging is an appropriate interpolation method, but special care must be paid to the options specified in this method. The most important consideration for this application is the magnitude of the nugget effect. I suspect that the authors specified no nugget effect, or a very small nugget effect. This leads to contour maps that are overly detailed (tent pole effect, or halos around stations).

For example, the 5-yr 2-hr map has a lot of concentric contours. The contours do not reflect true patterns in extreme rainfall. Rather, they show variability in the frequency analysis results. The frequency analysis results for individual stations are uncertain, especially at higher return periods (10+ years). This is due to the limited length of records. The GEV distribution will tend to be very sensitive to ‘outliers’ in the dataset. By ‘outliers’ I mean large rainfall accumulates that occurred during the period of record. For example, it’s possible that some stations received 100-yr or 500-yr rainfall accumulations in a 20-year record.

It is important to smooth out these variations and uncertainties in the frequency analysis results. Spatial interpolation will do this, if performed appropriately. I think that the rainfall maps need to be re-done for this study with careful attention paid to the interpolation method. I have experimented with interpolation methods using the data for this report, and have attached a document summarizing my findings in more detail.

Response	**X** Agree	Disagree

Agree with this comment and the Kriging was redone with parameters that can match what was used in this review question. We were guided by the beneficial comments on parameter selection used by the reviewer.

Comment 2:

I did not do any analysis of the data to determine accuracy of the analysis results.
The interpolation grid size must be re-evaluated to determine an optimum size that can provide reasonable estimates and reasonable isohyets. In this process, it may be beneficial to evaluate the grid in terms of the location of rainfall gauging stations used in the analysis. Regardless of the outcome of this evaluation, fewer contour lines will provide better clarity.

Response	**X** Agree	Disagree

Fewer contour lines are provided.

Comment 3:

Depression areas in the isohyets must be carefully looked at to confirm that actual low points do exist. Comparison with previous Florida isohyetal maps, the isohyets developed in this study show more depression areas. This may be a consequence of the interpolation grid size, or may be actual depressions.

Response	**X** Agree	Disagree

The grid size and the contour interval were reset.

Comment 4:		
The interpolation grid and the resulting isohyets extend well off shore. An assessment of the extent of the interpolation off shore should be looked at carefully to determine if the extrapolation to is not excessive. It is not clear how this was done into the Ocean and Gulf. It is reasonable to allow some extrapolation over the water to obtain isohyets over coastal areas, but the grid should not extend too far off the coastline. It is also reasonable to compare the results with a specially generated inland subset of the isohyets.		
Response	**X** Agree	Disagree
The ocean contours were removed.		

Comment 5:		
A comparison of the final results should be performed to determine the variation from previously published results. Upon spot checking by comparing the results with previously published results, there appears to be locations that the new results indicate lower rainfall depths while in other locations the new rainfall depths were higher.		
Response	**X** Agree	Disagree
There should be differences among the Water Management Districts, County, and the Florida Department of Transportation curves and ones the study generated because of the years of data used, curve fit procedures, and the methods of determining "good" data from others. As implied, there is no reason to believe they would be the same. Nevertheless providing comparisons were discussed early in the research and it was decided to leave the comparisons to after the research was completed so as not to bias the work. Also there was fear of biasing the results if a set of other curves was used and then some data could be dropped from the present data based in hopes of getting a closer fit. After this study is completed, comparisons should be made.		

Comment 6:		
The spatial interpolations methods used in the development of iso-pluvial curves were not explained clearly in the reports/documents. Details of the selection process of nearest neighbors (number and the number of gages used in a specific direction), semi-variograms (isotropic or anisotropic along with type [Gaussian, exponential, spherical and others]) and the exponent in inverse distance weighting method (IDWM) were not provided. Tent-pole effect is evident in almost all the spatial interpolations. Spatial interpolation assessment should be based on split-sample approach to quantitatively validate the performance of different interpolation schemes. This approach requires a jack-knife analysis (leave one out). It is not clear why so many interpolation methods were evaluated. It is also not clear if the optimum distance based Inverse distance based method was used. IDWM can be improved by using optimal power parameters or radius limited interpolations. Iso-pluvial lines beyond the state boundary may not be required and can be avoided for future.		
Response	**X** Agree	Disagree
Additional explanations are added to the on-line materials.		

Comment 7:		
The interpolated rainfall maps in the study are too heavily influenced by individual station data. I agree that kriging is an appropriate interpolation method, but special care must be paid to the kriging options. The most important consideration for this application is the magnitude of the nugget effect. I suspect that the authors specified no nugget effect, or a very small nugget effect. This leads to contour maps that are overly detailed (tent pole effect, or halos around individual stations). Please see additional information regarding the evaluation of Spatial Interpolation Methods.		
Response	**X** Agree	Disagree
We were in conversation with the reviewer and very much appreciate his help relative to the kriging parameters and method so that we were able to assess the results of a new spatial analyses done essentially the same way as he was doing it. The method is subjective but based on observations and in many ways the observations add to the credibility of the analyses. While all results cannot be checked for consistency, many were such as those relating increasing depth with increasing return periods for the same ground location.		

V. References and Other Reports Links

Comment 1:		
Gupta R. 2008. Hydrology and Hydraulic Systems Sokolov, A. A., Rantz, S. E. and Roche, M. Floodflow computation: Methods compiled from World Experience, studies and Reports in Hydrology, Report # 22, UNESCO.		
Response	**X** Agree	Disagree
We appreciate the reference.		

VI. General Comments

Comment 1:		
There are a few typos in the document. I assume that the report will undergo editing prior to publication. As such, I have focused my review on the methodology – not the document itself.		
Response	**X Agree**	Disagree
Another reading of the document by a professional in this area was done and only a few changes were made (two of the changes were typos.)		

III. Comment 3 Additional Information

Station Name:	**Grady**
Duration:	**2 hr**
Years of Record:	**29**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	2.26	2.26	2.30	2.29
5	0.2	0.8	0.84	2.81	2.83	2.86	2.88
10	0.1	0.9	1.28	3.16	3.21	3.20	3.20
25	0.04	0.96	1.75	3.62	3.68	3.58	3.53
50	0.02	0.98	2.05	3.96	4.04	3.84	3.73
100	0.01	0.99	2.33	4.29	4.39	4.08	3.89

Summary Statistics

Product Moments:

Mean (in):	2.364
St. Dev. (in):	0.614

Gumbel Fit with Product Moments:

α:	0.479
ξ:	2.087
κ:	0.000

Probability Weighted Moments:

b_0:	2.364
b_1:	1.356
b_2:	0.968

Gumbel Fit with L Moments:

α:	0.503
ξ:	2.074
κ:	0.000

L Moments:

λ_1 = 2.364

λ_2 = 0.348

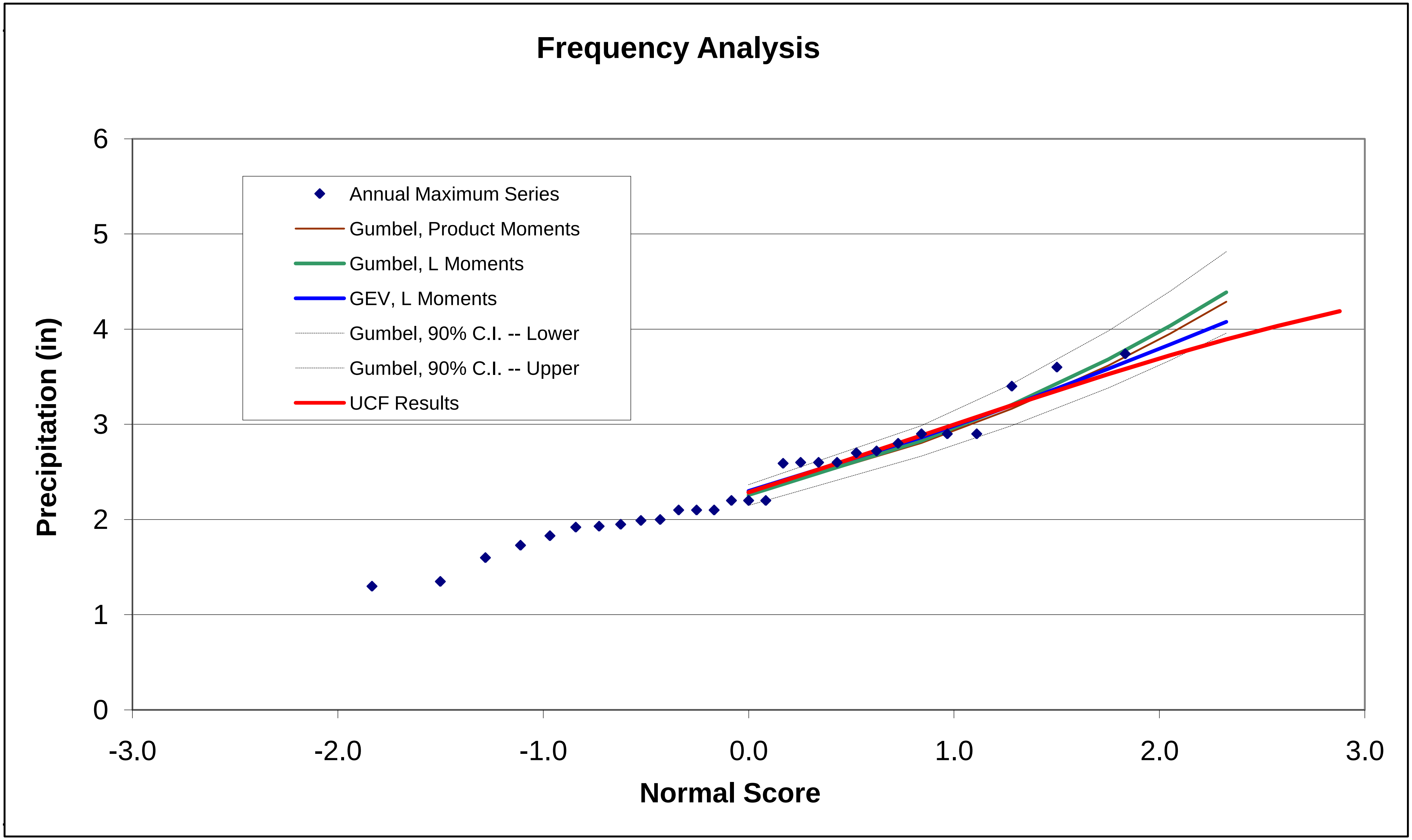
λ_3 = 0.034

GEV fit with PWM's:

α:	0.5531
ξ:	2.1014
κ:	0.1147
c:	0.0145
$\Gamma(1+k)$:	0.9456
Z:	0.8231
Is κ significant at 90% level?	No

Confidence Limits for Gumbel Distribution

		Product Moments:		L Moments:		
Gumbel Red. Variate	Prod. Mom. Quantile Var.	90% C.I. Lower (in)	90% C.I. Upper (in)	L Moment Quant. Var.	90% C.I. Lower (in)	90% C.I. Upper (in)
0.367	0.005	2.144	2.381	0.004	2.149	2.367
1.500	0.012	2.623	2.988	0.009	2.668	2.988
2.250	0.020	2.931	3.398	0.018	2.987	3.423
3.199	0.034	3.316	3.921	0.033	3.382	3.982
3.902	0.047	3.600	4.311	0.049	3.672	4.399
4.600	0.062	3.881	4.698	0.068	3.959	4.815


Frequency Analysis
Annual Maximum Series
Gumbel, Product Moments
Gumbel, L Moments
GEV, L Moments
Gumbel, 90% C.I. -- Lower
Gumbel, 90% C.I. -- Upper
UCF Results
Precipitation (in)
0
1
2
3
4
5
6
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
Normal Score

Precipitation Frequency for Daily Data

Raw Data:		**Ranked Data**		**Computation of St. Dev.**	**Computation of Probability Weighted Moments**					
Year	Annual Maxima (in)	Rank	Annual Maxima (in)	(X-μ)^2	For b1:	For b2:	Exceedance Probability	Non-Exc. Prob.	Z-score	Annual Maxima Ranked (in)
1959	1.35	1	3.74	1.893945	0.1290	0.1290	0.0333	0.9667	1.8339	3.74
1960	2.59	2	3.6	1.528207	0.1197	0.1153	0.0667	0.9333	1.5011	3.6
1961	1.95	3	3.4	1.073725	0.1089	0.1008	0.1000	0.9000	1.2816	3.4
1962	1.99	4	2.9	0.287518	0.0893	0.0794	0.1333	0.8667	1.1108	2.9
1963	1.73	5	2.9	0.287518	0.0857	0.0730	0.1667	0.8333	0.9674	2.9
1964	1.92	6	2.9	0.287518	0.0821	0.0669	0.2000	0.8000	0.8416	2.9
1965	2.72	7	2.8	0.190276	0.0759	0.0590	0.2333	0.7667	0.7279	2.8
1966	2.90	8	2.72	0.126883	0.0703	0.0521	0.2667	0.7333	0.6229	2.72
1967	1.93	9	2.7	0.113035	0.0665	0.0468	0.3000	0.7000	0.5244	2.7
1968	3.74	10	2.6	0.055794	0.0608	0.0406	0.3333	0.6667	0.4307	2.6
1969	2.60	11	2.6	0.055794	0.0576	0.0363	0.3667	0.6333	0.3407	2.6
1970	1.83	12	2.6	0.055794	0.0544	0.0323	0.4000	0.6000	0.2533	2.6
1971	2.00	13	2.59	0.05117	0.0510	0.0284	0.4333	0.5667	0.1679	2.59
1972	2.10	14	2.2	0.026828	0.0406	0.0211	0.4667	0.5333	0.0837	2.2
1973	2.90	15	2.2	0.026828	0.0379	0.0183	0.5000	0.5000	0.0000	2.2
1975	2.10	16	2.2	0.026828	0.0352	0.0157	0.5333	0.4667	-0.0837	2.2
1976	2.60	17	2.1	0.069587	0.0310	0.0126	0.5667	0.4333	-0.1679	2.1
1977	1.30	18	2.1	0.069587	0.0284	0.0105	0.6000	0.4000	-0.2533	2.1
1978	3.60	19	2.1	0.069587	0.0259	0.0086	0.6333	0.3667	-0.3407	2.1
1979	2.60	20	2	0.132345	0.0222	0.0066	0.6667	0.3333	-0.4307	2
1980	2.80	21	1.99	0.139721	0.0196	0.0051	0.7000	0.3000	-0.5244	1.99
1981	1.60	22	1.95	0.171225	0.0168	0.0037	0.7333	0.2667	-0.6229	1.95
1982	2.20	23	1.93	0.188176	0.0143	0.0026	0.7667	0.2333	-0.7279	1.93
1983	2.90	24	1.92	0.196952	0.0118	0.0018	0.8000	0.2000	-0.8416	1.92
1984	2.20	25	1.83	0.284935	0.0090	0.0010	0.8333	0.1667	-0.9674	1.83
1985	2.20	26	1.73	0.401694	0.0064	0.0005	0.8667	0.1333	-1.1108	1.73
1986	2.70	27	1.6	0.58338	0.0039	0.0001	0.9000	0.1000	-1.2816	1.6
1987	3.40	28	1.35	1.027776	0.0017	0.0000	0.9333	0.0667	-1.5011	1.35
1988	2.10	29	1.3	1.131656	0.0000	0.0000	0.9667	0.0333	-1.8339	1.3

III. Comment 4 Additional Information

Spot Check of Frequency Analysis

Overview. Frequency analysis results were checked for five stations, selected at random. The duration evaluated for each station was also selected at random. Table 1 lists the stations and durations checked.

Table 1: Stations and Durations Checked

Station	Duration
Grady	2 hours
Panama City 5N	4 days
Lamont 6 WNW	2 days
Homestead Exp Stn	4 days
Key West Intl AP	24 hours

The Gumbel (EV1) distribution was fit to each AMS using product and L moments. The GEV was fit using L moments only. This differs from the use of maximum likelihood estimators (MLE) used in the UCF study, but is useful as a cross-check. My GEV results were identical to the UCF study results for four of the five stations examined. Results for the Grady site are sufficiently different to warrant further investigation. The study authors should determine the reason for this difference, and evaluate whether other stations might be affected. Of course, it is possible that the mistake is on my end. I will send a copy of my spreadsheet for the Grady station to make this evaluation easier.

Tables 2 through 6 and Figures 1 through 5 compare my results with the UCF study.

Table 2: Frequency Analysis Check for Grady, 2-hr Duration

Station Name:	**Grady**
Duration:	**2 hr**
Years of Record:	**29**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	2.26	2.26	2.30	2.29
5	0.2	0.8	0.84	2.81	2.83	2.86	2.88
10	0.1	0.9	1.28	3.16	3.21	3.20	3.20
25	0.04	0.96	1.75	3.62	3.68	3.58	3.53
50	0.02	0.98	2.05	3.96	4.04	3.84	3.73
100	0.01	0.99	2.33	4.29	4.39	4.08	3.89

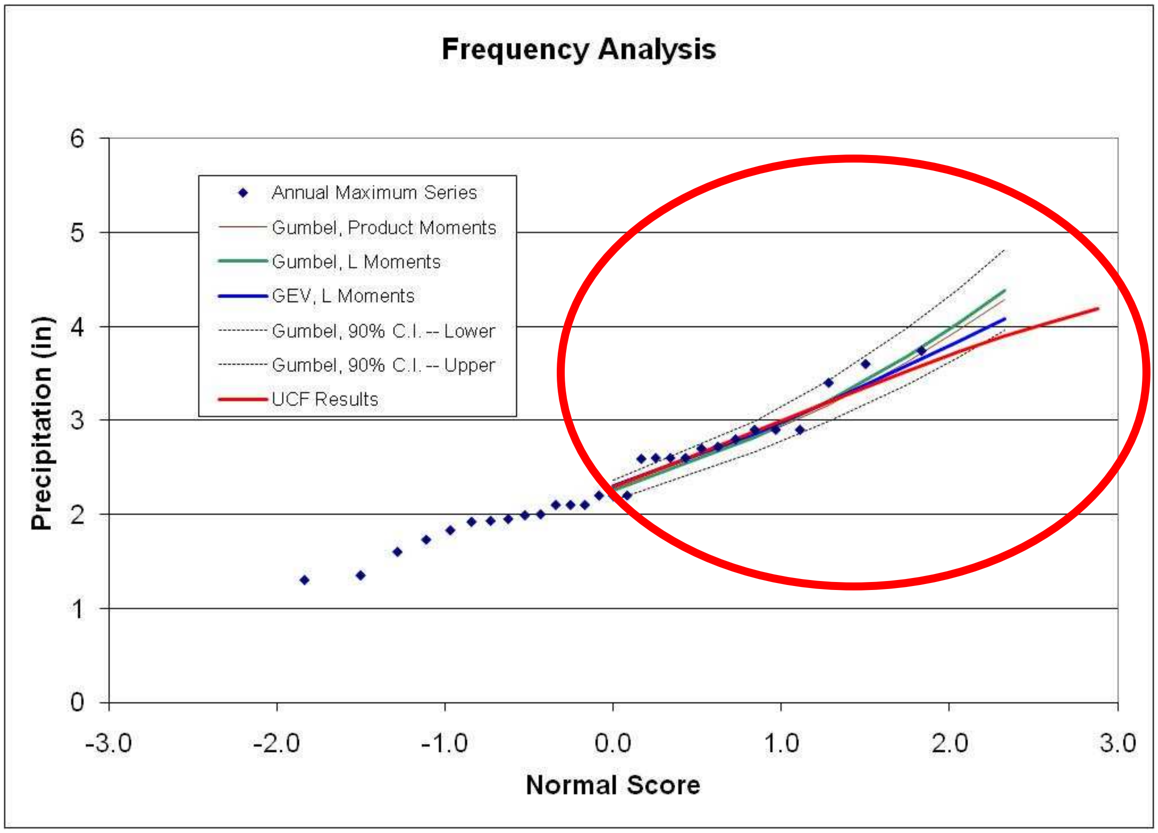


Figure 1: Spot Check of Grady, 2-hr

Table 3: Frequency Analysis Check for Panama City 5N, 4-day Duration

Station Name:	**Panama City 5N**
Duration:	**4 day**
Years of Record:	**27**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	5.98	6.02	5.83	5.8344
5	0.2	0.8	0.84	8.16	7.97	7.75	7.7472
10	0.1	0.9	1.28	9.60	9.26	9.21	9.2051
25	0.04	0.96	1.75	11.43	10.89	11.30	11.2986
50	0.02	0.98	2.05	12.78	12.09	13.06	13.0562
100	0.01	0.99	2.33	14.13	13.29	14.99	14.9945

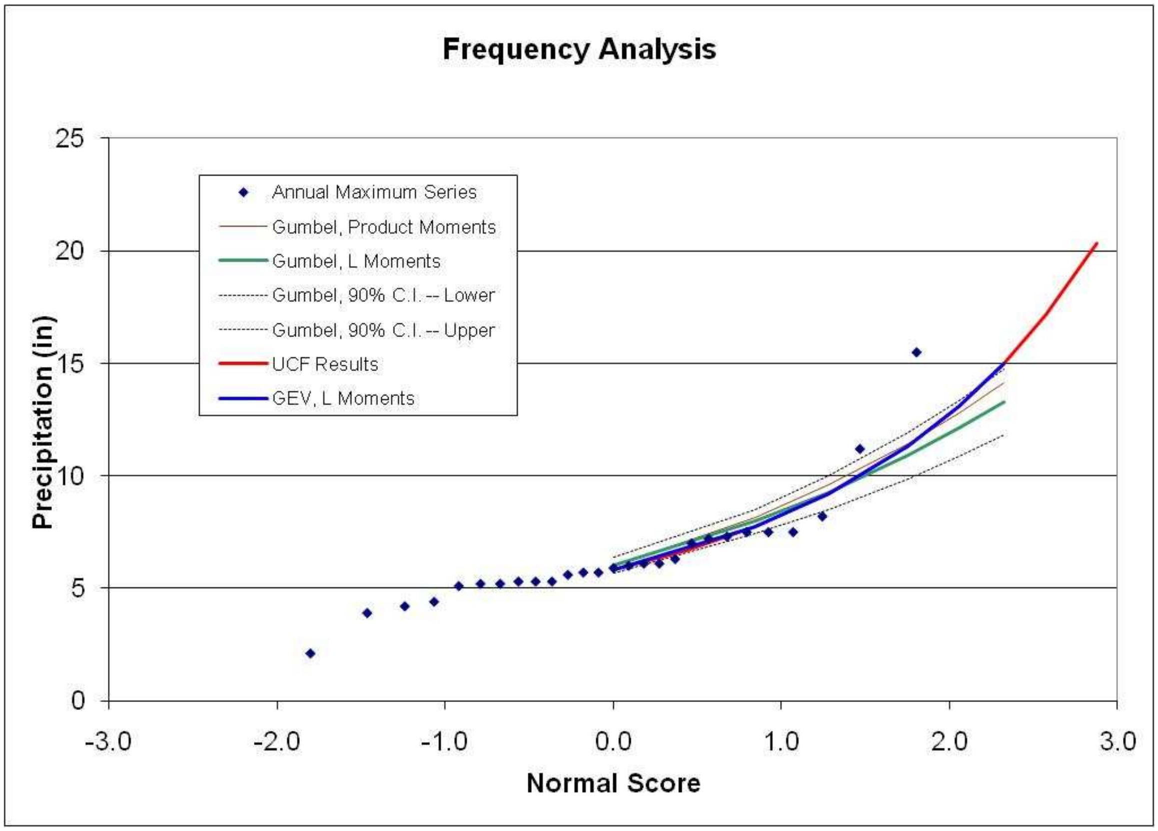


Figure 2: Spot Check of Panama City 5N, 4-day

Table 4: Frequency Analysis Check for Lamont 6 WNW, 2-day Duration

Station Name:	**Lamont 6 WNW**
Duration:	**2 day**
Years of Record:	**29**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	4.72	4.72	4.54	4.54
5	0.2	0.8	0.84	6.73	6.73	6.53	6.53
10	0.1	0.9	1.28	8.06	8.07	8.02	8.02
25	0.04	0.96	1.75	9.74	9.75	10.15	10.15
50	0.02	0.98	2.05	10.99	11.00	11.92	11.92
100	0.01	0.99	2.33	12.23	12.24	13.85	13.85

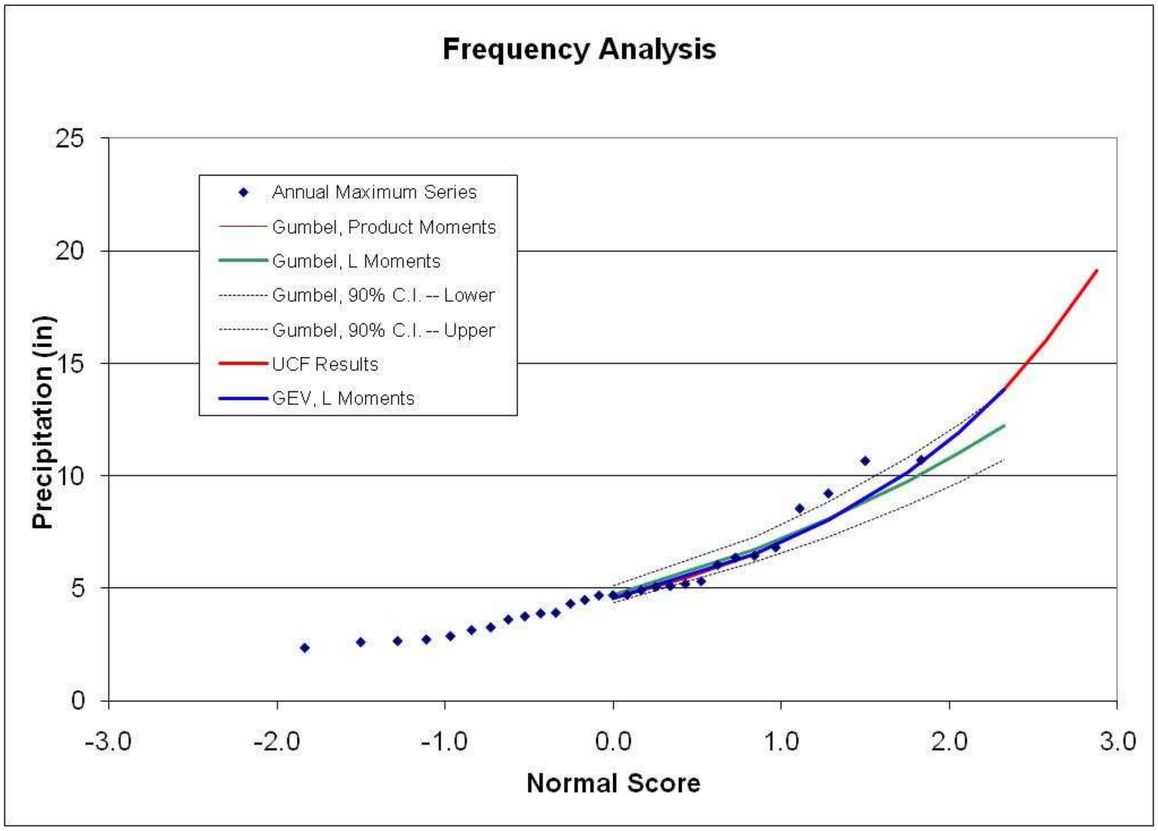


Figure 3: Spot Check of Lamont 6 WNW, 2-day

Table 5: Frequency Analysis Check for Homestead Exp Stn, 4-day Duration

Station Name:	**Homestead Exp Stn**
Duration:	**4 day**
Years of Record:	**36**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	6.53	6.58	6.35	6.35
5	0.2	0.8	0.84	9.04	8.83	8.55	8.55
10	0.1	0.9	1.28	10.70	10.31	10.25	10.25
25	0.04	0.96	1.75	12.80	12.20	12.70	12.70
50	0.02	0.98	2.05	14.35	13.59	14.78	14.78
100	0.01	0.99	2.33	15.90	14.98	17.09	17.09

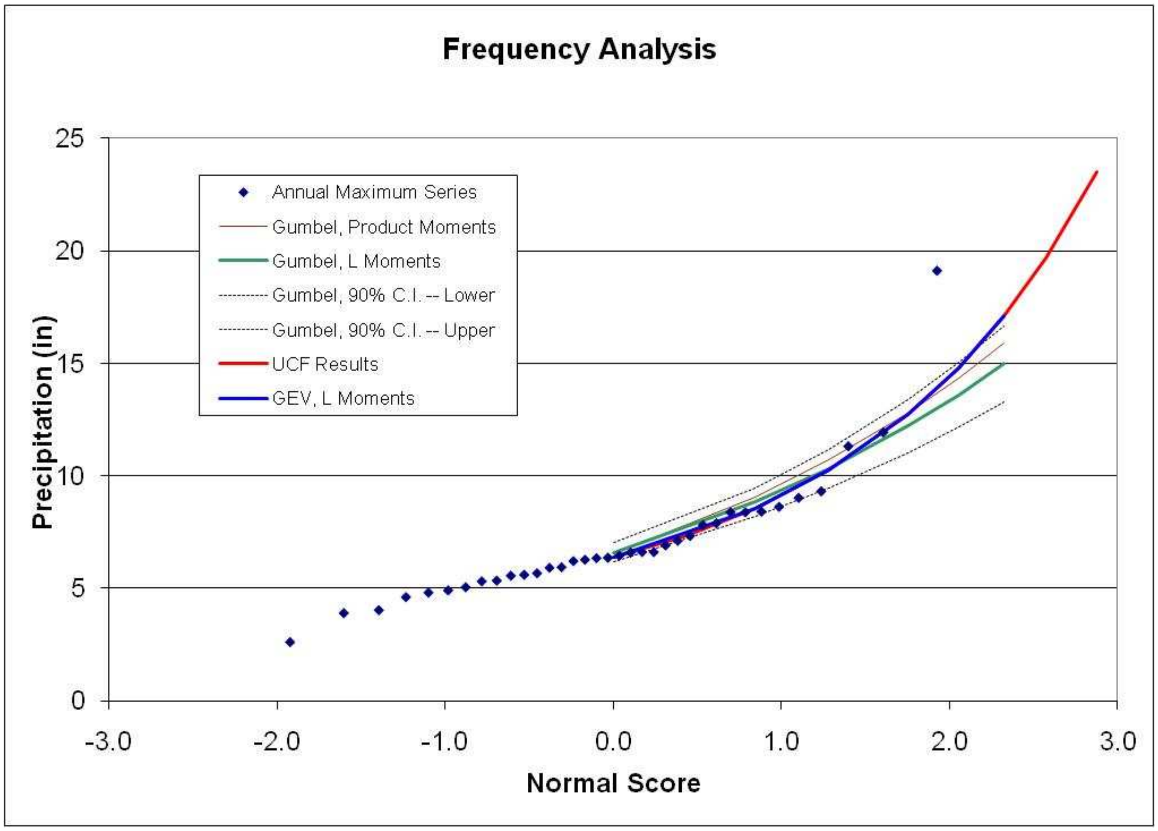


Figure 4: Spot Check of Homestead Exp Stn, 4-day

Table 6: Frequency Analysis Check for Key West Intl AP, 1-day Duration

Station Name:	**Key West Intl AP**
Duration:	**1 day**
Years of Record:	**47**

Estimated Accumulations for Daily Rainfall for Given Return Periods

Note: Based on annual maximum series -- not converted to partial duration series.

Return Period (Years)	Exc. Prob.	Non-Exc. Prob.	Normal Score	Gumbel Product Moments Est. (in)	Gumbel L Moments Estimate (in)	GEV Estimate (in)	UCF Study GEV (in)
2	0.5	0.5	0.00	4.44	4.56	4.11	4.11
5	0.2	0.8	0.84	7.38	6.86	6.20	6.20
10	0.1	0.9	1.28	9.32	8.38	8.06	8.06
25	0.04	0.96	1.75	11.78	10.30	11.16	11.16
50	0.02	0.98	2.05	13.60	11.72	14.15	14.15
100	0.01	0.99	2.33	15.41	13.14	17.87	17.87

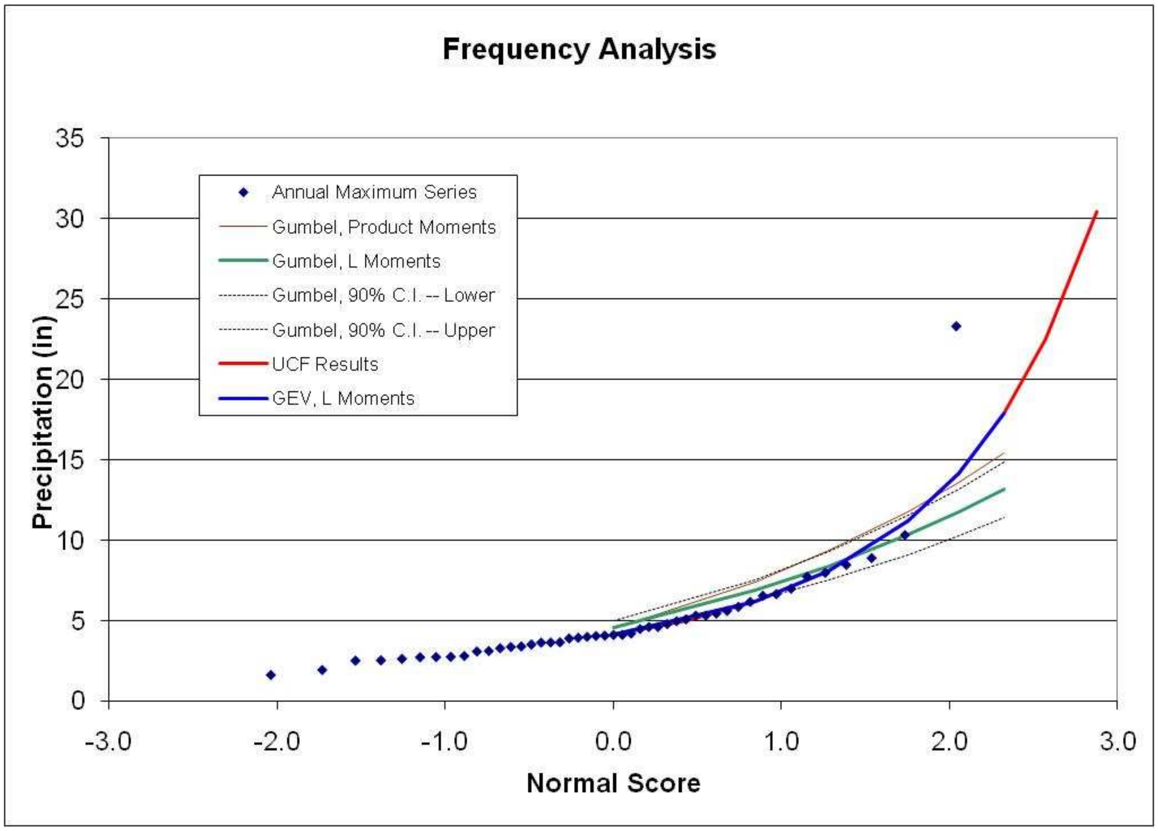


Figure 5: Spot Check of Key West Intl AP, 1-day

IV. Comment 7 Additional Information

Evaluation of Spatial Interpolation Methods

Overview. The interpolated rainfall maps in the study are too heavily influenced by individual station data. I agree that kriging is an appropriate interpolation method, but special care must be paid to the kriging options. The most important consideration for this application is the magnitude of the nugget effect. I suspect that the authors specified no nugget effect, or a very small nugget effect. This leads to contour maps that are overly detailed (tent pole effect, or halos around individual stations).

For example, the 5-yr 2-hr map from the UCF rainfall study (see Figure 1) has a lot of concentric contours. The contours do not reflect true patterns in extreme rainfall. Rather, they highlight uncertainty in the frequency analysis results. The frequency analysis results for individual stations are uncertain, especially at higher return periods (10+ years). This is due to the limited length of records. The GEV distribution will tend to be very sensitive to 'outliers' in the dataset. By 'outliers' here, I mean large rainfall accumulates that occurred during the period of record – not true statistical outliers. For example, it's possible that a station received a 500-yr rainfall accumulation in a 20-year record. This large event will skew the rainfall frequency estimates for that station upwards.

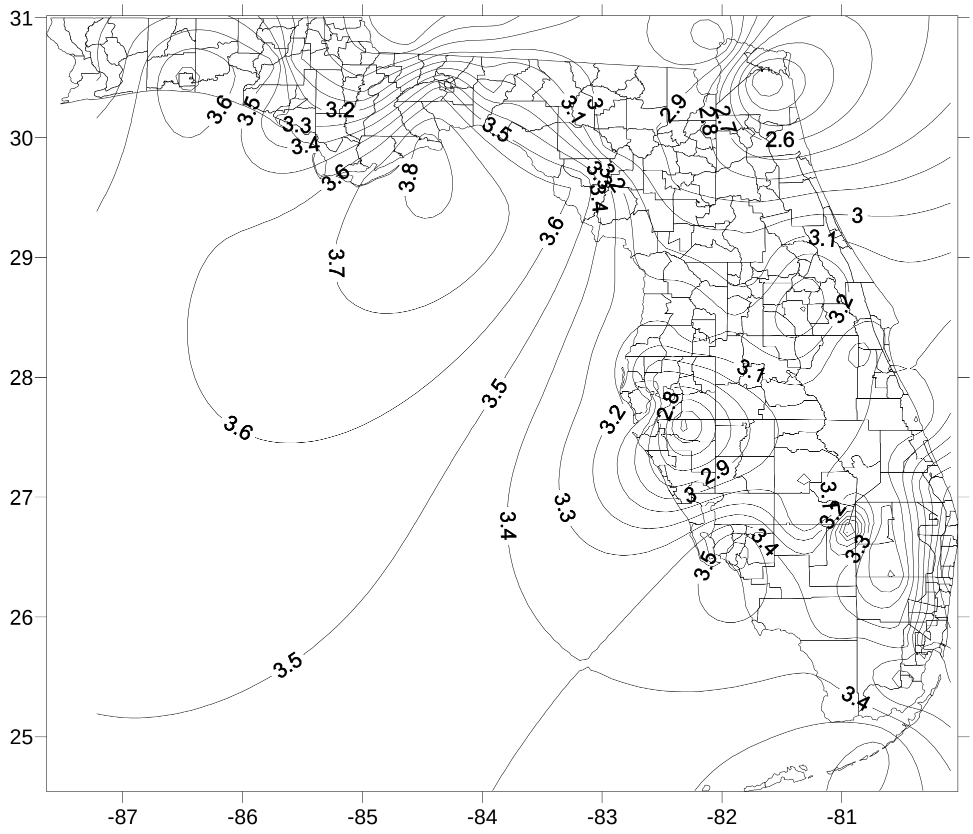


Figure 1: 5-yr, 2-hr Rainfall Depths from UCF Rainfall Study

It is important to smooth out variations and uncertainties in the frequency analysis results. Spatial interpolation will do this, if performed appropriately. For example, Figure 2 shows a contour map of 5-yr, 2-hr rainfall depths using the UCF rainfall data. This map shows 0.1” contours, just like in Figure 1. However, the trends displayed are generalized and probably reflect the true distribution of rainfall extremes more accurately.

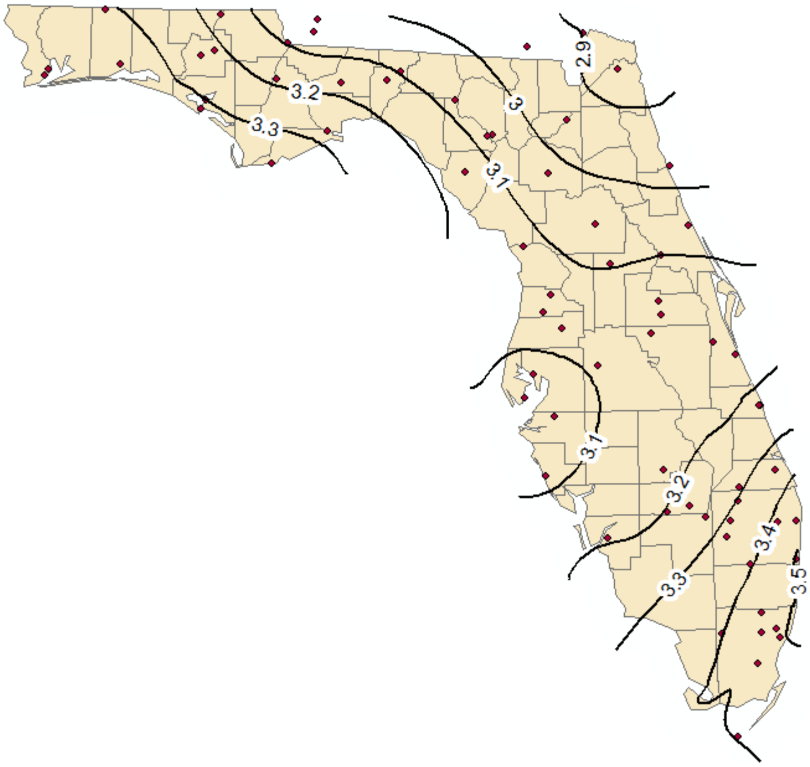


Figure 2: Alternate Map of 5-yr, 2-hr Rainfall Depths

The rainfall maps for this study need to be re-done with careful attention paid to the interpolation method. I have experimented with interpolation methods using the data for this report. This document summarizes my findings.

Spatial Interpolation of 5-yr, 2-hr Rainfall Depths

I focused my attention on the 5-year, 2-hour rainfall data. The data for this combination of return period and duration were loaded into ArcGIS 9.3 directly from an Excel file. The stations were divided into calibration (48 stations) and validation (23 stations) data sets. Locations were mapped assuming that the latitude and longitude in the file were based on NAD83. This assumption would not impact results significantly.

I employed a range of interpolation methods, results for three are discussed here: Inverse Distance Weighting (IDW), Local Polynomial Interpolation (LPI) and ordinary kriging (OK).

Figures 3 through 7 show contour maps of 5-yr, 2-hr rainfall depths as determined using IDW, LPI, OK with default options, OK with an anisotropic semivariogram model, and OK with no nugget effect, repectively. Appendices A through E contain the calibration and validation results for each method of interpolation. The color scheme on the contours is consistent from map to map, and the contour interval is constant at 0.1 in.

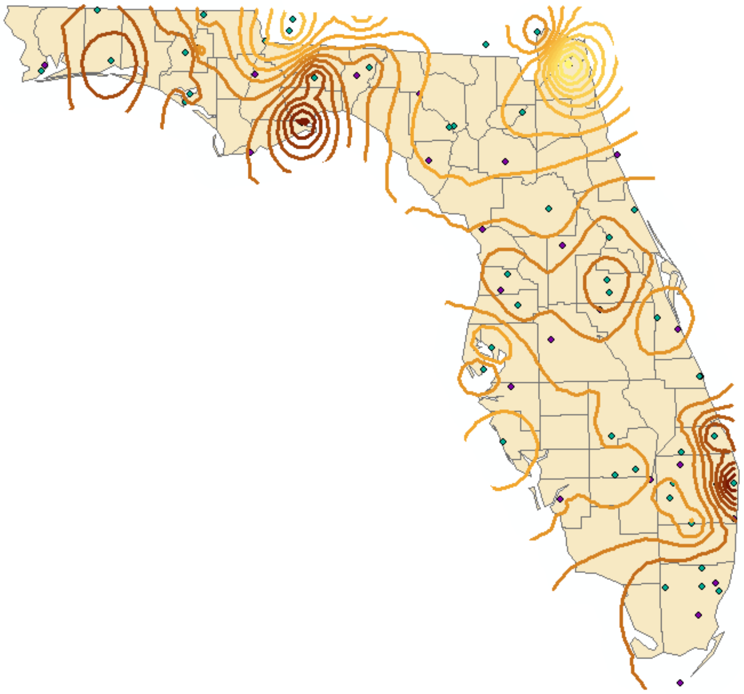


Figure 3: IDW-derived contours for 5-yr, 2-hr rainfall depths.

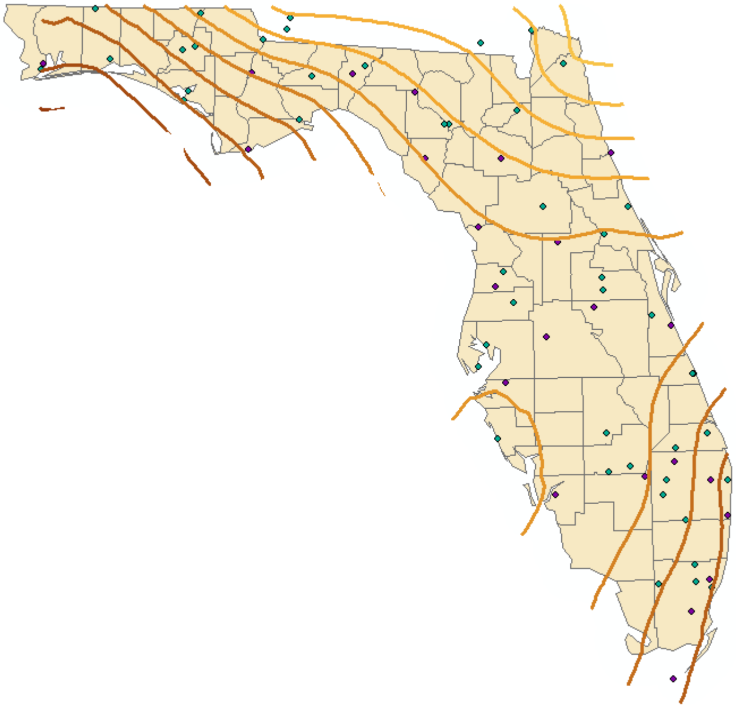


Figure 4: LPI-derived contours for 5-yr, 2-hr rainfall depths.

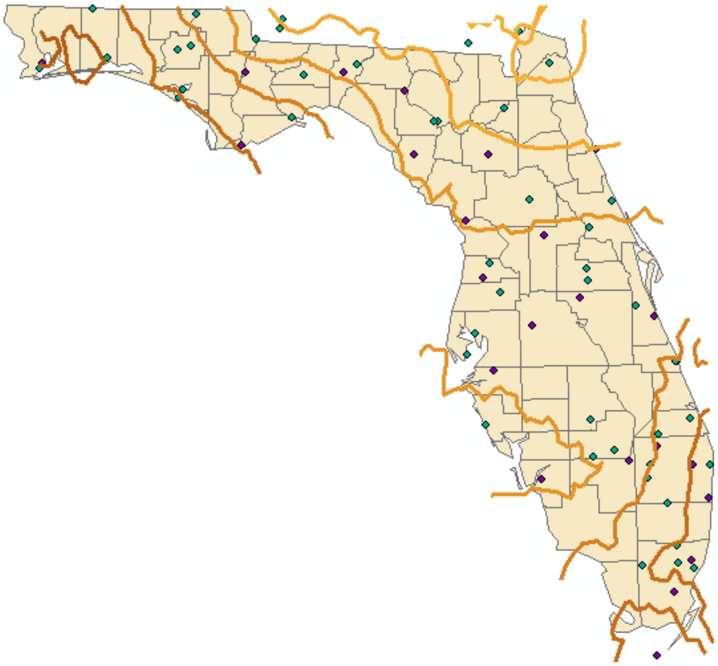


Figure 5: OK-derived contours for 5-yr, 2-hr rainfall depths, default parameters.

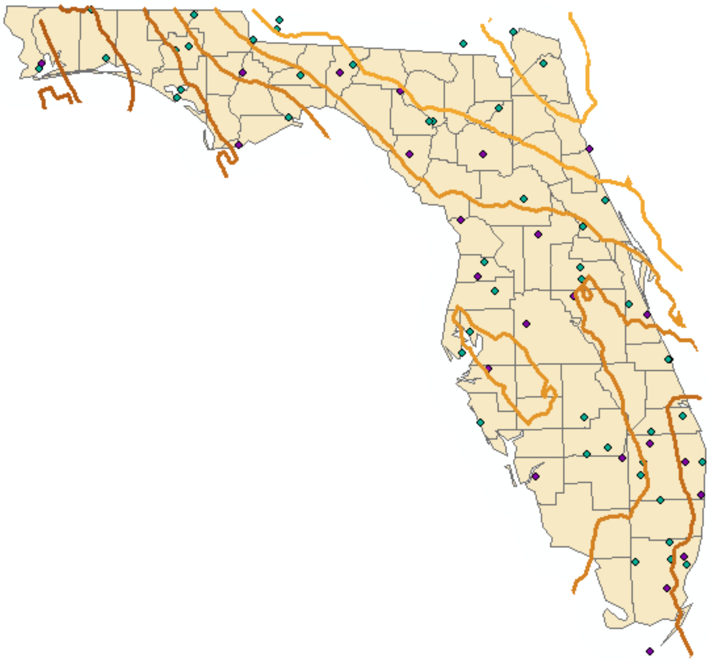


Figure 6: OK-derived contours for 5-yr, 2-hr rainfall depths, anisotropic variogram model.

Figure 7: OK-derived contours for 5-yr, 2-hr rainfall depths, no nugget effect.

Table 1 shows the calibration and validation root mean square differences (RMS) for the five maps shown above. Note that the prediction (calibration) RMS is not very meaningful here. It is possible to over-fit the calibration dataset. This is indeed the case for both the IDW and OK (no nugget) methods. These two methods exhibit the lowest RMS differences because they are 'true' to the original data (no smoothing). In actuality, smoothing does occur at the grid cell scale for these methods.

Table 1: RMS for Calibration and Validation for 5-yr, 2-hr Rainfall Depths

Method	**Prediction RMS (in)**	**Validation RMS (in)**
IDW, default parameters	0.279	0.349
LPI, dafault parameters	0.327	0.335
OK, default parameters	0.300	0.365
OK, anisotropic variogram	0.310	0.359
OK, no nugget	0.259	0.346

The important column in Table 1 is the validation RMS. The validation RMS is essentially the same for all five methods presented. The sample size for the validation is small (23 stations), so the difference between the lowest RMS (0.335 for LPI) and the highest (0.365 for OK) is most likely not significant.

The three methods used to interpolate the data (IDW, LPI, and OK) all have advantages and disadvantages. IDW is simple to implement, true to the original data (no smoothing), but produces horrible-looking contour maps. IDW does not consider the fact that the individual data points are uncertain. General trends in the data are overwhelmed by this site-specific uncertainty.

LPI will produce the smoothest contour maps, and will smooth out local variability in the data. However, the extrapolation of data beyond the spatial extend of the data points is problematic. This is evident to a slight degree in Figure 4, in the NW part of Florida. A more extreme example is shown in Appendices F and G for the 5-year, 72-hour rainfall depths.

Kriging is the most attractive spatial interpolation method, from a mathematical standpoint. Kriging allows the user to fit a model to the correlation structure present in the data. User-defined parameters are critical to the success of this interpolation approach; parameters for the correlation models must be selected with care. This is evidenced in Figures 5, 6, and 7. As mentioned earlier, the nugget effect is very important to this interpolation exercise. Each data point in the interpolation is uncertain. The nugget effect allows this uncertainty to be explicitly accounted for in the correlation model. If the nugget effect is set to zero, the resulting contour map (Figure 7) looks very much like an IDW map.

I experimented with several variogram models, and found that the interpolation is not sensitive to the form of the model (spherical, Gaussian, exponential, etc.). The nugget effect, however, is very important. Again, this is due to the uncertainty in individual station results.

Kriging does not produce the smoothest contours, so some post-processing of the kriged surface is desireable. The contours in Figure 2 were smoothed using the ‘Smooth Line’ function in the ArcToolbox. Figures 8 through 10 below show an alternate approach to smoothing the contours produced by kriging. Figure 8 shows the raw contours produced by the ArcGIS Geostatistical Analyst. The kriged surface was then converted to a raster with a coarse grid cell size (0.3 degrees). This coarse grid was resampled to a 0.05 degree grid using bilinear sampling (to smooth the grid out). The resampled grid was then contoured. Figures 9 and 10 show the resulting contour map.

It may seem from my discussion that smooth contours are desirable just for aesthetic reasons. This is not the case. If the contour maps are complicated and difficult to read, it is more likely that users will misread rainfall values from them. In addition, there is little reason to think that the rainfall values will vary rapidly in space. True, there will be coastal effects and longitudinal variation. However, the rainfall depths should not vary rapidly as you move up or down the coast.

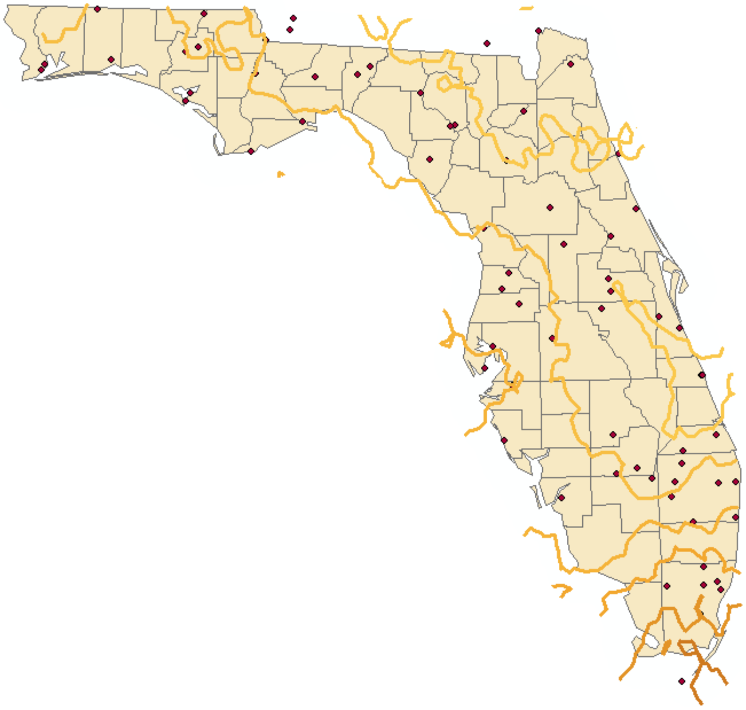


Figure 8: Contours of 500-year, 24-hour Rainfall using OK

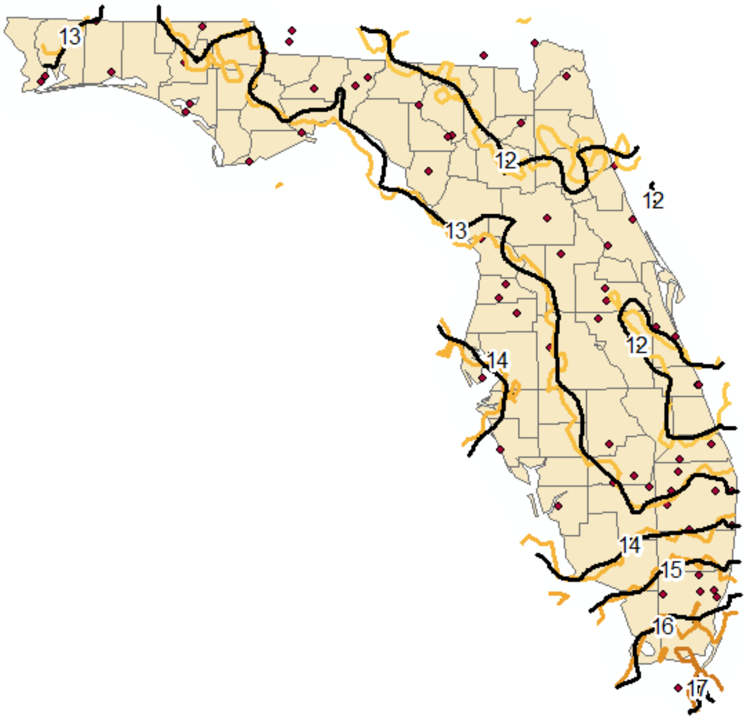


Figure 9: Contours of 500-year, 24-hour Rainfall using OK, Smoothed

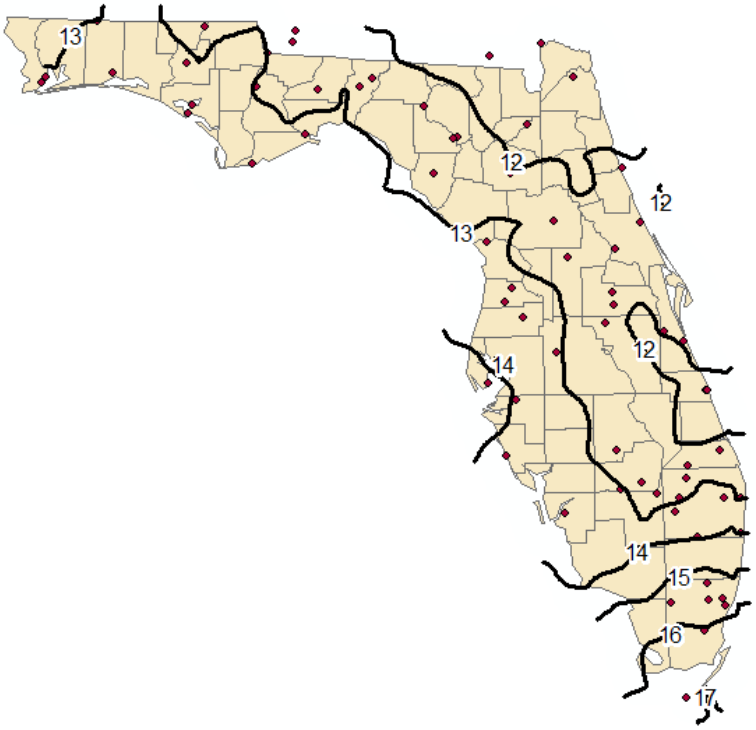
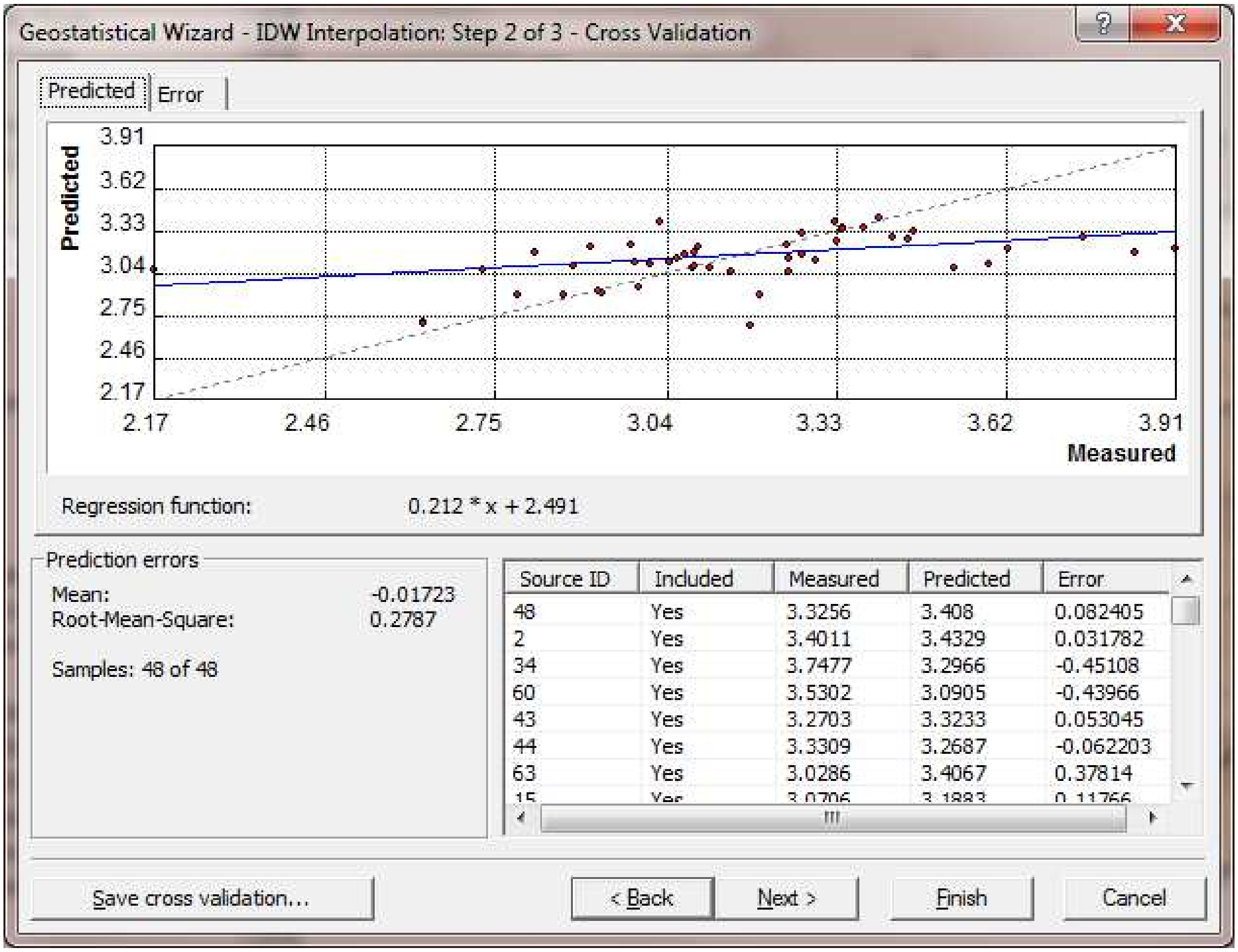


Figure 10: Contours of 500-year, 24-hour Rainfall using OK, Smoothed

Appendix A

5-yr, 2-hr: IDW – Default Parameters

IDW was employed using default parameters in ArcGIS. The defaults specify a power of two on the distance weighting (inverse distance squared).

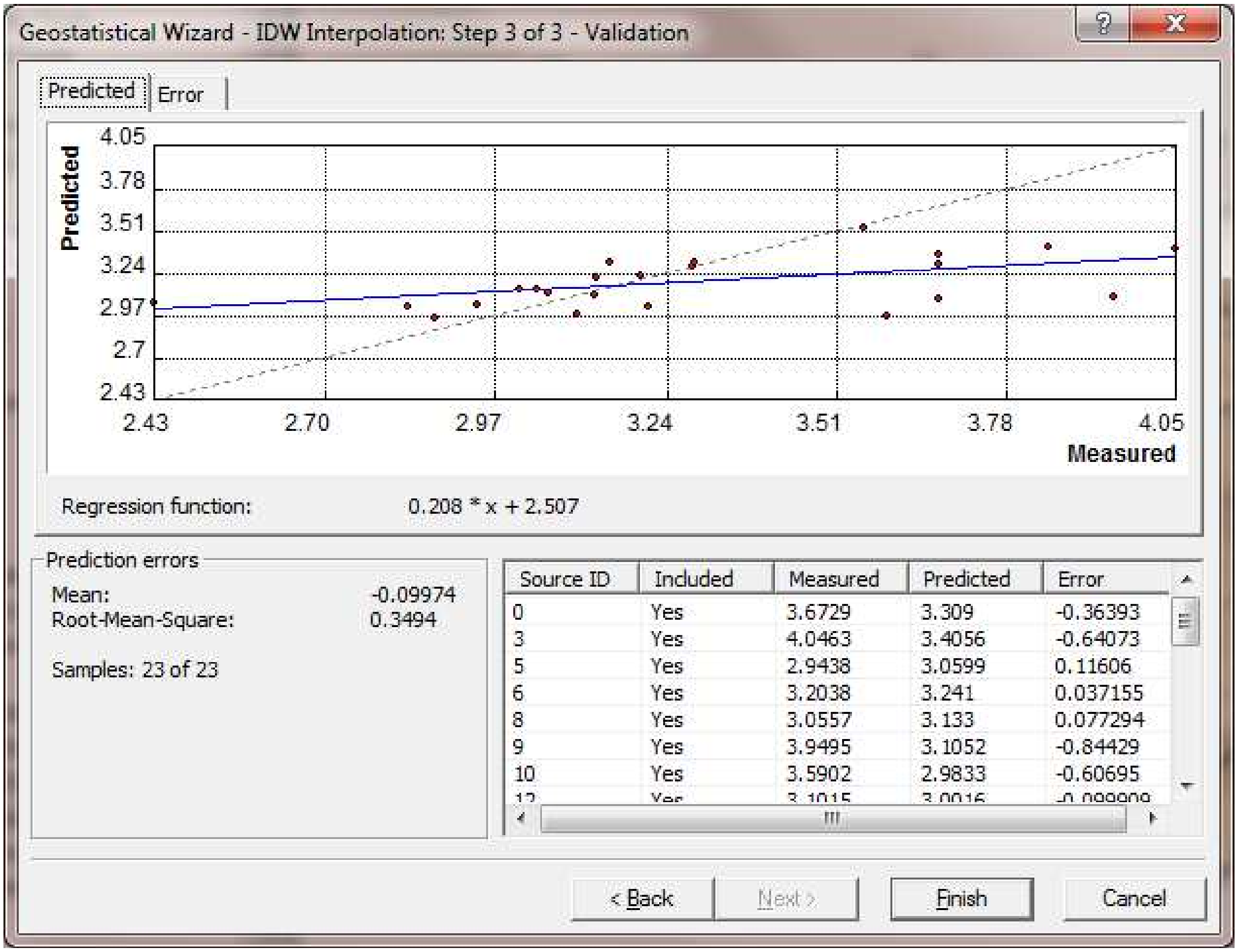


Regression function: 0.212 * x + 2.491

Mean: -0.01723
Root-Mean-Square: 0.2787

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	3.3256	3.408	0.082405
2	Yes	3.4011	3.4329	0.031782
34	Yes	3.7477	3.2966	-0.45108
60	Yes	3.5302	3.0905	-0.43966
43	Yes	3.2703	3.3233	0.053045
44	Yes	3.3309	3.2687	-0.062203
63	Yes	3.0286	3.4067	0.37814
15	Yes	3.0706	3.1883	0.11766



Regression function: 0.208 * x + 2.507

Prediction errors

Mean: -0.09974

Root-Mean-Square: 0.3494

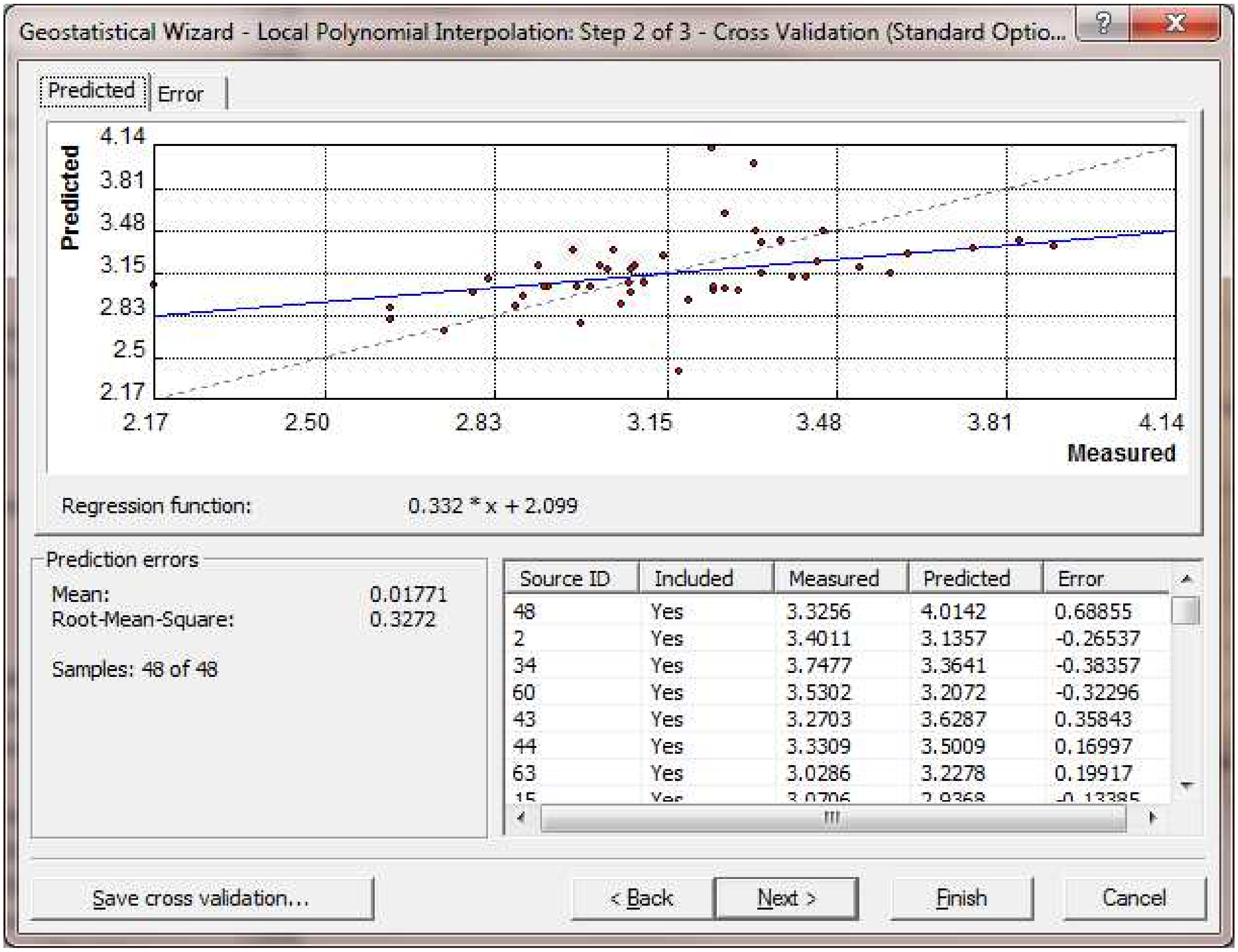
Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	3.6729	3.309	-0.36393
3	Yes	4.0463	3.4056	-0.64073
5	Yes	2.9438	3.0599	0.11606
6	Yes	3.2038	3.241	0.037155
8	Yes	3.0557	3.133	0.077294
9	Yes	3.9495	3.1052	-0.84429
10	Yes	3.5902	2.9833	-0.60695

Appendix B

5-yr, 2-hr: Local Polynomial Interpolation

LPI was performed using default parameters. LPI fits a smooth surface to data, similar to a spline function fit to a 2D dataset.



Geostatistical Wizard - Local Polynomial Interpolation: Step 2 of 3 - Cross Validation (Standard Optio...

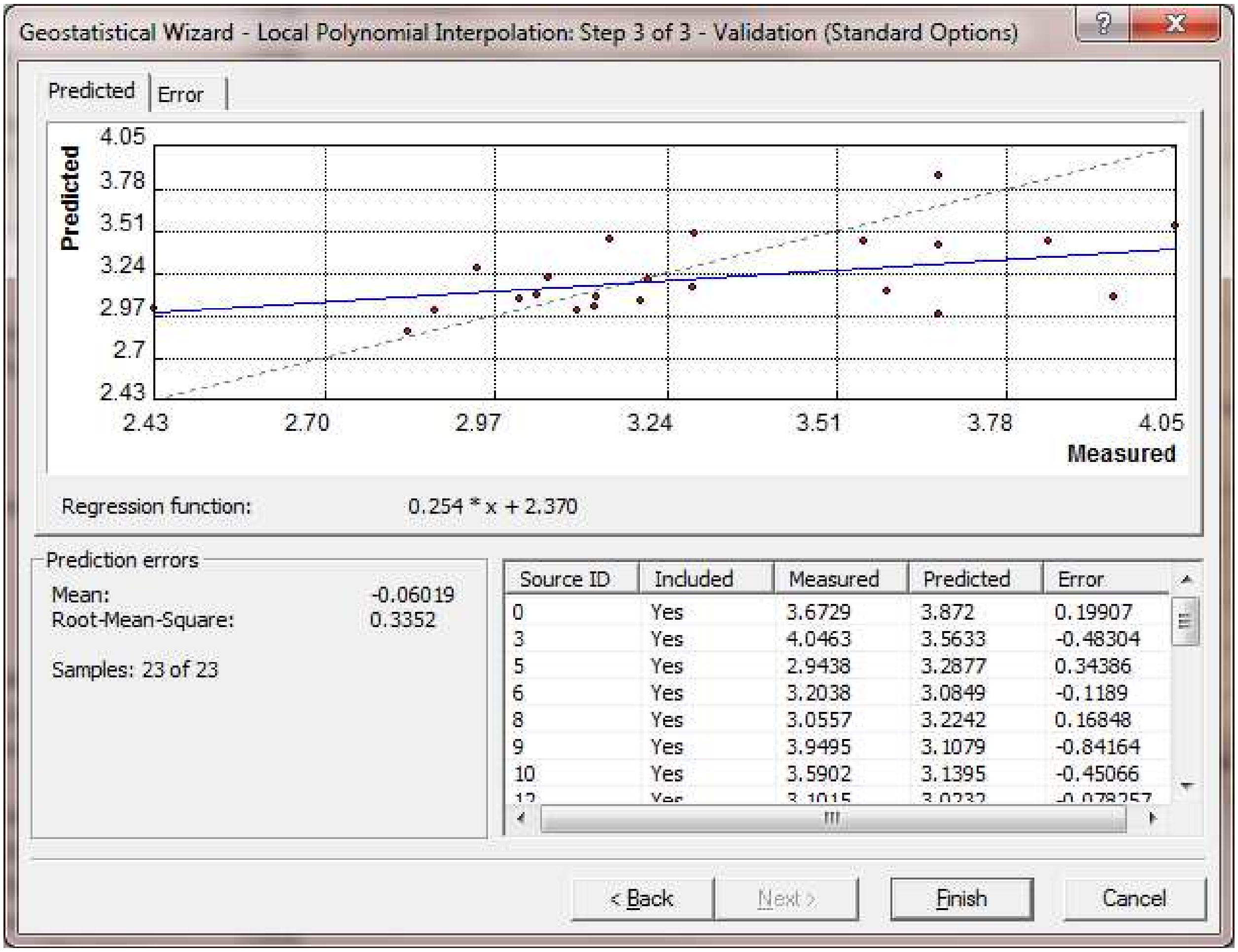
Regression function: 0.332 * x + 2.099

Prediction errors

Mean: 0.01771
Root-Mean-Square: 0.3272

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	3.3256	4.0142	0.68855
2	Yes	3.4011	3.1357	-0.26537
34	Yes	3.7477	3.3641	-0.38357
60	Yes	3.5302	3.2072	-0.32296
43	Yes	3.2703	3.6287	0.35843
44	Yes	3.3309	3.5009	0.16997
63	Yes	3.0286	3.2278	0.19917



Regression function: 0.254 * x + 2.370

Prediction errors

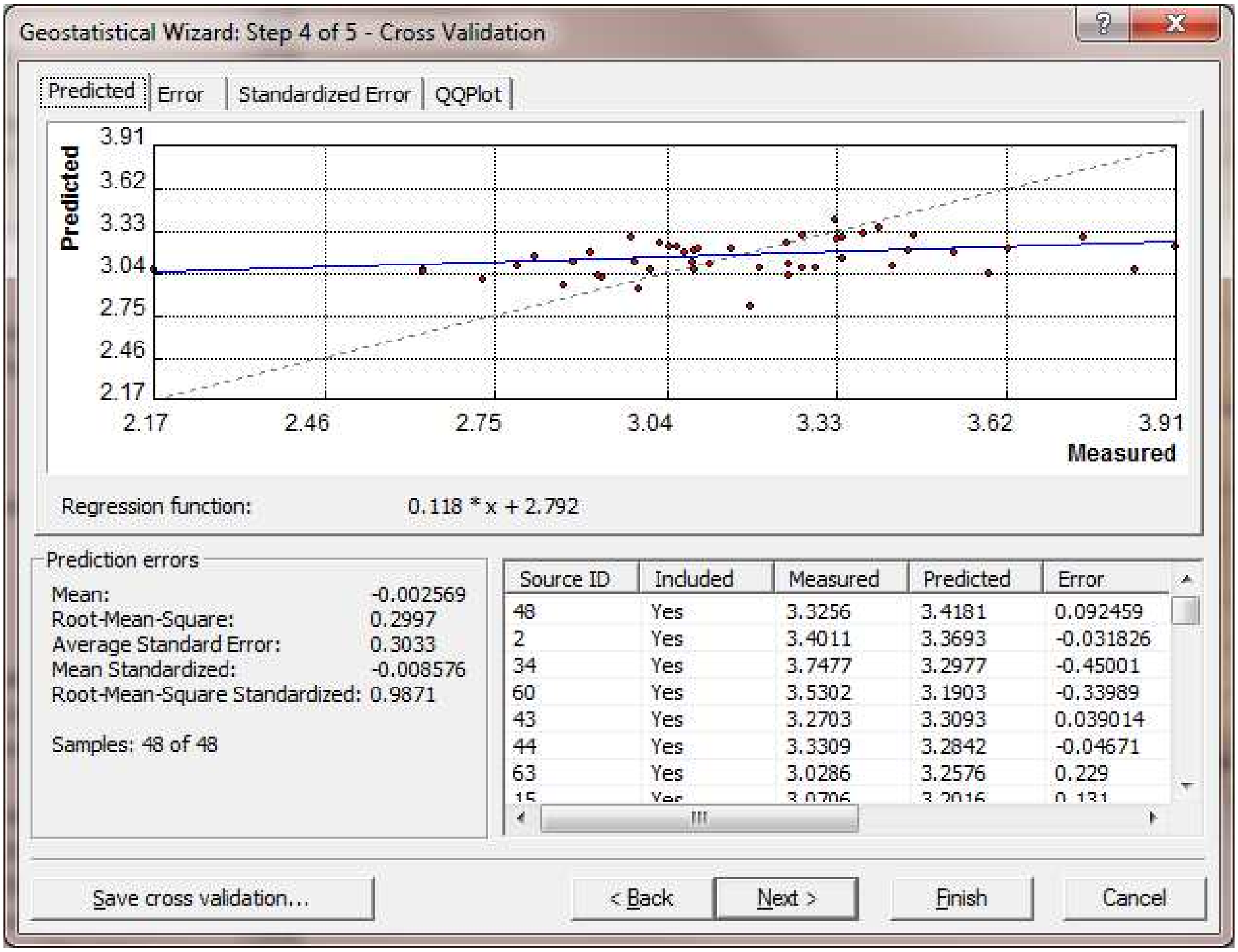
Mean: -0.06019
Root-Mean-Square: 0.3352

Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	3.6729	3.872	0.19907
3	Yes	4.0463	3.5633	-0.48304
5	Yes	2.9438	3.2877	0.34386
6	Yes	3.2038	3.0849	-0.1189
8	Yes	3.0557	3.2242	0.16848
9	Yes	3.9495	3.1079	-0.84164
10	Yes	3.5902	3.1395	-0.45066
12	Yes	3.1015	3.0232	-0.078257

Appendix C

5-yr, 2-hr: Ordinary Kriging – Default Parameters



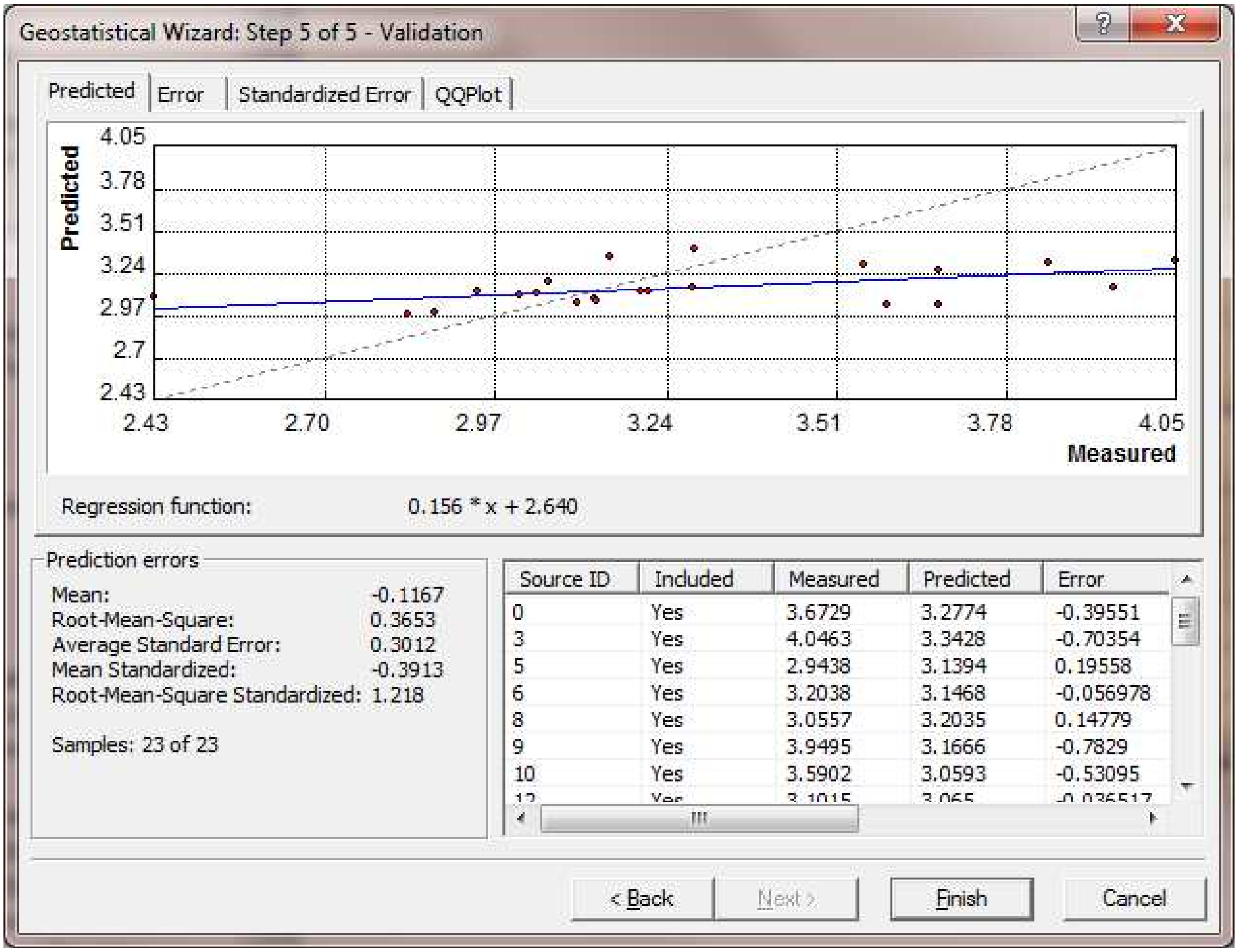
Regression function: 0.118 * x + 2.792

Prediction errors

Mean: -0.002569
Root-Mean-Square: 0.2997
Average Standard Error: 0.3033
Mean Standardized: -0.008576
Root-Mean-Square Standardized: 0.9871

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	3.3256	3.4181	0.092459
2	Yes	3.4011	3.3693	-0.031826
34	Yes	3.7477	3.2977	-0.45001
60	Yes	3.5302	3.1903	-0.33989
43	Yes	3.2703	3.3093	0.039014
44	Yes	3.3309	3.2842	-0.04671
63	Yes	3.0286	3.2576	0.229



Regression function: 0.156 * x + 2.640

Prediction errors

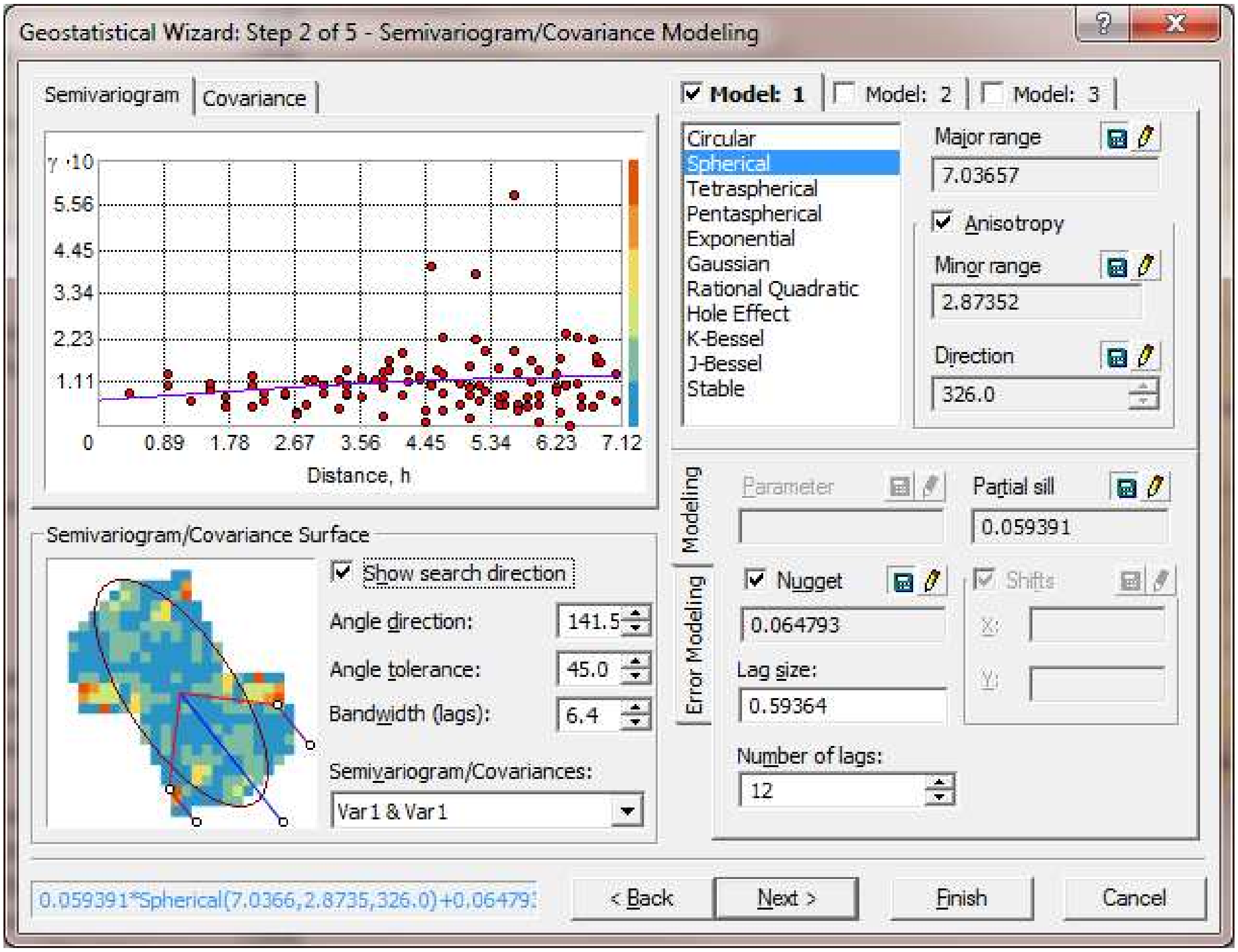
Mean:	-0.1167
Root-Mean-Square:	0.3653
Average Standard Error:	0.3012
Mean Standardized:	-0.3913
Root-Mean-Square Standardized:	1.218

Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	3.6729	3.2774	-0.39551
3	Yes	4.0463	3.3428	-0.70354
5	Yes	2.9438	3.1394	0.19558
6	Yes	3.2038	3.1468	-0.056978
8	Yes	3.0557	3.2035	0.14779
9	Yes	3.9495	3.1666	-0.7829
10	Yes	3.5902	3.0593	-0.53095

Appendix D

5-yr, 2-hr: Ordinary Kriging, Anisotropy



Geostatistical Wizard: Step 2 of 5 - Semivariogram/Covariance Modeling

☑ Model: 1 ☐ Model: 2 ☐ Model: 3

Circular
Spherical
Tetraspherical
Pentaspherical
Exponential
Gaussian
Rational Quadratic
Hole Effect
K-Bessel
J-Bessel
Stable

Major range: 7.03657

☑ Anisotropy

Minor range: 2.87352

Direction: 326.0

Partial sill: 0.059391

☑ Nugget: 0.064793

Lag size: 0.59364

Number of lags: 12

☑ Shifts

☑ Show search direction

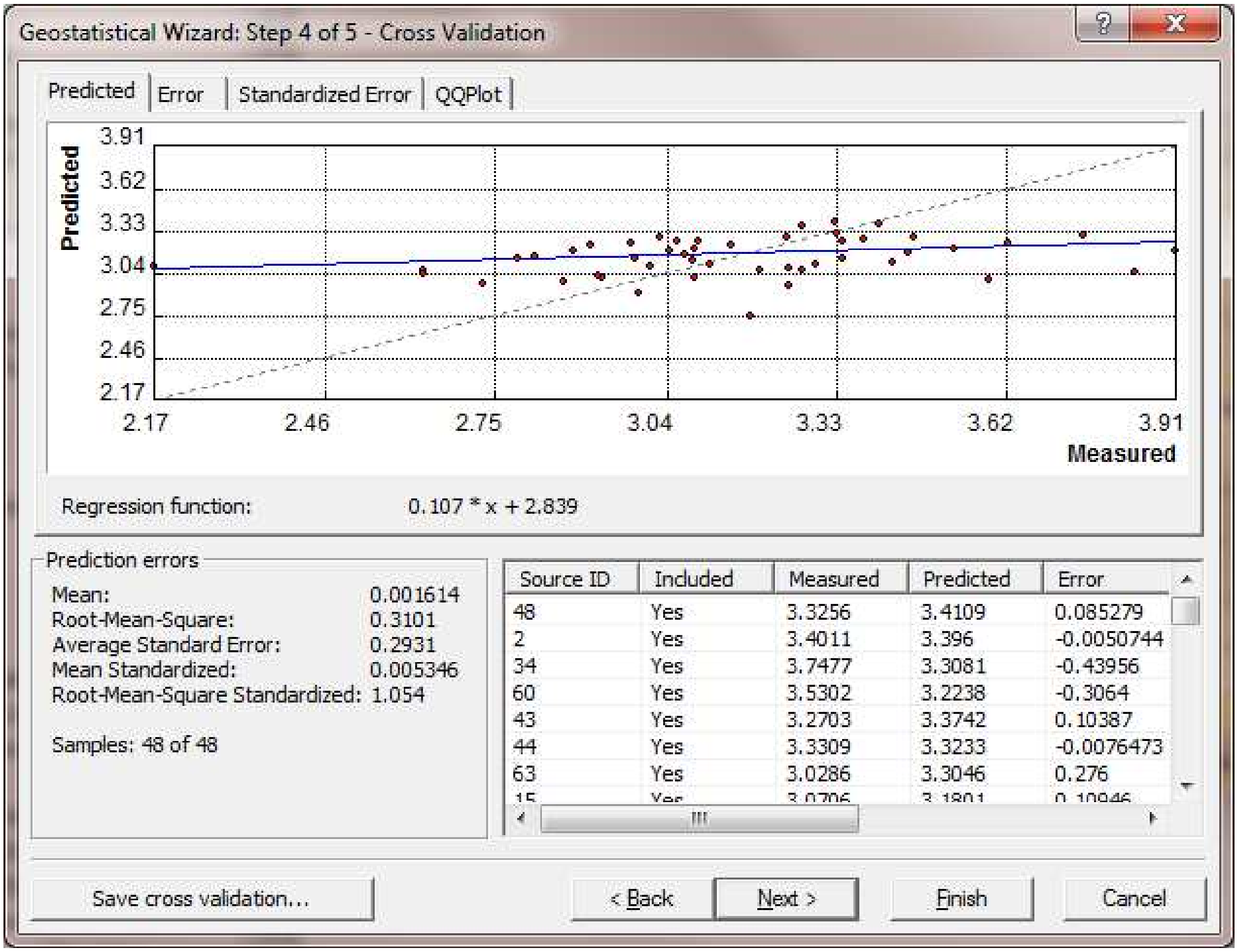
Angle direction: 141.5

Angle tolerance: 45.0

Bandwidth (lags): 6.4

Semivariogram/Covariances: Var1 & Var1

0.059391*Spherical(7.0366,2.8735,326.0)+0.06479



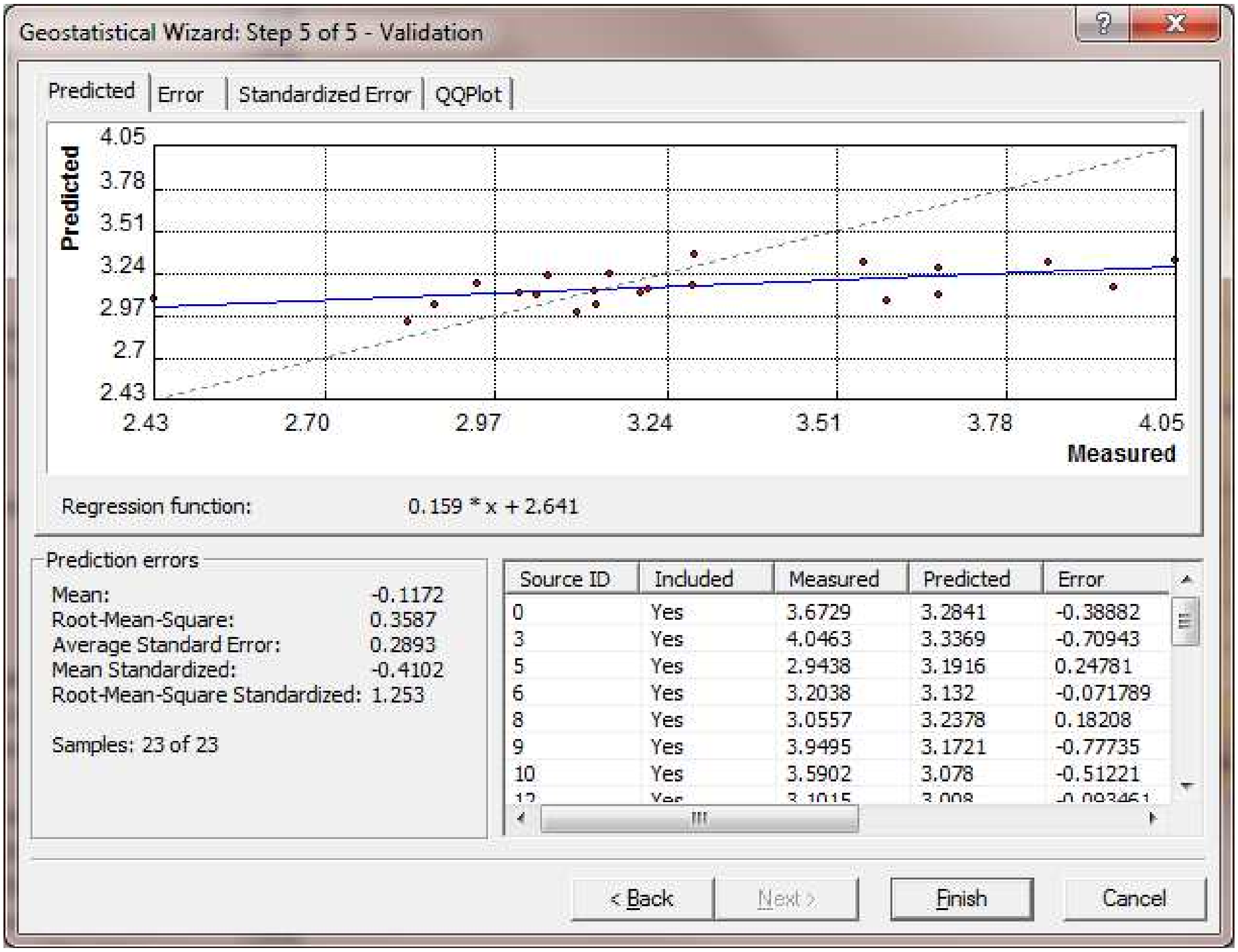
Regression function: 0.107 * x + 2.839

Prediction errors

Mean: 0.001614
Root-Mean-Square: 0.3101
Average Standard Error: 0.2931
Mean Standardized: 0.005346
Root-Mean-Square Standardized: 1.054

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	3.3256	3.4109	0.085279
2	Yes	3.4011	3.396	-0.0050744
34	Yes	3.7477	3.3081	-0.43956
60	Yes	3.5302	3.2238	-0.3064
43	Yes	3.2703	3.3742	0.10387
44	Yes	3.3309	3.3233	-0.0076473
63	Yes	3.0286	3.3046	0.276



Regression function: 0.159 * x + 2.641

Prediction errors

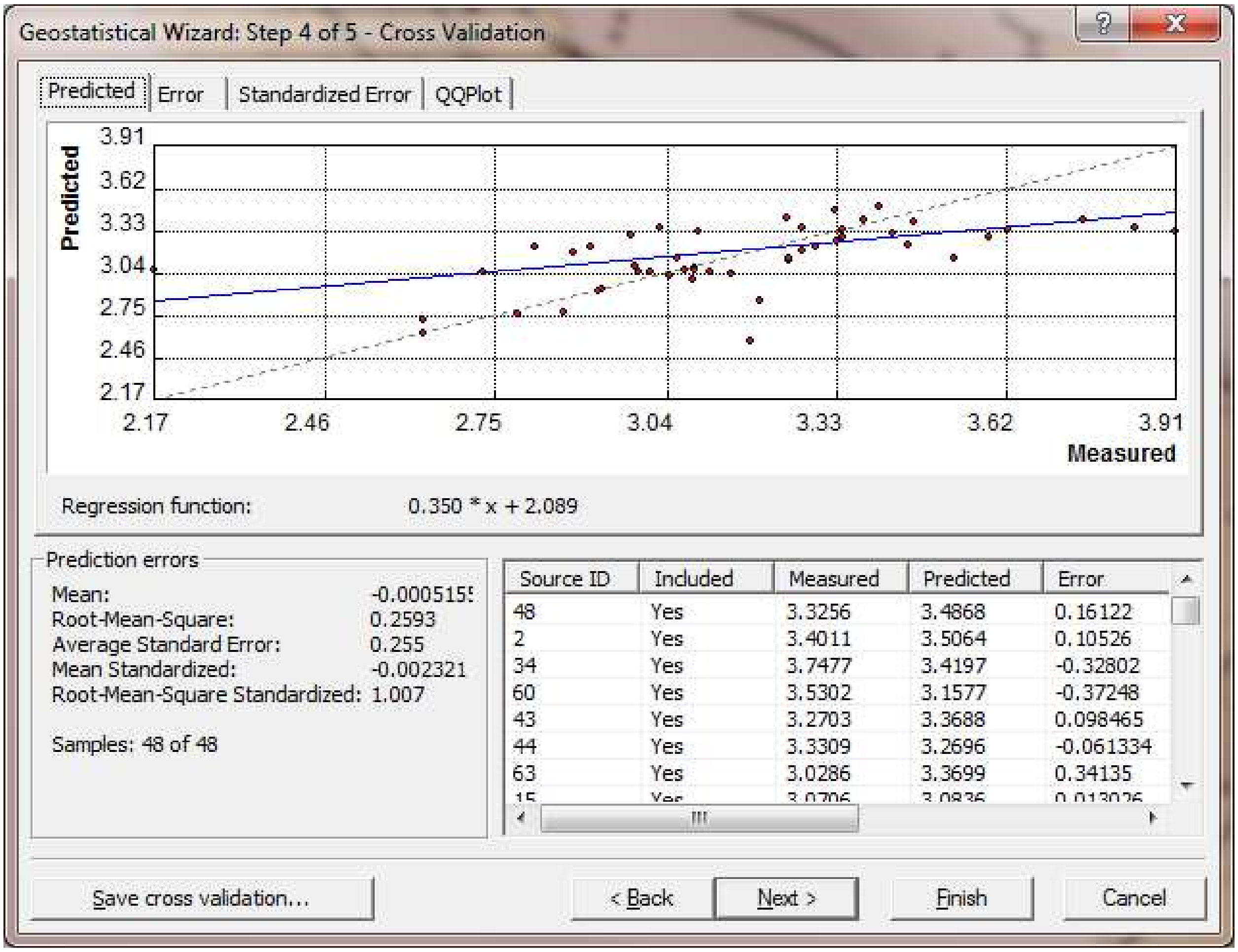
Mean: -0.1172
Root-Mean-Square: 0.3587
Average Standard Error: 0.2893
Mean Standardized: -0.4102
Root-Mean-Square Standardized: 1.253

Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	3.6729	3.2841	-0.38882
3	Yes	4.0463	3.3369	-0.70943
5	Yes	2.9438	3.1916	0.24781
6	Yes	3.2038	3.132	-0.071789
8	Yes	3.0557	3.2378	0.18208
9	Yes	3.9495	3.1721	-0.77735
10	Yes	3.5902	3.078	-0.51221
12	Yes	3.1015	3.008	-0.093461

Appendix E

5-yr, 2-hr: Kriging with No Nugget Effect



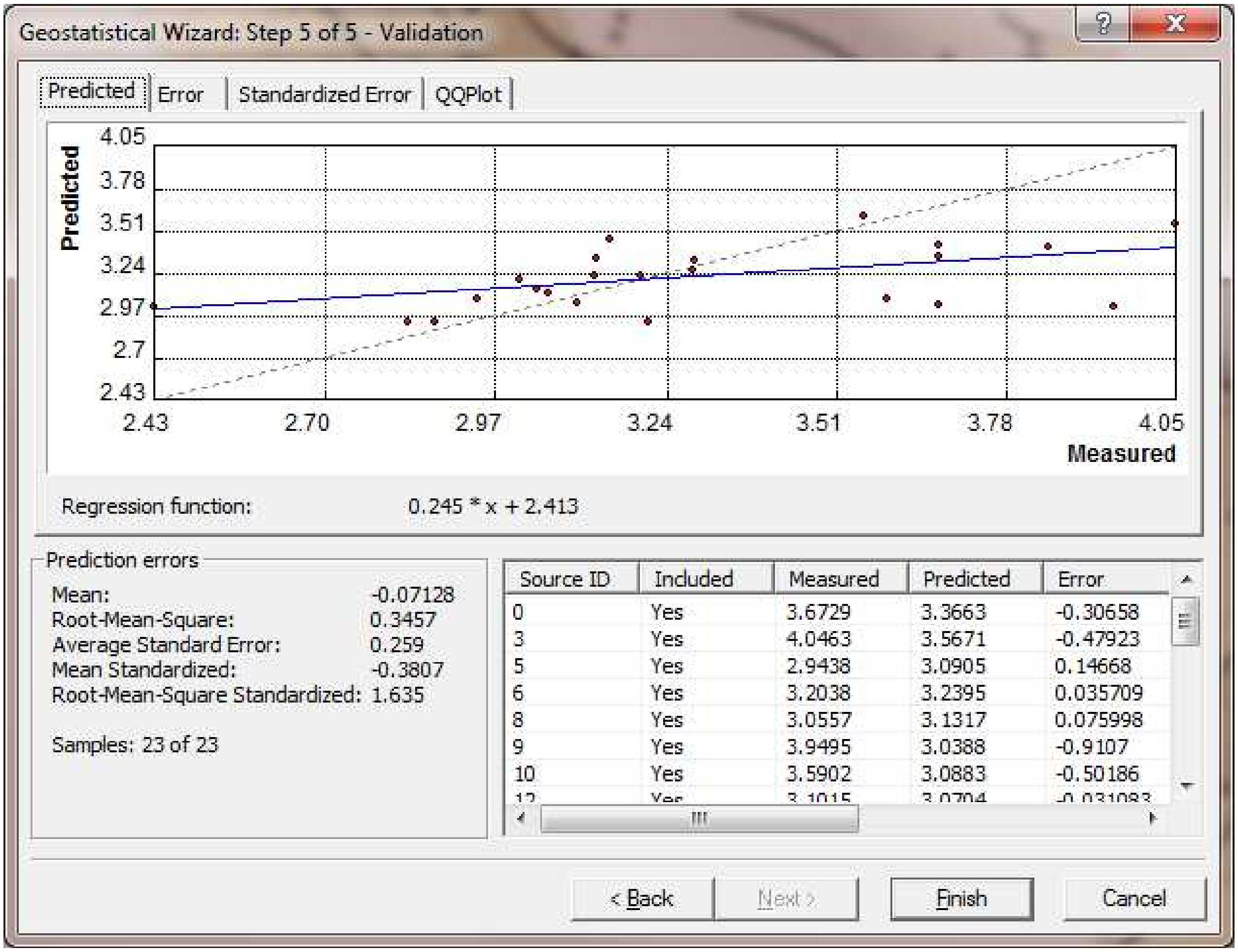
Regression function: 0.350 * x + 2.089

Prediction errors

Mean:	-0.000515
Root-Mean-Square:	0.2593
Average Standard Error:	0.255
Mean Standardized:	-0.002321
Root-Mean-Square Standardized:	1.007

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	3.3256	3.4868	0.16122
2	Yes	3.4011	3.5064	0.10526
34	Yes	3.7477	3.4197	-0.32802
60	Yes	3.5302	3.1577	-0.37248
43	Yes	3.2703	3.3688	0.098465
44	Yes	3.3309	3.2696	-0.061334
63	Yes	3.0286	3.3699	0.34135



Regression function: 0.245 * x + 2.413

Prediction errors

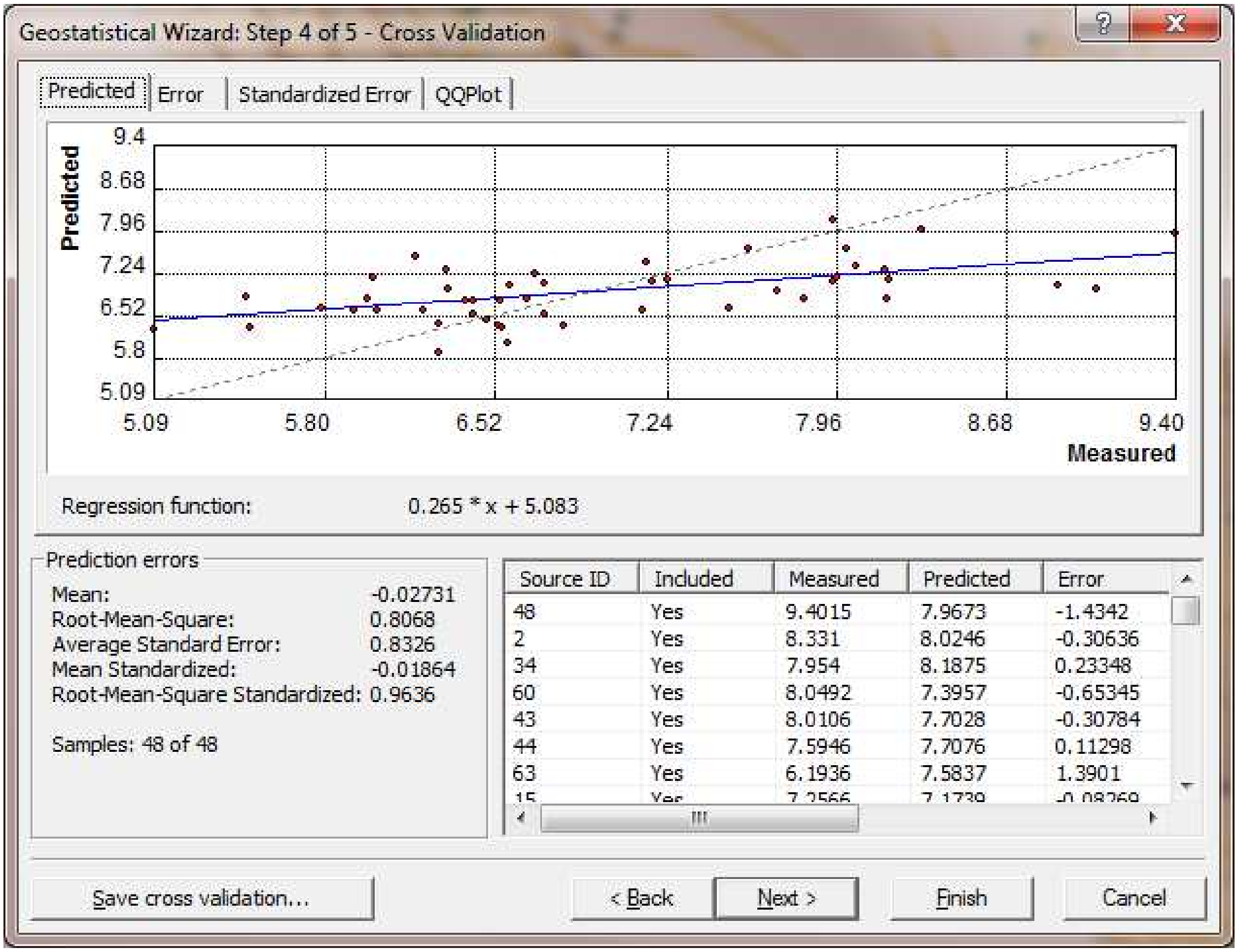
Mean: -0.07128
Root-Mean-Square: 0.3457
Average Standard Error: 0.259
Mean Standardized: -0.3807
Root-Mean-Square Standardized: 1.635

Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	3.6729	3.3663	-0.30658
3	Yes	4.0463	3.5671	-0.47923
5	Yes	2.9438	3.0905	0.14668
6	Yes	3.2038	3.2395	0.035709
8	Yes	3.0557	3.1317	0.075998
9	Yes	3.9495	3.0388	-0.9107
10	Yes	3.5902	3.0883	-0.50186
12	Yes	3.1015	3.0704	-0.031083

Appendix F

5-year, 72-hr: Kriging with Anisotropy



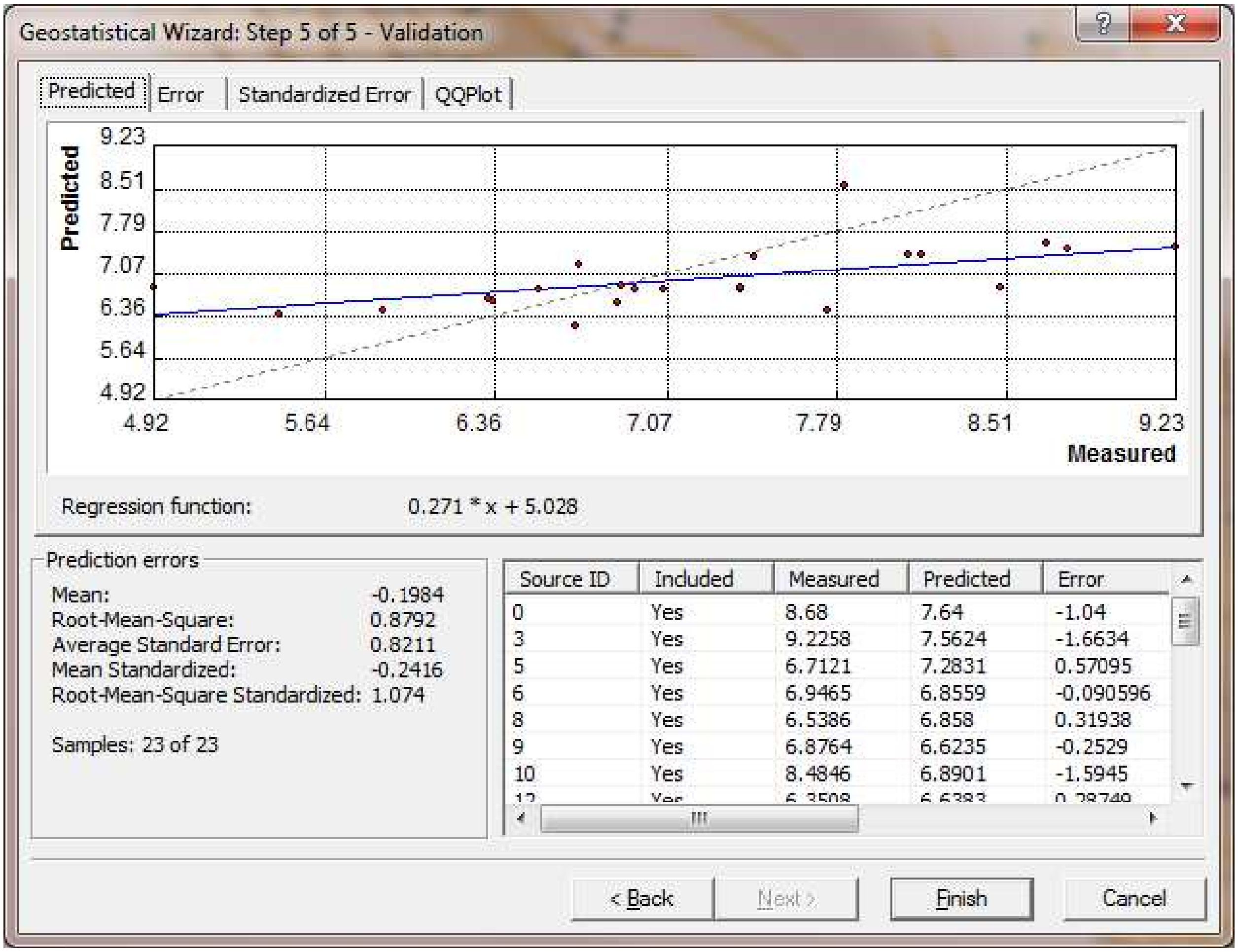
Regression function: 0.265 * x + 5.083

Prediction errors

Mean:	-0.02731
Root-Mean-Square:	0.8068
Average Standard Error:	0.8326
Mean Standardized:	-0.01864
Root-Mean-Square Standardized:	0.9636

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	9.4015	7.9673	-1.4342
2	Yes	8.331	8.0246	-0.30636
34	Yes	7.954	8.1875	0.23348
60	Yes	8.0492	7.3957	-0.65345
43	Yes	8.0106	7.7028	-0.30784
44	Yes	7.5946	7.7076	0.11298
63	Yes	6.1936	7.5837	1.3901
15	Yes	7.2566	7.1739	-0.08269



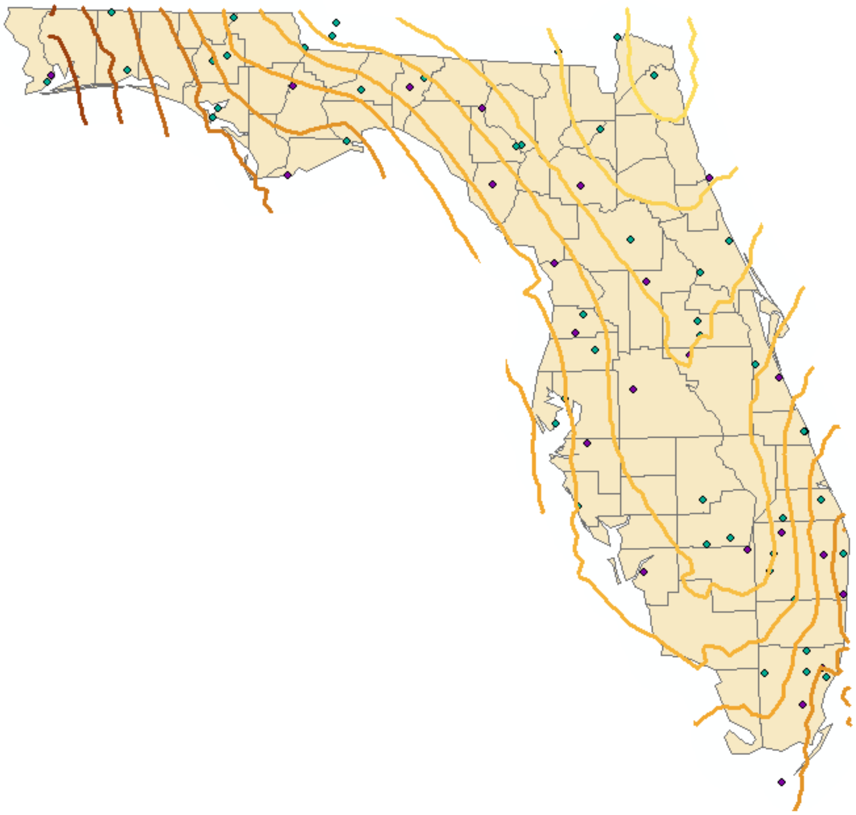
Regression function: 0.271 * x + 5.028

Prediction errors

Mean:	-0.1984
Root-Mean-Square:	0.8792
Average Standard Error:	0.8211
Mean Standardized:	-0.2416
Root-Mean-Square Standardized:	1.074

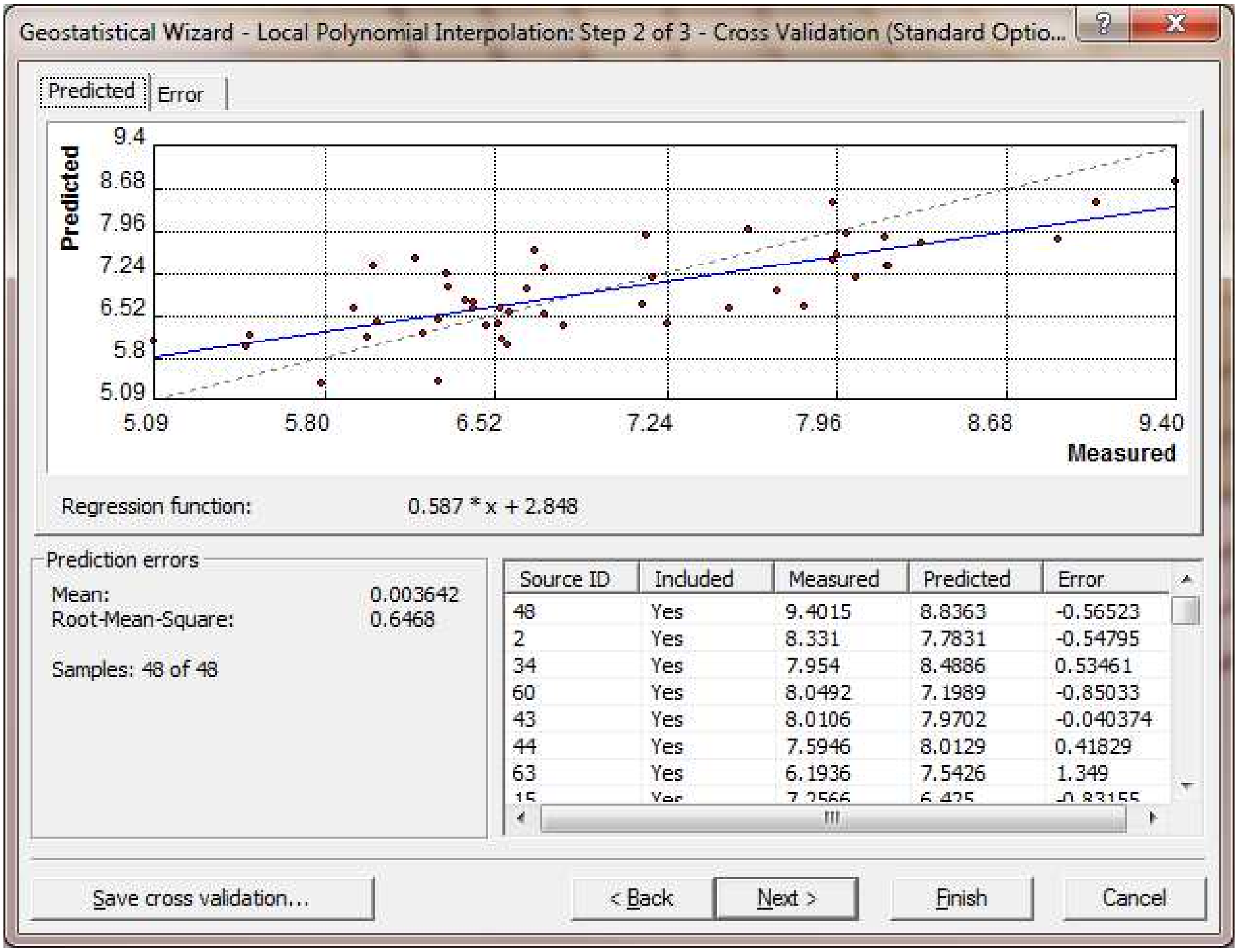
Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	8.68	7.64	-1.04
3	Yes	9.2258	7.5624	-1.6634
5	Yes	6.7121	7.2831	0.57095
6	Yes	6.9465	6.8559	-0.090596
8	Yes	6.5386	6.858	0.31938
9	Yes	6.8764	6.6235	-0.2529
10	Yes	8.4846	6.8901	-1.5945



Appendix G

5-year, 72-hr: Local Polynomial



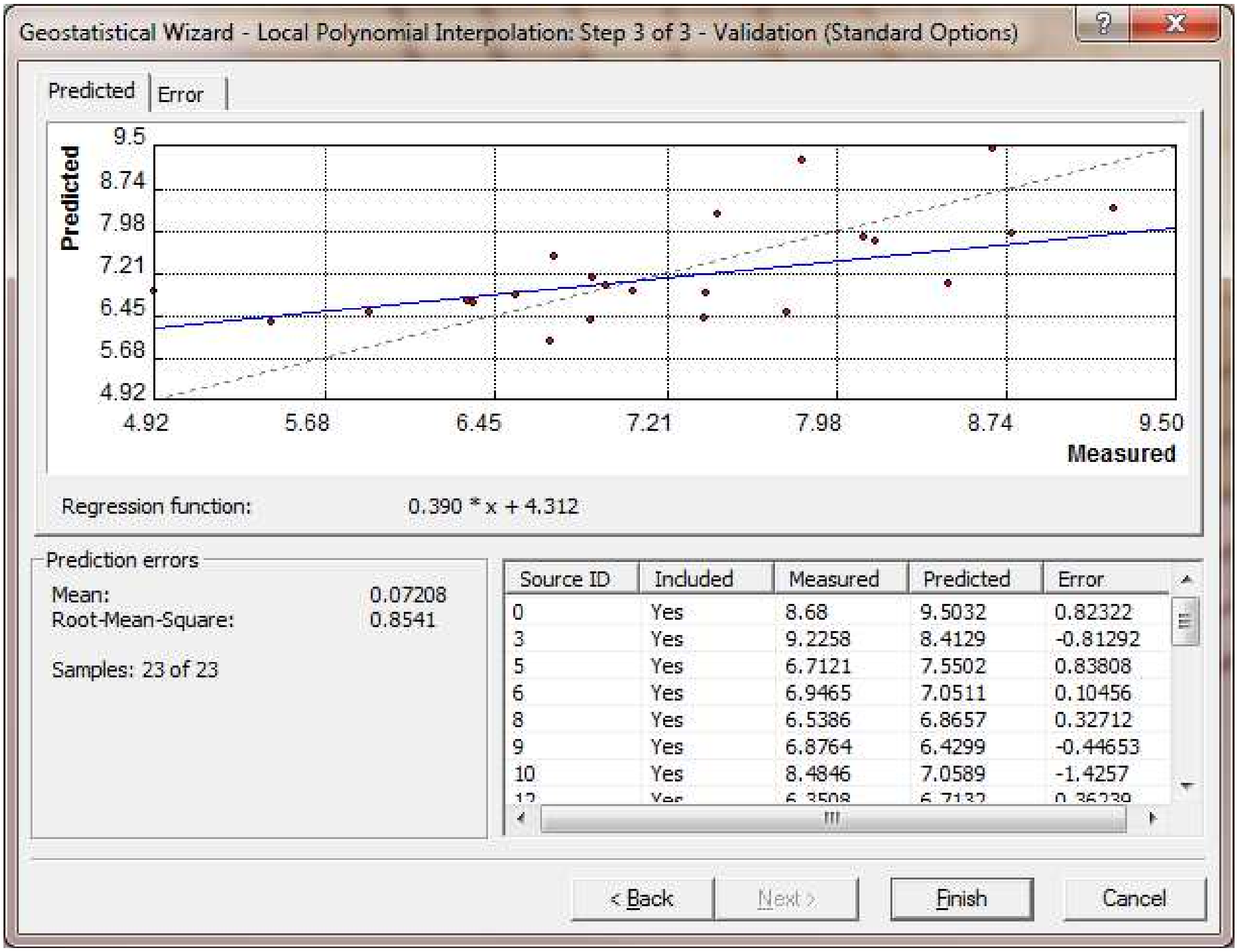
Regression function: 0.587 * x + 2.848

Prediction errors

Mean: 0.003642
Root-Mean-Square: 0.6468

Samples: 48 of 48

Source ID	Included	Measured	Predicted	Error
48	Yes	9.4015	8.8363	-0.56523
2	Yes	8.331	7.7831	-0.54795
34	Yes	7.954	8.4886	0.53461
60	Yes	8.0492	7.1989	-0.85033
43	Yes	8.0106	7.9702	-0.040374
44	Yes	7.5946	8.0129	0.41829
63	Yes	6.1936	7.5426	1.349
15	Yes	7.2566	6.425	-0.83155



Geostatistical Wizard - Local Polynomial Interpolation: Step 3 of 3 - Validation (Standard Options)

Regression function: 0.390 * x + 4.312

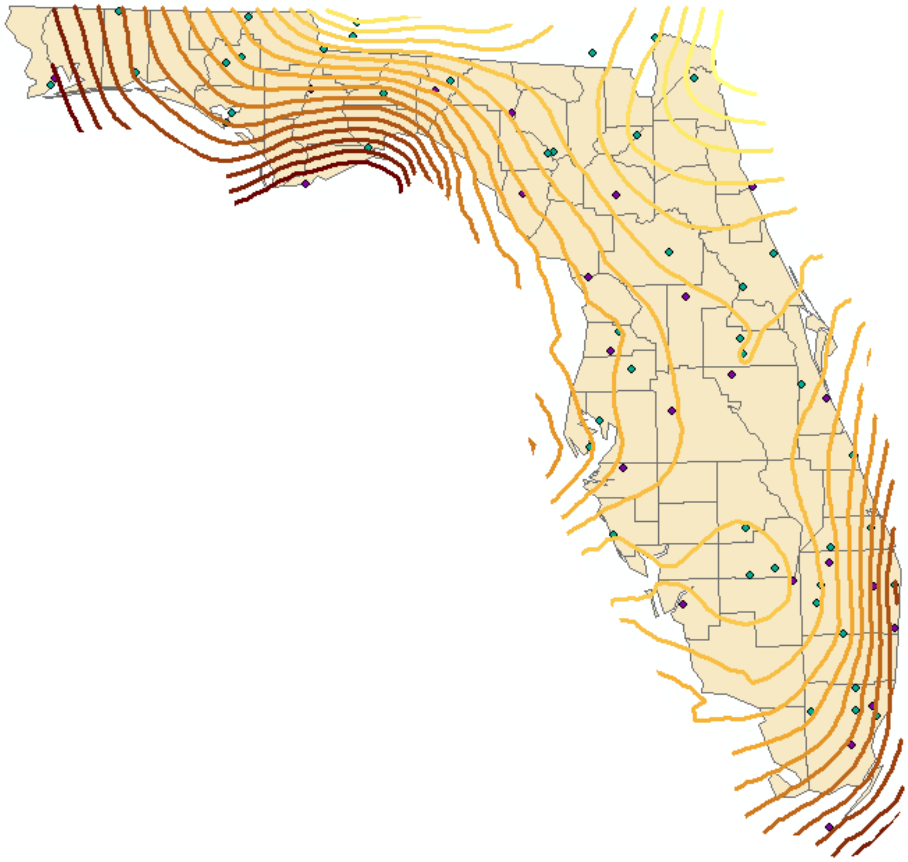
Prediction errors

Mean: 0.07208

Root-Mean-Square: 0.8541

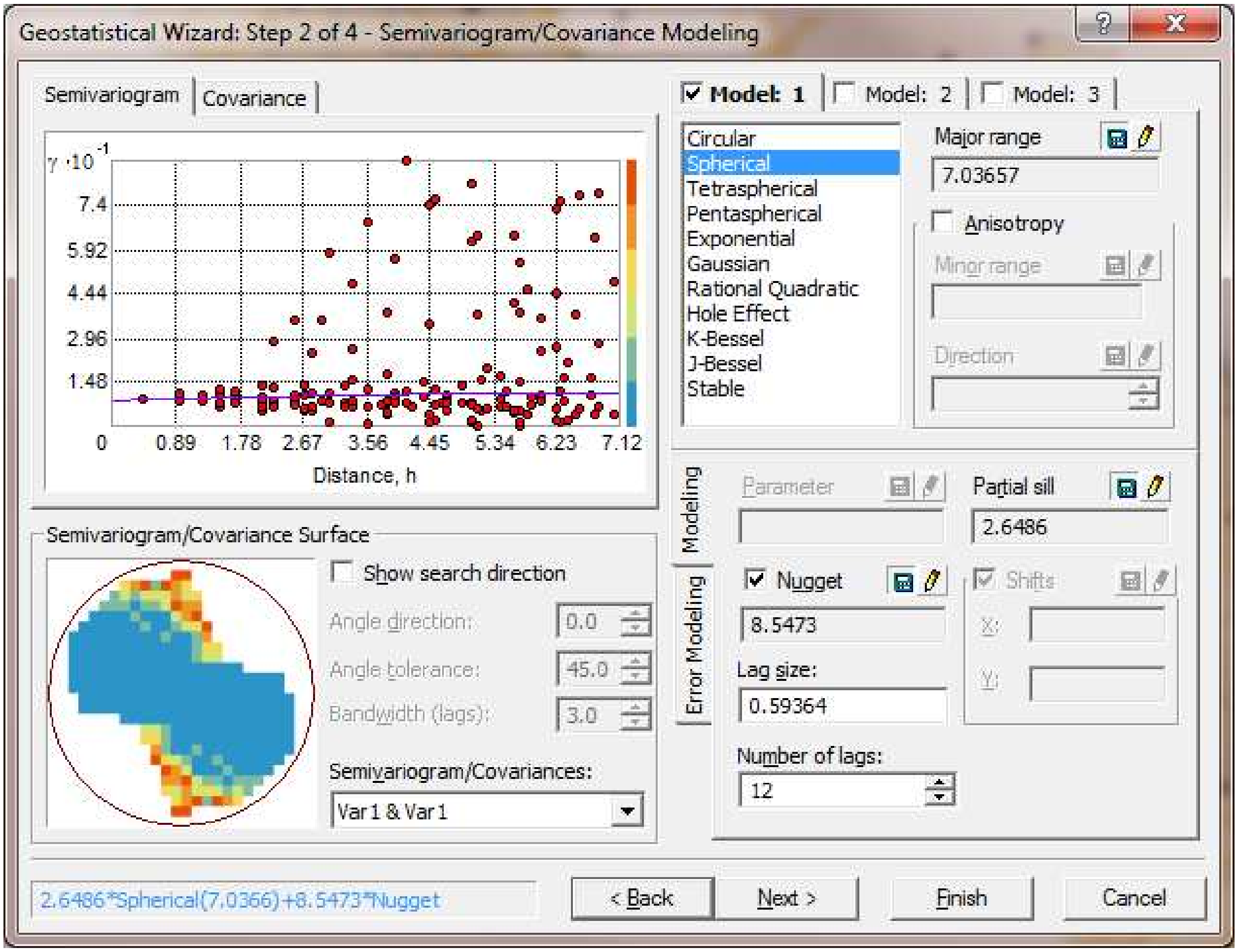
Samples: 23 of 23

Source ID	Included	Measured	Predicted	Error
0	Yes	8.68	9.5032	0.82322
3	Yes	9.2258	8.4129	-0.81292
5	Yes	6.7121	7.5502	0.83808
6	Yes	6.9465	7.0511	0.10456
8	Yes	6.5386	6.8657	0.32712
9	Yes	6.8764	6.4299	-0.44653
10	Yes	8.4846	7.0589	-1.4257



Appendix H

500-year, 24-hour: Ordinary Kriging, Default Options



Geostatistical Wizard: Step 2 of 4 - Semivariogram/Covariance Modeling

☑ Model: 1 ☐ Model: 2 ☐ Model: 3

Spherical

Major range: 7.03657

☐ Anisotropy

Partial sill: 2.6486

☑ Nugget: 8.5473

Lag size: 0.59364

Number of lags: 12

☐ Show search direction

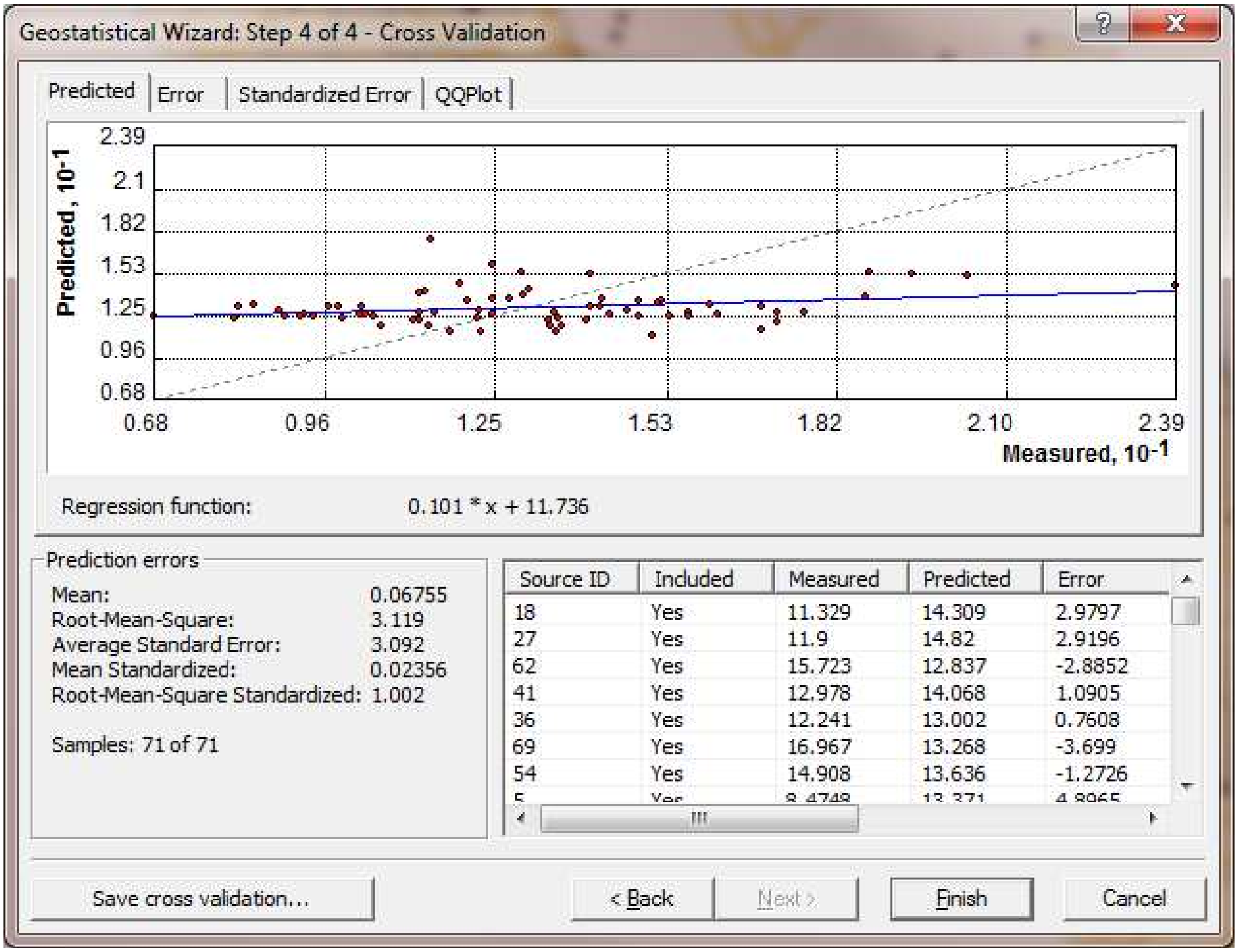
Angle direction: 0.0

Angle tolerance: 45.0

Bandwidth (lags): 3.0

Semivariogram/Covariances: Var1 & Var1

2.6486*Spherical(7.0366)+8.5473*Nugget



Regression function: 0.101 * x + 11.736

Prediction errors

Mean:	0.06755
Root-Mean-Square:	3.119
Average Standard Error:	3.092
Mean Standardized:	0.02356
Root-Mean-Square Standardized:	1.002

Samples: 71 of 71

Source ID	Included	Measured	Predicted	Error
18	Yes	11.329	14.309	2.9797
27	Yes	11.9	14.82	2.9196
62	Yes	15.723	12.837	-2.8852
41	Yes	12.978	14.068	1.0905
36	Yes	12.241	13.002	0.7608
69	Yes	16.967	13.268	-3.699
54	Yes	14.908	13.636	-1.2726