Interim Report (March 7, 2021)

Updating Statewide Extreme Rainfall

Florida Department of Business and Professional Regulation
Florida Building Commission

And

Sea Level Solutions Center (SLSC), Florida International University (FIU)

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Project Team & Strategy:

Project Investigators:

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2. Dr. Mike Sukop, Co-PI (modeling)
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3. Dr. Tiffany Troxler, Co-PI (Florida Building Code)
   Director of Science, Sea Level Solutions Center, FIU.
4. Dr. Anupama John, Post-doctoral Associate, Sea Level Solutions Center, FIU

Dr. Obeysekera, the Lead PI devised the strategy and provided technical guidance. Dr. John who received her Ph.D. from FIU was recruited as a Postdoctoral Associate to collect and analyze the large amount of data that have been collected.

<u>Acknowledgment</u>: Dr. Obeysekera, PI, is a collaborator in a project on rainfall extremes, funded by the South Florida Water Management District (SFWMD) and awarded to US Geological Survey (USGS). His participation in and input during weekly calls on that project has been beneficial to the current state-wide effort as it will ensure that, the results produced by SFWMD are consistent with the current products of this effort. We have made an extensive effort to use consistent analytical techniques and data and have received excellent collaboration from USGS. Also, SFWMD, in their project with USGS, included a task for FIU to facilitate an expert review panel. FIU SLSC appreciates receiving some of the raw data and computer codes that are being developed by USGS for the SFWMD.

Introduction

Communities across Florida are frequently at risk of flooding due to extreme rainfall. Recent research suggests that there is a potential for this risk to increase in the future although local and regional information on exact predictions is not readily available. Extreme rainfall data used in the Florida Building Code is quite dated (probably dating back to the 1970s) and needs to be updated and projected under future conditions. In this project, the Florida International University (FIU), Sea Level Solutions Center (SLSC) (henceforth FIU SLSC) shall extend the rainfall projections of the 2018 Miami-Dade pilot study titled "Potential Implications of Sea-Level Rise and Changing Rainfall in Florida Building Code for Communities in Florida using Miami-Dade County as a Case Study" to all communities across the State of Florida. This updated extreme rainfall information will be invaluable for all future infrastructure planning and design projects across all communities in Florida.

Scope of Work Progress

The scope of the project included several tasks. The ensuring subsections of this report provide brief descriptions of the progress made in each task. The task language is included for convenience.

Task 1. External Advisory Panel (EAP)

This task required the following actions (as included in the SOW):
FIU SLSC shall establish an advisory panel to seek input on specific needs of updated rainfall projections, methods of analysis, appropriate duration and return periods for engineering projects, and ideal outcomes. This panel will include 8-10 members from (a) academic institutions across the state of Florida who are members of the Florida Climate Institute; (b) Florida Water Management Districts; (c) Engineers from 2-3, selected county governments; (d) State agencies which will include, but are not limited to, the Florida Department of Environmental Protection (FDEP), and the Florida Department of Transportation (FDOT), (e) Engineering consulting firms; (f) Federal agencies including United States Geological Survey, and the United States Army Corps of Engineers. The advisory panel shall be established within two months of the project initiation. The advisory panel shall meet on at least two to three occasions over the duration of the project. Early in the project planning timeline, FIU SLSC shall consult, via teleconference meetings, with representatives of the External Advisory Panel to determine the most appropriate and useful durations and return periods for engineering projects.

Interim Progress

FIU SLSC has established a diverse External Advisory Panel (EAP) to seek guidance on rainfall datasets, analysis methods, desirable rainfall durations, and design return periods for engineering projects. As shown in Table 1, EAP includes about ten members who are highly qualified and experienced professionals from SFWMD, St. Johns River WMD, Tampa Bay Water, Academia (UF, UM), several state agencies (FDOT, and FDEP), Broward County, and three federal agencies (USGS, NOAA, USACE). Many in the EAP are also members of the panel established for the SFWMD rainfall project and through the interaction with those panel members, valuable input on data, analytical methods, model validation, and new approaches have been received.

All members listed in Table 1 have agreed to participate in the EAP. The FIU Team is scheduling a meeting with the entire EAP panel on a mutually agreeable date in April. During this meeting, we will present the technical approach for the state-wide assessment and details of the datasets that would be included in the analysis. The second and final meeting will be scheduled for late May when all the technical results will be available.

Table 1 External Advisory Panel (EAP) established for the FBC Rainfall Update Project

Panel Member	**Institution**	**Title**
Ana Carolina Coelho Maran, Ph.D., P.E.	South Florida Water Management District, (SFWMD)	District Resiliency Officer
Brian J. Soden, Ph.D.	The University of Miami (UM)	Professor
Chou Fang, Ph.D.	St. Johns River Water Management District	Technical Program Manager
Christopher D. Frans, Ph.D, P.E.	United States Army Corps of Engineers (USACE)	Civil Engineer
Jennifer Green, P.E.	Florida Department of Transportation (FDOT)	State Drainage Engineer
Jennifer Jurado, Ph.D.	Broward County	Chief Resiliency Officer
Johnna Infanti, Ph.D.	NOAA	Scientist
Michelle Miro, Ph.D.	RAND Corporation	Engineer
Stacey A. Archfield, Ph.D.	United States Geological Survey (USGS)	Research Hydrologist
Tirusew Asefa, Ph.D., P.E.	Tampa Bay Water	Planning & Decision Support Manager
Wendy D. Graham, Ph.D.	University of Florida (UF)	Professor and Director, Water Institute
Whitney Gray	Florida Department of Environmental Protection (FDEP)	Administrator, Florida Resilient Coastlines Program

Task 2. Development of Future Conditions Extreme Rainfall Data

FIU SLSC shall develop extreme precipitation projections for several durations and return periods relevant to the design of storm water systems for future planning horizons. Specifically, they shall include but are not limited to ~2030 (2010-2049), ~2060 (2040-2079), or ~2070 (2050-2089). This task shall include the following subtasks:

This required the following subtasks:

Task 2.1. Acquisition and Assessment of current datasets

- *FIU SLSC shall acquire and evaluate the best available rainfall data sets and studies available from (a) Florida Water Management Districts; (b) National Oceanographic and Atmospheric Administration's site specific observations and Atlas 14 Depth-Duration-Frequency (DDF) Data; (c) Florida Department of Transportation; (d) University of Florida's Institute of Food and Agricultural Sciences (IFAS) Florida Automated Network; and (e) Office of the State of Florida Climatologist.*
- *Because NOAA's Atlas 14 DDF database has good state-wide coverage, FIU SLSC shall focus on updating and projecting future DDF data for over 200 stations available from this database. FIU SLSC shall assemble a database of available rainfall data, including Atlas 14, and observed extreme rainfall up to Year 2019. For extreme value modeling (see methods below), FIU SLSC shall also develop a time series of annual and sub-annual extremes for various durations ranging from 1 hour to up to 10 days.*
- *In determining the most useful durations and return periods relevant to the design of storm water systems, FIU SLC shall consider the following regulations:*
    - *The requirements of the Department of Transportation's Rule 14-86.002, Florida Administrative Code, which states that in determining critical storm duration, typical durations up through and including the 10-day duration should be considered for closed basins and through the 3-day duration for basins with positive outlets, and*
    - *The requirements of Florida's water management districts which require 25-year return periods and 100-year return periods for design and permitting of storm water systems.*

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<u>Duration and Return Periods</u>:

Chapter 14-86 FAC defined a Critical Duration as follows: *"Critical Duration" means the length of time of a specific storm frequency which creates the largest volume or highest rate of net stormwater runoff (post-improvement runoff less pre-improvement runoff) for typical durations up through and including the 10-day duration for closed basins, i.e. without a positive outlet, and up through the 3-day duration for basins with positive outlets. The critical duration for a given storm frequency is determined by calculating the peak rate and volume of stormwater runoff for various storm durations and then comparing the pre-improvement and post-improvement conditions for each of the storm durations. The duration resulting in the highest peak rate or largest net total stormwater volume is the "critical duration" storm (volume is not applicable for basins with positive outlets).*

To meet the above requirement, the rainfall durations selected for updating extreme rainfall include 1-day, 3-days, 5-days, 7-days, and 10-days. These selected durations will be sufficient to meet the requirements of stormwater criteria typically used by state agencies such as FDOT and all the Water Management Districts.

Return periods selected for updating Depth-Duration curves include but are not limited to 5-year, 10-year, 25-year, 50-year, and 100-years.

Historical Rainfall

The following historical rainfall data sets were acquired for this project:

Station Data:
1. Annual maximum series of precipitation from NOAA Atlas 14 for durations from 5 minutes to 60 days and the Depth-Duration-Frequency Data available from PF Data Server-PFDS/HDSC/OWP (noaa.gov)
2. University of Florida Institute of Food and Agricultural Sciences (IFAS), Florida Automated Weather Network (FAWN) (https://fawn.ifas.ufl.edu/)
3. Rainfall data at rainfall stations in the state of Florida from the Climatologists Office at FSU (COAPS)

Gridded Data
4. PRISM data (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu)
5. South Florida Water Management District (SFWMD) daily gridded dataset

The historical data above are being used for evaluating the skills of the future climate model datasets with due consideration to differences in spatial resolution among the datasets.

NOAA Atlas 14 Data Set

NOAA Atlas 14 (NOAA 2013) contains estimates of precipitation depth-duration-frequency (DDF) curves along with associated 90% confidence intervals for the United States and territories at both weather stations and as a gridded product with 30 arc-second resolution (approx. 0.5 mi). Supplementary information available as part of this product includes the annual maximum series (AMS) data used in developing the DDF curves, analysis of the AMS seasonality and trends, and the temporal distribution of heavy precipitation. The results are published through the Precipitation Frequency Data Server (PFDS) at http://hdsc.nws.noaa.gov/hdsc/pfds. The AMS data is generally available up to the years 2011-2012, depending on the station. Volume 9 of NOAA Atlas 14 covers the Southeastern states including Florida.

AMS series have been downloaded from the PFDS for 242 weather stations in the State of Florida (Figure 1). Although data were available for over 450 stations, only 242 locations were selected based on the criteria that the record length should be sufficiently long to obtain reasonably accurate estimates of depth-duration-frequency using extreme value modeling. Periods of records at these stations can go back as far as 1840 and end in 2011-2012.

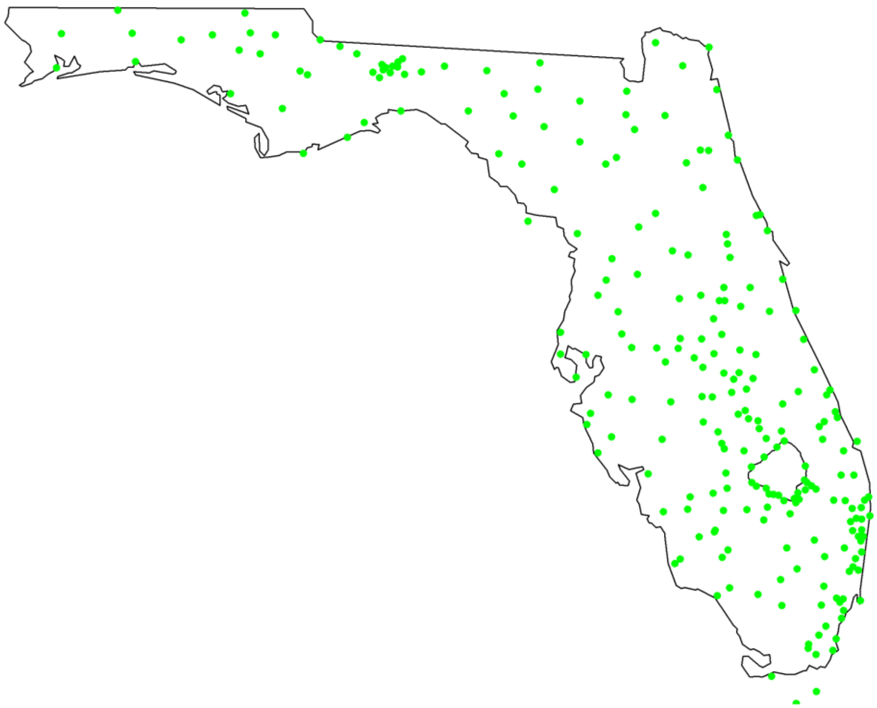


Figure 1. Locations of the 242 rainfall gage locations in Florida available from the NOAA Atlas 14 portal

The NOAA Atlas 14 project portal provides the DDF data for all the stations in Florida. These official Atlas 14 DDF curves for the Southeastern region have been developed by fitting a Generalized Extreme Value (GEV) distribution to the extremes (*unconstrained* AMS) for each duration of interest independently (Irizarry et al.2017). Regional frequency analysis (RFA), which uses data from nearby stations that are expected to have similar frequency distributions, was used to obtain regional estimates of L-moment ratios. Regional L-moment ratios for the region of interest (ROI) were then used to estimate higher-order L-moments at the target station for that particular duration. The parameters of the GEV distribution were then estimated from the at-station average L-moments for each duration. As a final step, the GEV fits were smoothed across durations to improve the shape of the DDF curves. An example of a typical DDF curve for a station in the state of Florida is shown in Figure 2. Many other examples of the DDF curves are shown in Appendix I.

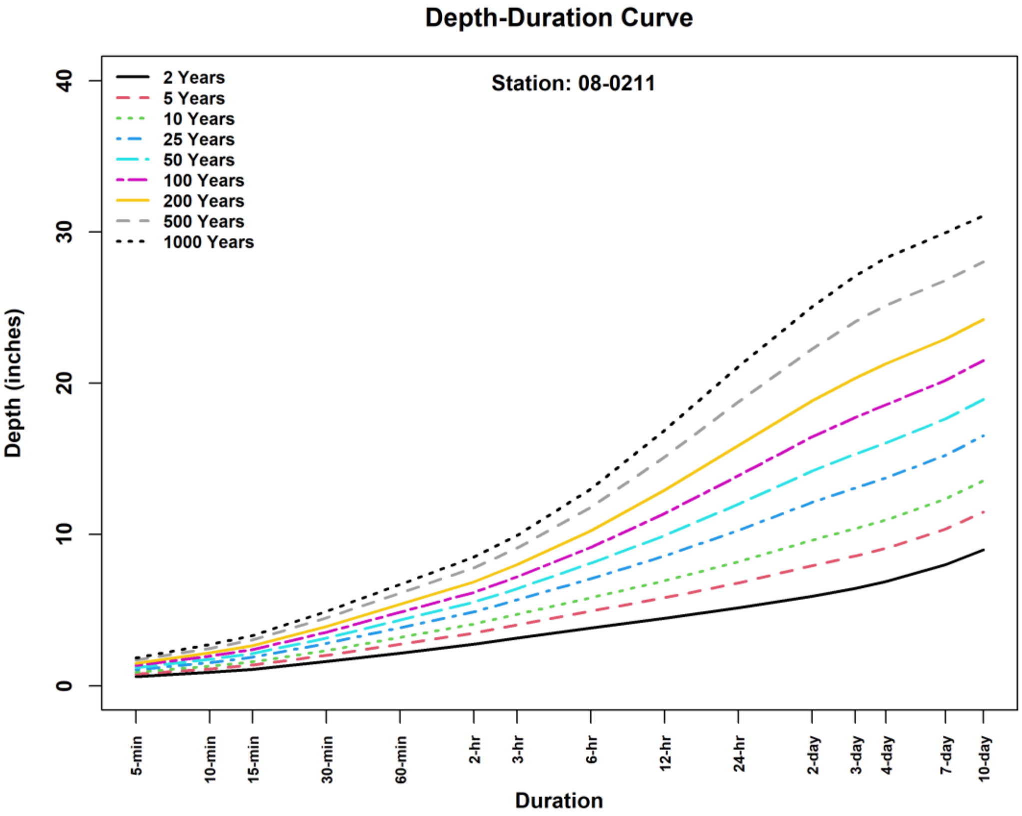


Figure 2 Official Atlas 14 DDF Curves at the Station 08-0211. Legend entries indicate the return period corresponding to the DDF curves.

The DDF curves published by NOAA (2013) are generally accepted as the best available information on rainfall depth-duration-frequency data for Florida and many agencies are beginning to adopt this data for planning purposes. For this project, we assume that the DDF curves available for the 242 stations across the state of Florida represent the best available historical data on rainfall depth, duration, and frequency information. As explained below, our approach will focus on adjusting these curves under future conditions representing climate change. As specified in the Scope of Work, at least two future periods (e.g. ~2050, and ~2070) will be considered.

University of Florida's IFAS FAWN rainfall data

The University of Florida's Institute of Food and Agricultural Sciences (IFAS) Florida Automated Weather Network (FAWN) provides near-real-time weather information directed towards agricultural users throughout the state of Florida (https://fawn.ifas.ufl.edu/) (Figure 3). Historical rainfall, precipitation, and other weather data are available for download at timesteps ranging from 15 minutes to daily, at https://fawn.ifas.ufl.edu/data/fawnpub/. FAWN datasets corresponding to 15-minute intervals have been downloaded from the above site. This data is available from 1997 to 2020.

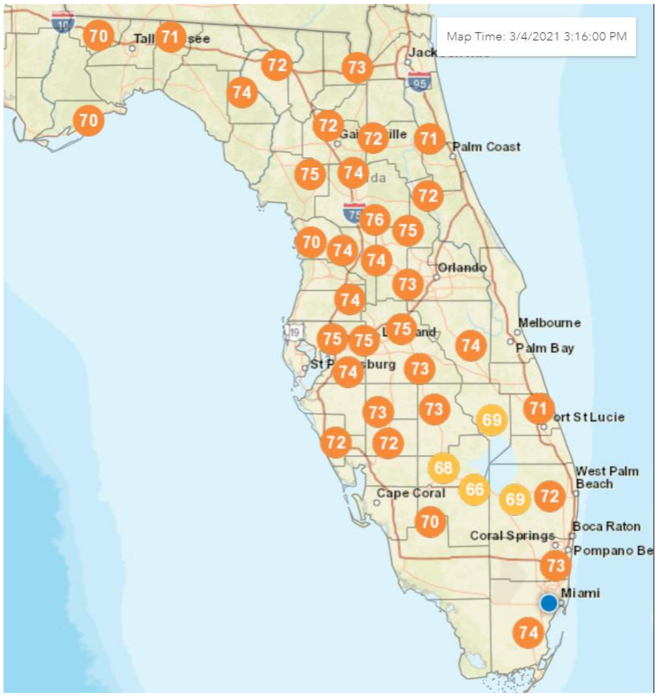


Figure 3 Locations of UF's FAWN data

PRISM Data Set

PRISM stands for Parameter-elevation Regressions on Independent Slopes Model (Daly et al. 2008). PRISM is a set of monthly, yearly, and single-event gridded data products of mean temperature and precipitation, max/min temperatures, and dewpoints, primarily for the United States (PRISM High-Resolution Spatial Climate Data for the United States: Max/min temp, dewpoint, precipitation | NCAR - Climate Data Guide (ucar.edu). In-situ point measurements are ingested into the PRISM statistical mapping system and it uses a weighted regression scheme to account for complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other factors. Climatologies (normals) are available at 30-arcsec (800 meters) and monthly data are available at 2.5-arcmin (4 km) resolution.

For this project, we have acquired the daily, gridded, PRISM data for the period 10/1/1981 through 12/31/2005. This data will be used for evaluating the skills of the climate models. Because it has a high spatial resolution (4 km), its gridded-rainfall should be representative of the rainfall observed at the nearest Atlas 14 station (see map in Figure 4).

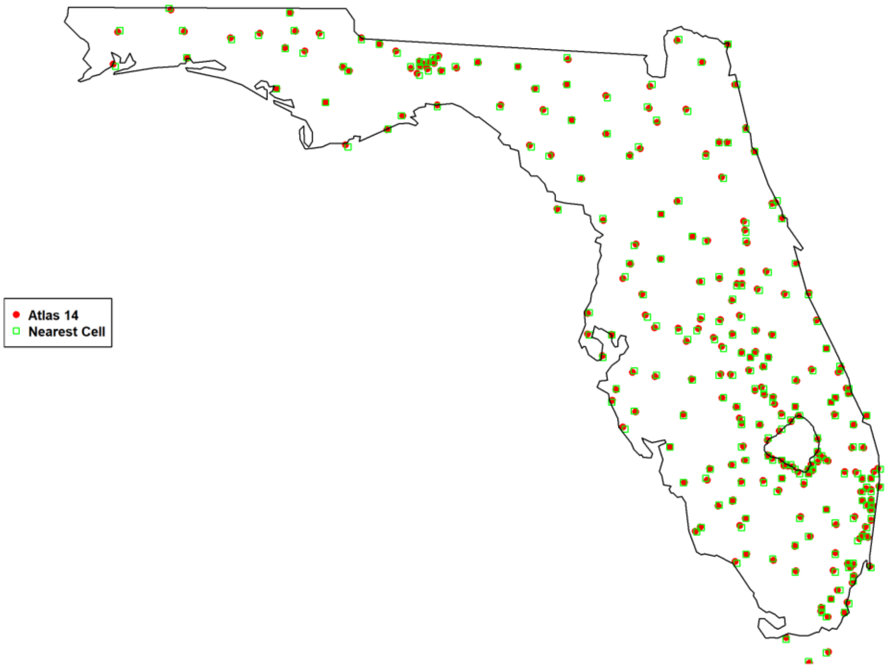


Figure 4. Atlas 14 rainfall stations and the nearest 4-km cell of the PRISM data set.

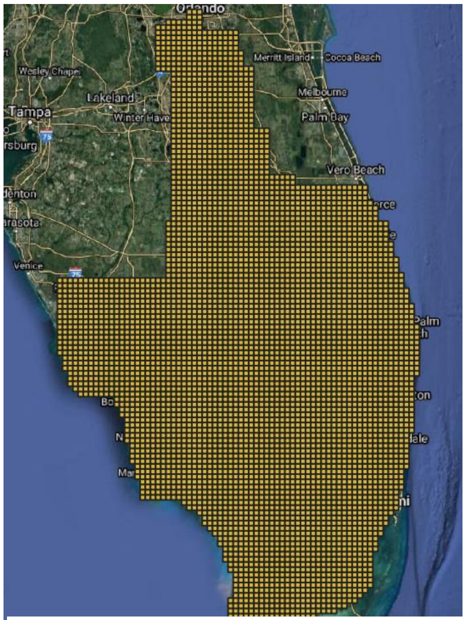


Figure 5 Spatial extent of the SFWMD's 2 mile x 2 mile, daily rainfall grid

SFWMD Data Set

This daily, gridded data set is used as the primary input to SFWMD's premier regional hydrologic simulation model, SFWMM. The grid which covers the SFWMD's boundary in south Florida has a cell size of 2 mile x 2 miles and includes daily snapshots of rainfall over the region since 1914 (Figure 5). Records of hundreds of rainfall stations, with adequate quality control checks, have been used to estimate the gridded rainfall using a TIN triangular plane for interpolation. The model uses the period of record of simulation from 1965 to 2015 and the density of rainfall stations during this period is high compared to the earlier years and therefore the Spatio-temporal pattern of rainfall for this period is considered to be accurate. This data set has been acquired for the project as one of the historical estimates of rainfall available for validation of climate models. Although this data set covers only the southern half of the state of Florida, it is considered to be accurate and useful for the current research.

Task 2.2. Acquisition and assessment of Climate Model Data for Future Periods

- *Modifications of the Depth-Duration-Frequency curves for future conditions require the use of the climate model data available for Florida. This subtask shall include the following:*
    - *FIU SLSC shall obtain available statistically and dynamically downscaled precipitation data for the State of Florida. The downscaled data shall include but is not limited to: (a) downscaled data from the US Bureau of Reclamation's BCCA (Bias-Corrected Constructed Analogues); (b) University of California-San Diego's LOCA (Localized Constructed Analogues) products; (c) World Climate Research Program's North America CORDEX (Coordinated Regional Climate Downscaling Experiment, with appropriate area reduction factors) product; and (d) Bias Corrected and Stochastic Analog (BCSA) dataset developed by the University of Florida for Tampa Bay Water. Periods of interest for analysis shall include the historical period (1950-2019) and at least two future periods centered in ~2030, ~2060, or ~2070.*
    - *FIU SLSC shall assess the NOAA Atlas 14 DDF data (developed using observations only up to 2012) to determine if additional data up to 2019 will result in significant changes to its reported DDF curves. Depending on this assessment, FIU SLSC shall update Atlas 14 DDF curves.*
    - *FIU SLSC shall extract climate model output data at grids nearest to each of the Atlas 14 locations.*

Interim Progress

Future Rainfall

Global climate models (GCMs) can provide prediction information on the changes in meteorology at spatial and temporal scales. However, from an impact modeling perspective, their spatial resolution is too coarse to capture the locally varying landscapes which have steep gradients in meteorological variables and circulation patterns (Abatzoglu & Brown, 2012). In complex terrains, even the finest GCM resolution of 100 x 100km tends to aggregate multiple landscapes into one grid cell. Downscaling techniques are employed to produce regional climate models (RCMs) covering smaller areas but providing projections at higher spatial resolutions required to capture localized extreme events. To date, the downscaling products can be categorized into two categories:

1. Statistical Downscaling
2. Dynamical Downscaling

As the name suggests, statistical downscaling employs statistical methods to project coarser GCM model output to a higher resolution (typically of the order 10 km to 25 km) on the land surface. Several downscaled data sets have a national coverage developed by using this technique. Dynamical downscaling is more physically based as it uses the higher-resolution, RCMs which use the GCMs for their boundary conditions. For this project we have acquired the following downscaled datasets:

1. Coordinated Regional Downscaling Experiment (CORDEX), dynamically-downscaled
2. Localized Constructed Analogues (LOCA), statistically downscaled
3. Multivariate Adaptive Constructed Analogs (MACA), statistically downscaled

It is important to recognize that these data products do not provide absolute projections of future rainfall. They represent plausible realizations of future rainfall due to selected scenarios of climate change as characterized by alternative Greenhouse Gas (GHGs) emission scenarios of the atmosphere and the land-use trajectories. The Intergovernmental Panel of Climate Change (IPCC), in their latest assessment report, has defined four scenarios known as Representative Concentration Pathways (RCPs) and they are typically identified as RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The number in the RCPs is the end-of-century radiative forcing (reflecting greenhouse gas effect in the atmosphere) in the year 2100. The lowest concentration scenario is RCP2.6, recognized as the pathway necessary to keep the global temperature increase below 2°C (van Vuuren et al 2011). RCP8.5 is the highest scenario which assumes a strong dependence on fossil fuels. The remaining scenarios RCP4.5 and RCP6.0 lie between these two extremes. In this project, we employ datasets corresponding to RCP4.5 and RCP8.5 representing a medium and the highest concentration pathways.

A summary of the data sets used for this project is presented in Table 2. The names of the GCMs used for different realizations of the climate models are shown in the last column of Table 2.

Table 2 Future rainfall data sets acquired for the project

Dataset	**Scenarios**	**Global Climate Models (GCM)**	
Coordinated Regional Downscaling Experiment (CORDEX)	Historical	CanESM2.CanRCM4,	GFDL-ESM2M.WRF
	RCP85	CanESM2.CRCM5-UQAM	HadGEM2-ES.RegCM4
		CanESM2.RCA4	HadGEM2-ES.WRF
		EC-EARTH.HIRHAM5	MPI-ESM-LR.CRCM5-UQAM
		EC-EARTH.RCA4	MPI-ESM-LR.RegCM4
		GEMatm-Can.CRCM5-UQAM	MPI-ESM-LR.WRF
		GEMatm-MPI.CRCM5-UQAM	MPI-ESM-MR.CRCM5-UQAM
		GFDL-ESM2M.RegCM4	
	RCP45	CanESM2.CanRCM4	EC-EARTH.HIRHAM5
		CanESM2.CRCM5-UQAM	EC-EARTH.RCA4
		CanESM2.RCA4	MPI-ESM-LR.CRCM5-UQAM
Localized Constructed Analogues (LOCA)	Historical	ACCESS1-0	GFDL-ESM2M
	RCP45	ACCESS1-3	GISS-E2-H
	RCP85	bcc-csm1-1-m	GISS-E2-R
		CanESM2	HadGEM2-AO
		CCSM4	HadGEM2-CC
		CESM1-BGC	HadGEM2-ES
		CESM1-CAM5	IPSL-CM5A-LR
		CMCC-CM	IPSL-CM5A-MR

		CMCC-CMS	MIROC5
		CNRM-CM5	MIROC-ESM
		CSIRO-Mk3-6-0	MIROC-ESM-CHEM
		EC-EARTH	MPI-ESM-LR
		FGOALS-g2	MPI-ESM-MR
		GFDL-CM3	MRI-CGCM3
		GFDL-ESM2G	NorESM1-M
Multivariate Adaptive Constructed Analogs (MACA)	Historical	bcc-csm1-1	HadGEM2-ES365
	RCP45	bcc-csm1-1-m	inmcm4
	RCP85	BNU-ESM	IPSL-CM5A-LR
		CanESM2	IPSL-CM5A-MR
		CCSM4	IPSL-CM5B-LR
		CNRM-CM5	MIROC5
		CSIRO-Mk3-6-0	MIROC-ESM
		GFDL-ESM2G	MIROC-ESM-CHEM
		GFDL-ESM2M	MRI-CGCM3
		HadGEM2-CC365	NorESM1-M

Coordinated Regional Climate Downscaling Experiment (CORDEX)

The Coordinated Regional Climate Downscaling Experiment (CORDEX) uses boundary conditions from the GCM simulations from CMIP5 as boundary conditions to derive outputs from RCMs. Most of North America is available at North American CORDEX (NA-CORDEX) at spatial resolutions of 0.22°(25km) or 0.44°(50km) from 1950-2100 under different RCPs (Table 3).

Table 3. The spatial resolution of CORDEX dataset by climate models and RCPs

	RegCM4	**WRF**	**CRCM5-OUR**	**CRCM5-UQAM**	**CanRCM4**	**RCA4**	**HIRHAM5**	
ERA-Int	50km	50km	0.22°	0.44°	0.44°	0.44°	0.44°	RCP
	25km	25km		0.22°	0.22°			
HadGEM2-ES	50km	50km						8.5
	25km	25km						
CanESM2				0.44°	0.44°	0.44°		4.5
					0.22°			
			0.22°	0.44°	0.44°	0.44°		8.5
				0.22°	0.22°			
GEMatm-Can				0.44°				8.5
				0.22°				
MPI-ESM-LR				0.44°				4.5
	50km	50km	0.22°	0.22°				8.5
	25km	25km		0.44°				
MPI-ESM-MR				0.44°				8.5
				0.22°				

GEMatm-MPI				0.44° 0.22°					8.5
EC-EARTH						0.44°			2.6
						0.44°	0.44°		4.5
						0.44°	0.44°		8.5
GFDL-ESM2M	50km 25km	50km 25km	0.22°						8.5

An example plot of a CORDEX model grid, the Atlas 14 station locations, and the nearest CORDEX cell of those stations are shown in Figure 6.

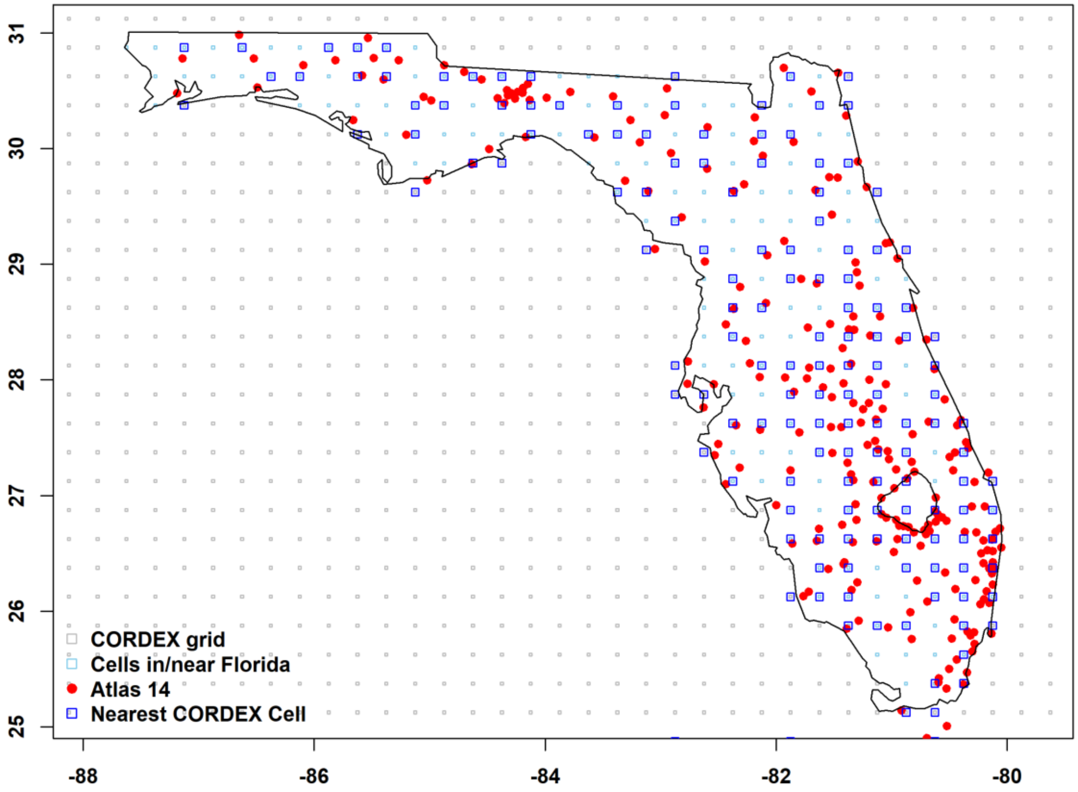


Figure 6.Example CORDEX grid in the region, its cell in and near Florida, Atlas 14 locations, and the nearest CORDEX cells

Localized Constructed Analogues (LOCA)

The Localized Constructed Analogues (LOCA) method was developed to address the issues that techniques like MACA encounter (next section) when using a weighted average of analog days. LOCA constructs the downscaled field using a single analog day (from a pool of 30 days) that best matches weather in the local region around the point being considered. The best matching observed day is scaled to match the amplitude of the modeled day being downscaled (additively for precipitation) and produce the final downscaled value (Pierce et al., 2014). In addition to the general limitations of statistical downscaling, LOCA is limited by the assumption that the relationship between local and area-averaged climate fields will not change in the future climate (Pierce et al., 2014).

The LOCA dataset covers North America from central Mexico through southern Canada at a 1/16th degree spatial resolution. The list of downloaded GCMs for scenarios for the LOCA model is presented in Table 2. An example of the LOCA grid, Atlas 14 stations, and the nearest LOCA cells are shown in Figure 7.

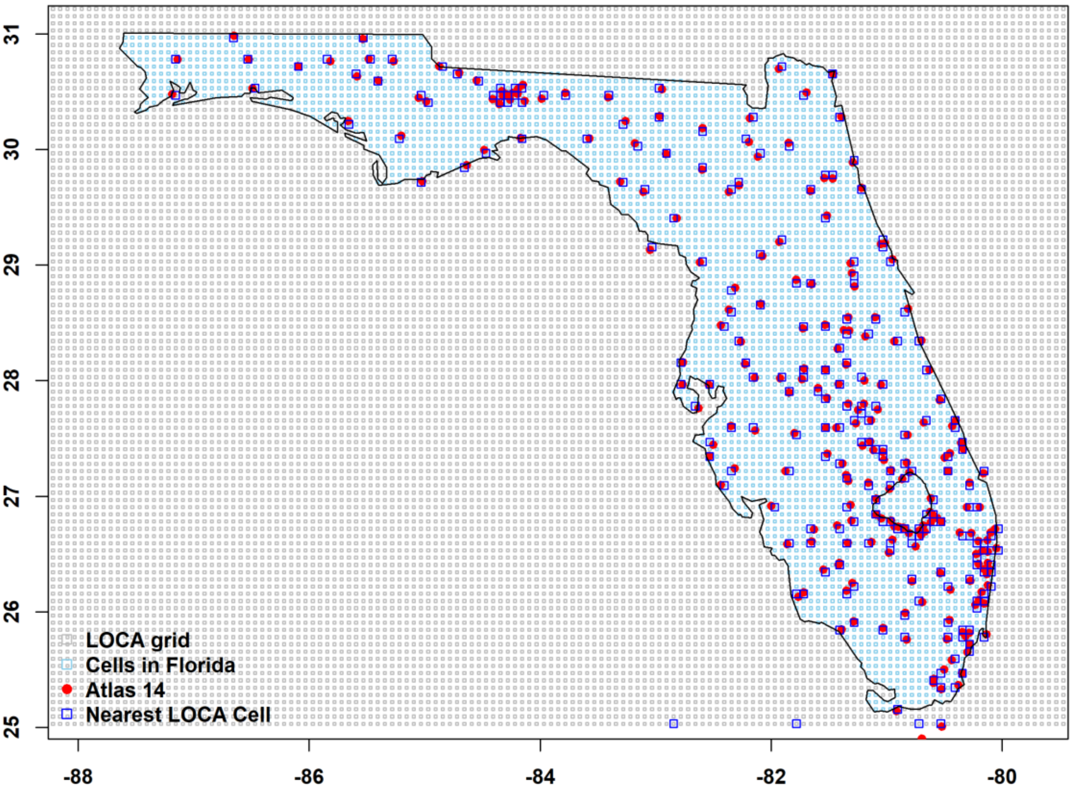


Figure 7. Example LOCA grid, the Atlast 14 stations, and the nearest LOCA cells

Multivariate Adaptive Constructed Analogs (MACA)

The Multivariate Adaptive Constructed Analogs (MACA) method uses a multi-step process for developing fine-scale spatial patterns using historical observations. The technique uses 20 CMIP5 GCMs (see downloaded datasets in Table) providing daily meteorological variables for historical (1950-2011), RCP4.5 and RCP8.5 scenarios which are bias-corrected using training data from two datasets: 1) Livneh et al. (2013) daily dataset from 1950-2011 with a 6km (1/16th degree) spatial resolution; and 2) gridMet daily dataset from 1979-2012 with a 4 km (1/24th degree) spatial resolution. The MACA method identifies the 30 best matching analog days in the historical occurrence and combines these analog days, using a weighted average method, to reproduce the target pattern (Abatzoglu & Brown, 2012, Pierce et al., 2014). The datasets cover the contiguous United States . The downloaded datasets are presented in Table 2.

Unlike direct interpolation methods, the MACA technique is advantageous as it uses historical observations to produce meteorological data with a high spatial resolution (needed by impact studies) while preserving the time-scales and patterns simulated by GCMs. The obvious limitation is that any imperfections in the training data are carried over while bias correcting. Also, GCM signals may be preserved for the period of the bias-correction but not at longer timescales (Abatzoglu & Brown, 2012). Since multiple analogs are averaged together to construct the downscaled field, a tendency to dampen the extremes increases the spatial coherence of downscaled fields produces precipitation, where none exists, is also observed (Pierce et al., 2014).

Figure 8 shows an example of the MACA grid, the Atlas 14 stations, and the nearest MACA grid cells.

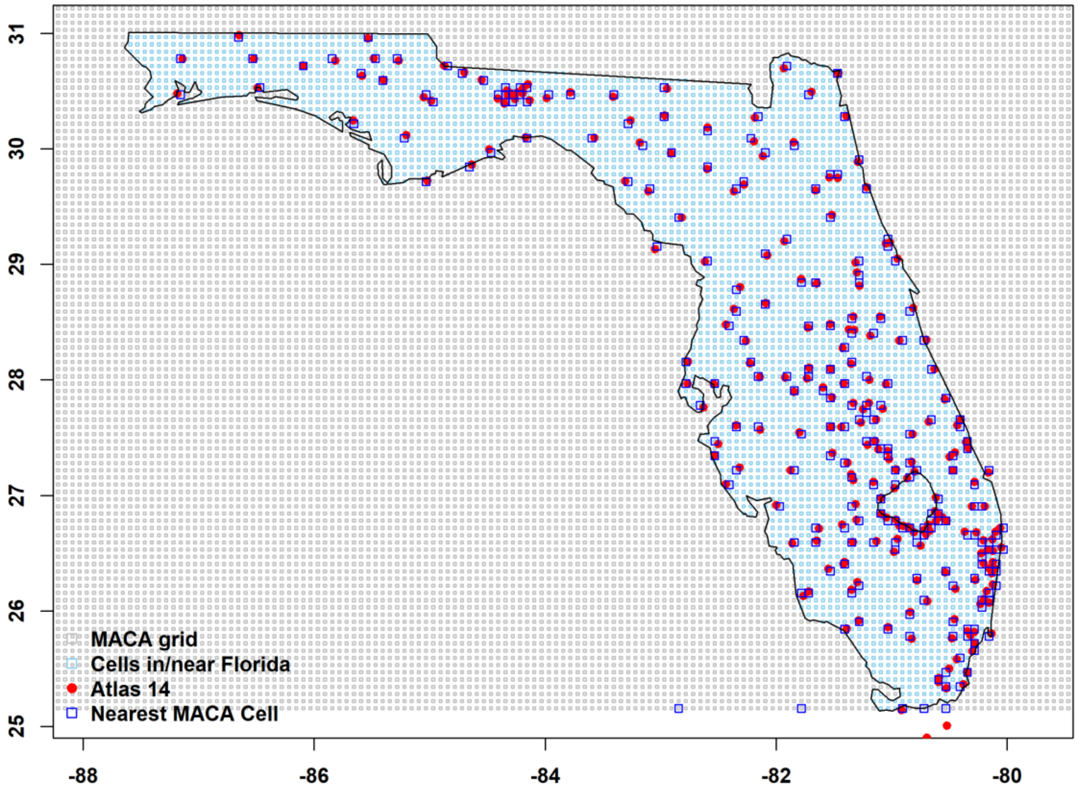


Figure 8. Example MACA grid, the Atlas 14 stations, and the nearest MACA cells

Task 2.3 Extreme Rainfall Modeling

- *FIU SLSC shall develop DDF curves at each of the NOAA Atlas 14 stations within the State of Florida for a range of durations (at a minimum, 1 day up to 10 days), and return periods (e.g. 5-, 10-, 25-, 50-, and 100-years), for historical periods (up to 2019), current model base period (1950-2019) and two future periods (e.g. 2030-2070 and 2060-2100). For future DDF curves, two Representative Concentration Pathways (future greenhouse gas scenarios), RCP4.5 and RCP8.5 shall be developed.*
- *FIU SLSC shall model the extreme rainfall using statistical models of extreme rainfall. Specifically, the methods shall include, but are not limited to, fitting of the Generalized Extreme Value (GEV) and the Generalized Pareto Distribution (GPD) for annual maxima (AMS) and the peaks-over-threshold (POT) events. For this task, popular R-libraries such as extRemes, available from R-software suite, shall be used. The final outcome of this modeling is the suite of DDF curves for current and future conditions.*
- *FIU SLSC shall use the resulting DDF curves to validate the downscaled historical precipitation extremes. When necessary bias-correction of the projected precipitation extremes using the quantile mapping methods shall be used. Where possible, quantile mapping methods and/or appropriate techniques shall be used for temporal disaggregation of daily precipitation extremes into sub-daily timescales.*
- *FIU SLSC shall summarize the results of this study based on percentiles (of extreme rainfall) across models and Representative Concentration Pathways (RCPs representing future climate scenarios).*
- *FIU SLSC shall generate maps of projected precipitation extremes for durations, return periods, and future periods of interest using GIS tools and shall post the maps online for public access.*
- *FIU SLSC shall develop statewide, web-based user interface for making extreme rainfall projections available to communities across the state.*

Interim Progress

Methodology

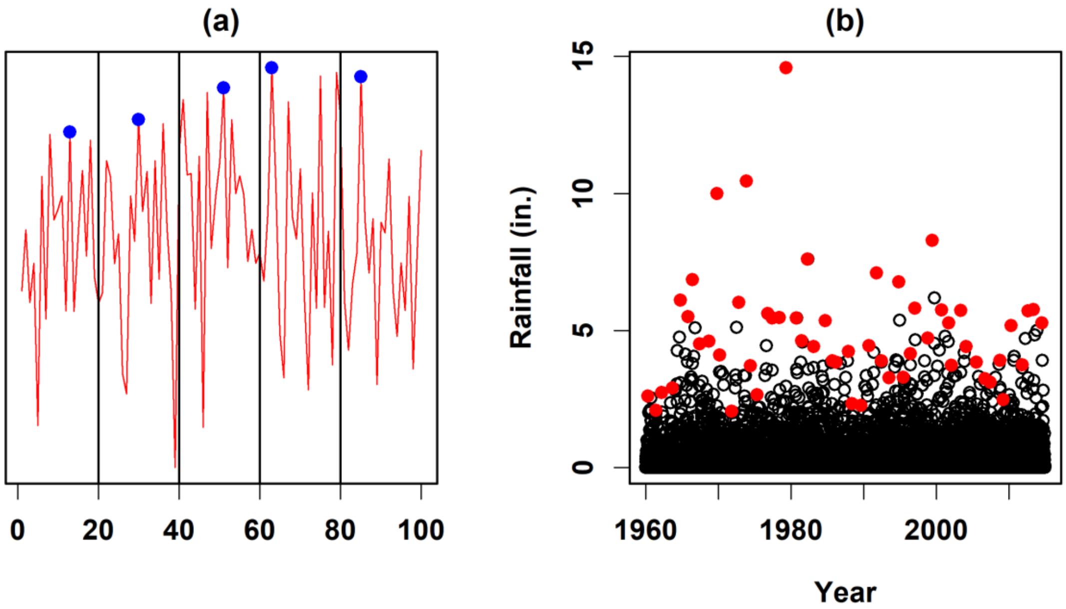
As outlined in the SOW, extreme value modeling will use two approaches for modeling:

1. Generalized Extreme Value (GEV) Distribution Fit for Annual Maxima Series (AMS)
2. Generalized Pareto Distribution (GPD) Fit for the Peaks Over Threshold (POT) Series

The conceptual framework for AMS (also known as Block Maxima) and POT is illustrated in Figure 9. The general approach for the project is to fit the probability distributions for two periods:

1. 1950 up to 2019 (considered the base or historical period)
2. Future periods 2030 to 2070 and 2060 to 2100

1. Annual (Block) Maxima Method



2. Peaks Over Threshold Method (POT)

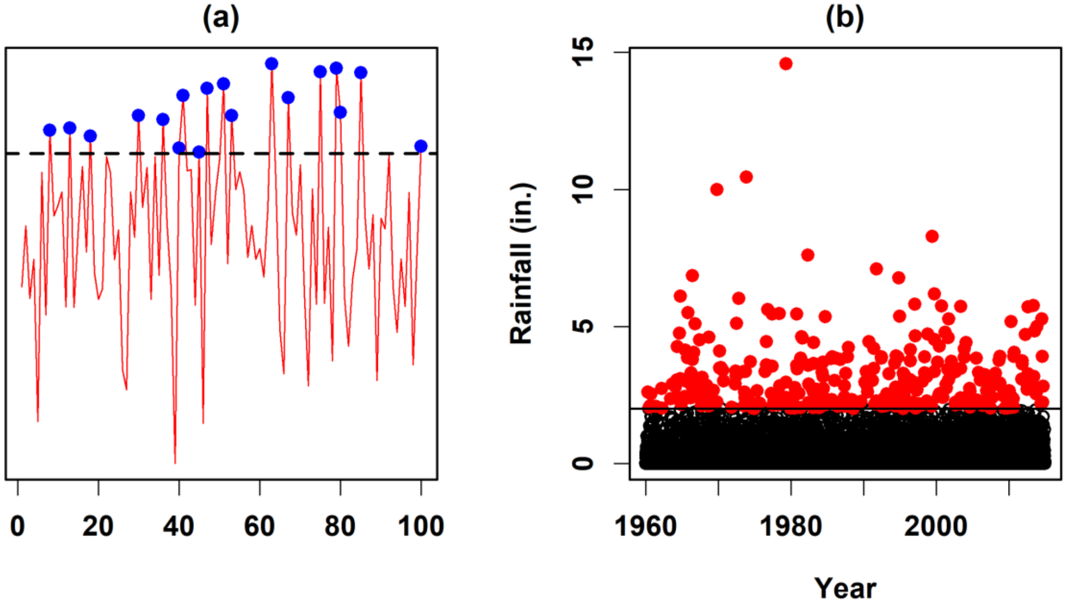


Figure 9. Illustration of Annual Maxima and Peaks Over Threshold

Generalized Extreme Value (GEV) Distribution

The Generalized Extreme Value (GEV) distribution provides a model for the distribution of block maxima and is given by (Coles, 2001):

$$G(z) = \exp\left\{-\left[1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \tag{1}$$

defined on the set

$$\left\{z: 1 + \xi\left(\frac{z-\mu}{\sigma}\right) > 0\right\},$$

Where

$$-\infty < \mu < \infty,$$
$$\sigma > 0,$$
$$-\infty < \xi < \infty,$$

And ξ is the shape parameter, μ is the location parameter and σ is the scale parameter. Depending on the values of the shape parameter ξ, the three different families of GEVs are defined as Gumbel ($\xi = 0$), Fréchet ($\xi > 0$), and Weibull ($\xi < 0$).

Estimates of the extreme quantiles of the annual maximum series is obtained by inverting Eq. (1) and is given by:

$$z_p = \mu - \frac{\sigma}{\xi}\left[1 - {y_p}^{-\xi}\right], \tag{2}$$

Where

$$y_p = -\log(1-p),$$

And $G(z_p) = 1 - p$ and z_p is the return level for the return period $1/p$. The return level plot, which is a plot of z_p vs y_p is linear when for Gumbel, convex with the asymptotic limit for Weibull, and concave with no finite bound for Fréchet (Coles, 2001).

Since the GEV models are implemented by blocking the data, the method is limited by the choice of the block size. Block selection can be a trade-off between bias and variance. Large blocks result in fewer block maxima while small blocks, which depending on the data recording may not be a choice, can result in bias in estimation and extrapolation (Coles, 2001). The next section presents another method to overcome some of these limitations.

Peaks-Over-Threshold (POT)

The peaks-over-threshold (POT) approach was first developed by hydrologists in the 1970s. This method fits a stochastic model to the exceedances over a threshold (u) and an independent exponential random variable to the model the amount of exceedance (Davison & Smith, 1990). The main advantage of employing the POT method is the increased sample size which results in more robust estimations of the shape parameter. Threshold models have previously been applied for rainfall depth and duration analysis (Palychuk & Guo, 2008). The POT approach used in this project is based on the family of distributions called Generalized Pareto distribution (GPD). The GPD, which implies the classical GEV distribution (Picklands, 1975; Davison & Smith, 1990;

Madsen et al., 1997), models the amount of exceedance and the distribution function is given by (Coles, 2001):

$$H(y) = 1 - \left(1 + \frac{\xi y}{\tilde{\sigma}}\right)^{-1/\xi} \tag{3}$$

Defined on the set

$$\{y\colon y > 0 \; and \; \left(1 + \frac{\xi y}{\tilde{\sigma}}\right) > 0\}$$

Where

$$\tilde{\sigma} = \sigma + \xi(u - \mu)$$

Like the GEV, the shape parameter ξ is dominant in determining the behavior of the GPD, but unlike the GEV, the block size does not affect the value of the GPD parameters (Coles, 2001). Ealy versions model the times of exceedances over the threshold using a non-homogenous Poisson process. In this project, we use the Poisson process of exceedance times with the GPD. It is given by,

$$F_Z^t(z) = \exp\left[-\Lambda(t)\left(1 + \frac{\xi(z - u)}{\tilde{\sigma}}\right)^{-1/\xi}\right] \tag{4}$$

where t is the period of interest, $\Lambda(t)$ is the number of events over time t, and $\tilde{\sigma}$ and ξ are parameters.

Similar to the GEV, the shape parameter ξ is dominant in determining the qualitative behavior of the GPD. The distribution is unbounded when $\xi = 0$, has no upper limit when $\xi > 0$, and is bounded by an upper limit of $u - \tilde{\sigma}/\,\xi$ when $\xi < 0$.

The N-year return level is given by (Coles, 2001):

$$z_N = u + \frac{\sigma}{\xi}\left[\left(N n_y \zeta_u\right)^{-\xi}\right], \tag{5}$$

A constrained estimation procedure that fits all durations at once to overcome issues with crossing curves experienced typically when fitting one duration at a time (Irizarry et al. 2017; Xu & Tung, 2009) will be used. Statistics and goodness of fit (GOF) will be computed using few or more of the following statistics (Serinaldi and Kislby 2014):

1. Kolmogorov-Smirnov
2. Anderson-Darling (AD)
3. Cramér-von Mises (CVM)
4. Pearson product moment correlation coefficient on P-P plots (PPCCPP)
5. Pearson product moment correlation coefficient on Q-Q plots (PPCCQQ)

Collaboration effort with USGS and SFWMD has produced several software scripts that have been made available to FIU SLSC. These scripts have been written in R-language using R-libraries such as extRemes. In particular, FIU SLSC has acquired the R-scripts for the following tasks:

1. Computing accumulated rainfall for durations 1 to 10 days for both historical and future periods
2. Fitting GPD and/or GEV distributions for each period
3. Mapping results

Future Projections

It is well known that the extreme rainfall predicted by climate models has a large negative bias. Typically, bias correction techniques are used to correct such biases. For this project, we will use what is known as the **Multiplicative Quantile Delta Mapping** (MQDM) method for adjusting the future. This methodology is illustrated in Figure 10. The expression for adjusting future rainfall quantiles is (Irizarry et al. 2016, 2017):

$$\hat{x}_{m-pad\,j.} = F_{m-padj.}^{-1}(G) = F_{m-p}^{-1}(G) * \left\{\frac{F_{o-c}^{-1}(G)}{F_{m-c}^{-1}(G)}\right\}$$

The variables used in MQDM are defined as follows. $\hat{x}_{m-padj.}$ is the adjusted quantile for the model (m) projections (p) for the future period, F_{o-c} is the Cumulative Distribution Function, CDF, of the observations (o) in the current baseline period (c),F_{m-c} is the CDF of the model (m) in the current baseline period (c), and $F_{m-p}$is the CDF for the model (m) projections (p) for the future period. *G* is the annual non-exceedance probability (CDF value) and is equal to *1-P*, *P* is the annual exceedance probability (AEP) which is related to the return period *T* by *1/P = T* (i.e. *G=1-1/T*), F^{-1} is the quantile function.

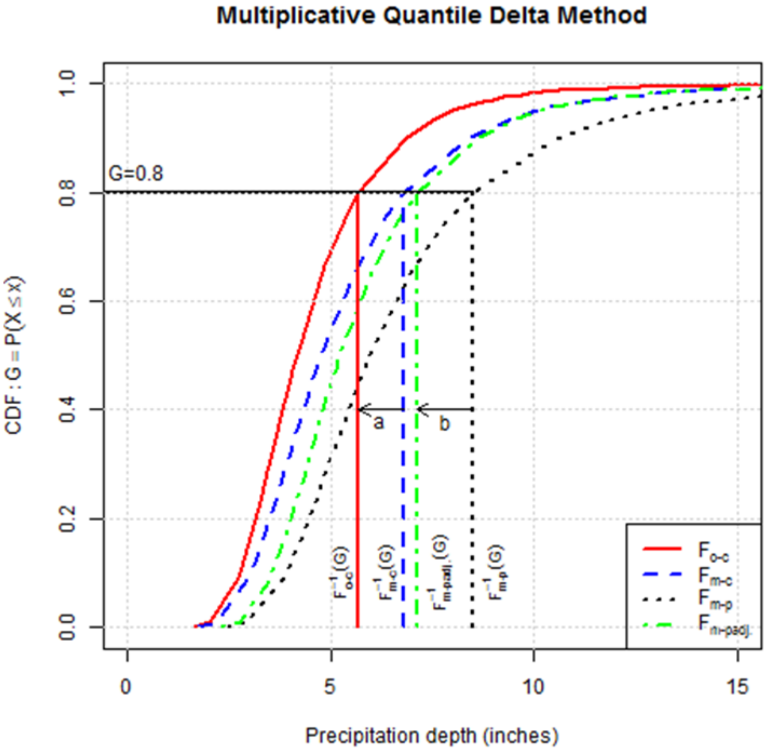


Figure 10 Multiplicating Quantile Delta Mapping (MDQM) method for correcting bias in rainfall quantiles computed from climate model data

Finally, the adjusted rainfall for the future is given by Eq (6) which allows the adjustment of the rainfall quantile corresponding to a given return period T = 1/p by combining estimates obtained from historical data (o-c), model output for the current period (m-c) and the model output for the future period.

$$\chi_{m-pdaj} = F^{-1}_{o-c}(G)\left[\frac{F^{-1}_{m-p}(G)}{F^{-1}_{m-c}(G)}\right] \tag{6}$$

The quantity inside the large square brackets in Eq. (6), is known as the Change Factor (CF). For the present project, we will provide Change Factors corresponding to all frequencies (5 to 100 year return periods) and durations (1 day to 10 days) for adjusting the Atlas 14 frequency curves at each of the 242 locations. This work will use the R-software as specified in the SOW.

Task 2.4. Evaluation of the FBC-related requirements.

- *FIU SLSC shall evaluate the Florida Building Code, 7th Edition, (2020), (FBC) requirements to recommend what additional steps will be necessary to incorporate results of the proposed study into the appropriate sections of the FBC. Specifically, the changes to the rain loads* *and their implications for rain loads as applied to figure 1611.1 of the FBC, Building and figure 1106.1 of the FBC, Plumbing shall be recommended.*

- *FIU SLSC shall provide specific recommendations for modifications to the Florida Building Code that are necessary to incorporate the results of the proposed study into the FBC.*

As was done for the previous FBC-funded project, the FIU SLSC team will evaluate the potential implications of sea-level rise and changing rainfall in the Florida Building Code for all communities across the state of Florida. After the future extreme rainfall projections are available, we will evaluate the changes to the rain loads and their implications for Rain Loads as applied to Figure 1611.1 and Figure 1106.1 of the FBC, Plumbing.

Task 2.5. Technical workshop

- *FIU SLSC shall hold a technical workshop to review the methodology and the outcomes of the study and how they may influence floodplain management activities and future flood elevations regulated by the Florida Building Code. This workshop shall be presented as a webinar to interested professionals associated with the organizations representing the External Advisory Panel. The workshop shall be hosted immediately following the submission of the final report.*

Interim Progress

This will be scheduled on a convenient date after the final report is submitted in June 2021.

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Citing Data

MACAv2-LIVNEH

Climate forcings in the MACAv2-LIVNEH were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the Livneh(Livneh et.al.,2013) observational dataset as training data.

MACAv2-METDATA

Climate forcings in the MACAv2-METDATA were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the METDATA (Abatzoglou, 2011) observational dataset as training data.