Workshop Report and Strategy Document: Development of Unified Rainfall Scenarios for Florida

Sea Level Solutions Center, Institute of Water and Environment at Florida International University under contract from the South Florida Water Management District

Introduction

The Sea Level Solutions Center (SLSC) at Florida International University (FIU) was requested by the South Florida Water Management District (SFWMD) to help develop a set of well-defined future climatic scenarios for various planning efforts underway. Such efforts include, but are not limited to, the Florida Protection Level of Service (FPLOS) program, Water Supply Planning, and CERP Planning/Everglades Restoration. As a first step in this process, FIU organized a workshop on May 16, 2019 to be attended by a selected group of experts in the field and representatives of various agencies, governments, and private sector. Through this workshop, FIU facilitated a dialog to develop a plan for preparing a set of statewide series of climate scenarios and prepared this final report summarizing the deliberations, recommendations, and future actions.

Workshop Notes

Introduction – Dr. Jayantha Obeysekera, Florida International University

Dr. Obeysekera welcomed attendees and talked about the goals of the workshop. He mentioned that climate models have issues with skill in rainfall predictions making it difficult to develop scenarios for planning. The state is in dire need of scientific support for both local and regional-level decision-making and planning.

Welcome Remarks – Akin Owosina, South Florida Water Management District

Mr. Owosina mentioned how a few years ago Dr. Obeysekera and him had some discussions on the work on sea level rise and climate change and a key question came up – how to obtain a consistent set of rainfall scenarios for planning, flood studies, etc. A few years ago, they had visited with the KNMI group in the Netherlands and were impressed with their work on this topic. Ideally, the scenarios should be applicable not only to the 16 counties within the South Florida Water Management District, but ideally state-wide so there is continuity across planning boundaries.

Mr. Owosina said that the purpose of this workshop was to seed the discussion and bring the planning and scientific communities together to identify needs, develop a strategy and find funders for this work. A big challenge is to work on MOAs and MOUs to get state funding. He is looking into a scope of work or roadmap for leaders at the state level to have some action on this front.

“Assessment of downscaled rainfall datasets” – Dr. Tibebe Dessalegne, South Florida Water Management District

Dr. Dessalegne started his presentation by providing some background on the SFWMD’s areas of responsibility. The SFWMD is responsible for managing the water resources in 16 counties in central and southern Florida serving a population of about 8.1 million. Its missions are diverse and include restoration, flood protection, and meeting the region’s water needs all while considering the quantity, quality, timing and distribution of water in the system.

The SFWMD service region consists on a heavily managed water control system and two major types of climate data are used in informing decisions: (1) long-duration (41-year+) spatially-distributed (2 mi x 2 mi) daily rainfall and reference evapotranspiration dry(RET), and (2) extreme event rainfall timeseries at 15-minute intervals.

Dr. Dessalegne then talked about global circulation models (GCMs) and the statistically and dynamically-downscaled data products derived from them. A key question is how well do these downscaled products simulate the south Florida climate and how it impacts the system. In terms of statistically-downscaled data products, the SFWMD has evaluated the US Bureau of Reclamation’s BCCA data product (12 km x 12 km), the University of California’s LOCA product (6 km x 6 km), and Self-organizing maps output (SOM) based on an FIU/Penn State Water Sustainability and Climate joint project. In particular, they have evaluated daily rainfall, and maximum and minimum temperatures for the BCCA product for performance at 32 gages throughout the state (point data), and regional data for the South Florida Water Management Model (SFWMM, 2 mi x 2 mi) domain for three periods: a base period (1970-2000), near future (2025-2055) and far future (2055-2085).

Dr. Dessalegne presented graphics showing the projected changes in mean annual temperature versus the percentage change in mean annual precipitation for the three different Representative Concentration Pathways (RCPs) in the near future period based on point data. The plot showed a much larger spread in projected precipitation changes than in temperature. Point data for the far future period showed a -10% to +20% change in precipitation with a larger spread in temperature change predictions for the far future compared to the near future, with RCP2.6 showing a smaller increase in temperature than RCP8.5 as expected due to increasing uncertainty in emissions with time.

Their analysis showed that the highest changes in precipitation would occur between the months of October and November. The changes in precipitation show no patter across the different RCPs. The largest changes in the seasonal cycle of temperature would occur under the RCP8.5 scenario.

Dr. Dessalegne mentioned how the District used TIN method to interpolate BCCA output to the 2-mi x 2-mi grid of the SFWMM for the period 1965-2005. The objective was to determine the skill of the projections. In terms of mean annual rainfall, the 36 BCCA models are on average 4.5 inches/year higher than the observations. SFWMD calculated RET based on the Hargreaves and Samani (1982) method for the period 1965-2005 and used the calibrated KT coefficient in predicting future RET based on BCCA daily maximum and minimum temperature output.

Future planning based on regional water resources water assessment models requires projections of daily long-term rainfall and RET as input. The SFWMD has simulated various future scenarios using the SFWMM and a delta method based on the following assumptions: (1) Rainfall varying from -10% to +10% from the base case, (2) temperature increase of 1.5°C, (3) sea level rise of 1.5 feet. The purpose was to evaluate the future vulnerability of the water resources in the region of south Florida covered by the model.

In addition, there is a need for weather data to use in the District's Flood Protection Level of Service project (FPLOS) including event rainfall and boundary stage timeseries. For this purpose, the District contracted out the development of future IDF curves based on BCCA model projections. It was found that the bias in the simulated extremes during the historical comparison period exceeds the projected changes in these extremes, which reduces the trust in future predictions even after bias-correction.

Dr. Dessalegne reiterated that, in his view, the solution to the GCM and downscaled output uncertainty would be to use a scenario-based approach such as the delta approach used by the District in the past. There are too many models and ensembles and too much uncertainty associated with that. The District is looking for this workshop to be a step towards a unified climate scenario approach to satisfy the needs of stakeholders in the state. The future climate scenarios should include daily or sub-daily rainfall and RET at 2 mi x 2 mi scale and a quantification of future expected changes in IDF curves.

"The AMO and Florida rainfall" – Jeremy Klavans, University of Miami

Mr. Klavans started his presentation by describing the Atlantic Multi-decadal Oscillation (AMO) and its relationship to Florida rainfall. The AMO is a basin-wide low-frequency warning and cooling of the North Atlantic with cycles on decadal and longer timescales (i.e. it has a broad spectral peak). It is more accurate to call it the Atlantic Multi-decadal Variability (AMV) since it is not a true oscillation.

A positive AMO implies a weakening of the atmospheric circulation and is positively correlated with Florida rainfall and inflows into Lake Okeechobee (e.g. rainfall in Florida climate division 4). Mr. Klavans has updated the JJA station data through 1950-2013 to show the positive correlation between the AMO and Florida rainfall. A key question is whether the AMO was causing these shifts.

Another question of his research is to see whether the CESM climate model can reproduce this positive correlation between the AMO And JJA precipitation in Florida. The CESM 42-member ensemble has identical forcing (historical forcing before 2005, RCP8.5 forcing after 2006) and the only difference between the ensemble members is small perturbations in initial conditions. The objective of the research was to quantify the internal variability of the system. The results of the modeling work showed a mean correlation of zero (and the correlation varying from – to +) between the AMO and JJA precipitation in Florida, as opposed to the observations which show mostly positive correlations. Therefore, a key question is whether the AMO is *causing* the shifts in Florida rainfall.

The modeling also shows that external forcing (i.e. the strong warming signal) will exert a larger influence on both AMO and Florida rainfall in the future. Another conclusion is that the AMO does not work well in constraining or culling the good models in Florida, but El Nino does a better job.

"Constraining model projections of regional precipitation projections or reducing uncertainty" – Dr. Ben Kirtman, University of Miami (presenting for Dr. Brian Soden)

Dr. Kirtman and his students at UM have looked at how climate models reproduce global means. Infanti et al. looked at the variability in downscaled models. They have looked at the uncertainty in precipitation changes in CMIP5 and in a subset of models based on how well they reproduce the mean state on a *global* perspective. They have found that by culling models, there is a 34% global mean reduction in uncertainty.

They also looked at projections for the state of Florida from US Bureau's BCSD statistically-downscaled data for near-term (2019-2045), middle-term (2046-2072), and long-term (2073-2099) periods. Based on the Standardized Precipitation Index (SPI), they split the data into wet, dry, neutral and no threshold events by season.

Most models in the BCSD product show a north to south gradient in precipitation changes in the state of Florida in the near-term (2019-2045) with a drying in the south and a wetting of the north during June-July-August (JJA). The line of no change is around Lake Okeechobee. This feature is present in both RCP4.5 and RCP8.5. They used a coefficient of variation measure to quantify the spread of the predictions and a robustness measure to quantify how many models agree on the sign of the prediction and show these spatially. A positive and large robustness value means that all models agree on a positive change. A negative and large robustness value means that all models agree on a negative change. Their long-term results show that the dry season will be uniformly wetter throughout the state based on all models.

When the models are constrained based on how well they reproduce natural variability induced by El Nino, only 5 models remain from an original total of 30. Now the maps for the remaining 5 models looks very different. The neutral events in the dry season show consistent drying in the future when sub-setting, whereas without sub-setting we saw wetter conditions. In the no threshold cases, the North to South gradient becomes even sharper with sub-setting during the wet season. The dry season wetting for the no-threshold condition increases with sub-setting.

"High-resolution and low-resolution climate model predictions for south Florida and southeast United States drought" - Dr. Ben Kirtman, University of Miami

Dr. Kirtman and his student Johnna Infanti have done some research on how much regional information can we squeeze out from the low-resolution climate change simulations. They used high-resolution global atmospheric and ocean models at 25-km and 10-km resolution. In particular, they used the Standardized

Precipitation Index averaged over 3, 12 or 36-month timescales (SPI-3, SPI-12, SPI-36), to constrain/subset for the good models. When comparing high-resolution (HR) to low-resolution (LR) models they found that for longer timescales, which are related to oscillations in the Gulf Stream, they found that the HR model is doing a far better job than the LR model.

If long-term SPI is captured well, then that is defined as a good model. It was found that HR models do a better job in South Florida than LR models in terms of capturing dry SPI-36 composites, which are related to AMO-induced drought. However, the performance in the Caribbean was lacking. The observations support a strong relationship between natural variability induced by ENSO (Nino3.4 SSTs) and rainfall in Florida. The HR models can capture that relationship well but not the LR models. Therefore, one can use the prediction problem as a way to increase confidence in the projection models.

Dr. Obeysekera mentioned a model constraining method by Tebaldi and others, and that ENSO could be used in constraining models due to its high correlation to dry season precipitation in Florida. Dr. Kirtman suggested using how well LR models capture teleconnections such as ENSO to constrain the set of models. He believes that HR models can much better capture the AMV than LR models. A key outstanding question in Dr. Kirtman's research is whether the 0 change in precipitation line around Lake Okeechobee is robust and what could be the physical explanation for it.

"An integrated evaluation of the simulated US hydroclimate system: focusing on extreme rainfall" – Dr. Kevin Reed, Stony Brook University/Hyperion Project

Dr. Reed presented on the Hyperion Project which is a DoE-supported project that spans multiple universities and government labs and stakeholders. The project is on its third year and preliminary results are coming out. Paul Ulrich from UC Davis is the scientific lead for the project. The main aspect of the project is to develop user-driven metrics for evaluating climate models. Outreach to stakeholders is paramount to this project. The goal of the project is to target potential improvements for regional climate models (RCMs) and assess the quality of the modeled hydroclimate system in the available regional climate datasets.

The metrics that are most useful to stakeholders are often-times related to extreme rainfall. The outcome of the project is focused on regional data analysis and includes new model runs, model sensitivity, and using the climate model output to drive hydrologic models.

Dr. Reed emphasized that the model accuracy has a variety of definitions which are quantified in terms of metrics. For example, if the climatology produced by a climate model agrees with observations, then we have some faith that it is a good model to use for future projections. But the metrics might be different depending on how projections would be used. The idea is to "tame the wild west of regional climate datasets." The project is focusing on four use case watersheds including Sacramento-San Joaquin Watershed in California, the Colorado River Headwaters, the Susquehanna River, and the Kissimmee River in Florida. It has been found that stakeholders in the four watersheds have similar data needs. The team has focused on those metrics that work on a wide-range of the basins use cases such as a water supply set of metrics, and a flooding set of metrics. There are also 2nd and 3rd order metrics to inform these main metrics.

The historical observed changes thus far can be used to evaluate future projections. For example, the historical data shows that the 1-in-5-year precipitation has had a robust increase in frequency and is increasing much faster than the mean precipitation in the entire US. These extremes are projected to further increase in the RCP simulations. For different regions of the US, there is a need to quantify whether this increase in extreme events is due to changes in afternoon thunderstorms versus tropical storms.

Dr. Reed showed how the full probability distribution for the US only gets into the observed range with high-resolution (HR) models (NCAR CAM5 model with refined grid down to 25-km resolution in the North Atlantic; also called Advanced Climate Models) compared to low-resolution (LR) models at 200 km resolution. He showed how the 25-km HR model can reproduce Hurricane Irma precipitation in the state by comparing to observations (taking into account that the observations are uncertain as well). The improvement in performance in the HR models compared to the LR models is due to being able to represent dynamical events behind the extreme event.

Using the NCAR model with HR over the North Atlantic and Eastern US (~25 km), Dr. Reed showed that these HR models can reproduce the number and paths of tropical cyclones better than LR models. The HR models simulate 10 storms/year compared to the observed 12 storms/year, and 2 storms/year simulated by LR models. Dr. Reed suggested building a coastal storm metric based on extracting the precipitation associated with the simulated storms. The wind field can be extracted at every location and changes in the dynamic size of the wind field can be used to extract precipitation associated with that storm to develop a coastal storm metric.

Based on historical observational data in Florida, annual tropical cyclones account for only 2% of overall annual precipitation in the state. Another metric he has looked at is how much of the average annual maximum 5-day accumulated precipitation (RX5day, ~6 inches on average for the state) is associated with a tropical cyclone. His findings were that ~27% (or about one out of every 5 years) of RX5day were associated with a tropical cyclone. The HR model results show an average of about 5 inches of rainfall for the RX5day metric, with approximately 20% of annual RX5day precipitation associated with tropical cyclones.

Dr. Reed mentioned how case study reports for each watershed are being developed with regional narratives assessing stakeholder needs. Currently, they have 12 distinct set ups of HR regional models available, some of which have the high-resolution extend into Africa, western US, etc. These high-resolution regional models are called advanced climate models, but they have the same physics as the parent model. However, they can dynamically resolve features that are important to simulating the regional climate. Finally, he emphasized the need for models that reproduce the weather so that extreme events are well reproduced.

“Aggregated climate change scenarios for the Netherlands: their construction and stakeholder uptake” – Bart van den Hurk, on behalf of Rijkswaterstaat, KNMI, Deltares, the Netherlands

Dr. van den Hurk started his talk by emphasizing how the Netherlands is existentially dependent on climate. He briefly talked on why unified climate scenarios need to be developed, namely to (1) translate IPCC findings to the national context, (2) as potential indicators of climate change and their uncertainties, (3) to develop plausible and consistent images of the future. He showed how a cascade of uncertainties in climate scenarios propagate to end up with a very large pool of potential scenarios, moving from socioeconomic scenarios to emission scenarios, then to concentration scenarios, radiative forcing projections, climate projections, and finally impacts.

He mentioned that there is a very large collection of European national climate scenarios which vary by country. For example, the Swiss approach consists of a downscaling chain until local scenarios for temperature and precipitation changes are developed. The Dutch approach is slightly different in that it consists of a decomposition of an ensemble between a global response and a local response. The idea is to identify region-specific mechanism which gives rise to regional effects starting from global effects.

The KNMI ’14 climate scenarios include various components. First, a set of scenarios that account for uncertainty consisting of a comprehensive summary of a large ensemble of climate projections. The task was to condense an enormous source of uncertainties into a smaller set of potential futures. This was achieved by looking into two important drivers of regional climate: (1) global temperature rise, and (2) anomalies related to variations in regional atmospheric circulation which affects moisture advection, precipitation and extremes (i.e. a high-value circulation pattern results in warm wetter winters and drier summers) as well as changes in ice cap dynamics and the consequent sea level rise. From these, 245 GCM projections were aggregated into four locally-relevant scenarios for the Netherlands. The local feedback that is affected by large scale atmospheric circulations may be different for different regions or climate zones (e.g. monsoon, snow, land surface feedbacks, local SST patterns, tropical storms, etc.).

The second component of the KNMI ’14 climate scenarios includes the local interpretation of these four scenarios, which are presented as location-specific summaries for the years 2050 and 2085. The general procedure is to go from GCM projections to dynamical downscaling using RCMs for the Netherlands, and then applying delta methods to develop timeseries for the future. For example, the timeseries of rainfall are transformed by adding or subtracting from climate model projections to observed climate time series with the changes applied by quantile. This causes shifts and also changes the shape of the probability density function (pdf) of the reference climatology. The advantage is that the local observations act as a baseline and this is a relatively simple procedure. The disadvantages are that the historical sequence of events is inherited from the baseline period, and that the operations can become quite complex given that changes in the mean may not equate to changes in extremes for example.

Dr. van den Hurk showed us the the effects from the transformation of the timeseries for 2050 rainfall, wet day frequency and average rainfall for the warm scenarios with high and low atmospheric circulation.

Based on the output from the timeseries transformation they have developed a Climate Impact Atlas which includes for example, the days per year with more than 15 mm of rainfall for the current climate (1981-2010) and the future climate under the warm high-atmospheric circulation scenario in 2050. The Climate Impact Atlas includes other useful metrics such as how the 1/10 year 24-hour rainfall event totals would vary from current to 2050 and 2085 within specific regions of the Netherlands.

Certain phenomena are not well captured by climate models. For example, observations show that at higher temperatures, the hourly rainfall extremes for short durations increase twice as fast as predicted by the Clausius-Clapeyron relationship between temperature and vapor pressure. This is called a "super Clausius-Clapeyron relationship." However, climate models do not simulate this well. Most current climate models do not simulate convective rainfall well and this might be a reason. High resolution models tend to perform better.

In summary, the Dutch approach is to aggregate uncertainty information and relate it to local impacts. Multiple downscaling steps are required for this purpose. The Netherlands is also working on a new set of climate scenarios to be released in 2021. In general, users now want more detailed information such as information on the urban climate, when and how do extremes happen, coastal-defense-oriented answers, etc.

"Rainfall variability over Florida: Opportunities and challenges" – Dr. Vasu Misra, Florida State University

Dr. Misra's talk is based on the results of research summarized on four (4) papers. First, he talked about how the climate of Florida is characterized by monsoon-like rains which are driven by ocean conditions. Peninsular Florida displays a very strong seasonal cycle of rain with a distinct wet season. Based on analysis of 50 years of rainfall data (1948-2005), he has found a very dramatic onset and demise of the wet season. Like an on/off switch. The climatological onset date is May 21st when rainfall goes from an average of 1.5 mm/day to about 7 to 9 mm/day. The climatological demise date over the 50 years is on October 10th when rainfall goes from an average of 10-12 mm/day to just 2-3 mm/day.

He has developed a methodology to determine the dates of onset and demise for every year based on a timeseries plot of cumulative daily rainfall minus annual mean rainfall. The day of onset of the wet season is defined as the point when the curve reaches its lowest point, while the day of demise is defined as the day when the curve reaches its highest point. Based on the 50-year record he found that the standard deviation for the onset and demise of the wet season in peninsular Florida is of 2 weeks (i.e. one-month standard deviation in wet season length).

By looking at the evolution of sea-surface temperatures (SSTs) in the West Atlantic and Gulf of Mexico, he has found that days prior to the wet season onset, the SSTs are cooler, while post-onset they begin to warm up. Cooling of SSTs being again post-demise. There are various factors that affect the SSTs such as atmospheric heat fluxes and the seasonal cycle of the Loop Current. The Loop Current transports oceanic heat to the east coast of Florida.

Dr. Misra has performed downscaling simulations of global atmospheric and oceanic general circulation models (AOGCMs) using his regional climate model (RSM-ROMS). He has done simulations to mimic the effects of a strong vs. a weak Loop Current by means of changing the sill depth of the Yucatan Channel. Reducing the sill depth, weakens the Loop Current and associated heat transport to the east coast of Florida. This in turn reduces wet season precipitation in peninsular Florida. This is evidence of a feedback loop of the Florida monsoon hydroclimate with the ocean.

He found that using SST data was more useful in getting the inflection points for defining the winter season. He further divided the state of Florida into four (4) regions: North Florida, Central Florida, Southwest Florida, and Southeast Florida. The seasonal length of the winter season is always variable with a one-month standard deviation in length. In North Florida, the longest season is winter. Spring and fall transition seasons are the shortest seasons in all four regions.

The simulation of the climate of Florida is challenging due to the state's peninsular structure. Dr. Misra showed how the land-sea masks of the ocean vs. atmospheric components of various AOGCMs (e.g. CCSM4 with a 100 km atmospheric component and slightly ocean resolution in the tropics, CanESM2, etc.) and found them to be quite different. There are large wide spaces that straddle the ocean than are neither in the ocean nor land. The atmospheric model does not predict anything in those blank spaces and the ocean model does not either. The flux coupler also does not predict anything at those locations. Therefore, values along coastlines are not predicted at all, but some are interpolated values. The RCM he developed has the same atmospheric and ocean resolution of 10 km.

Dr. Misra also showed us how the surface eddy kinetic energy, which affects ocean heat content and transport, is grossly underestimated in some 20th century simulations such as in the CCSM4 climate model. Many of the GCMs get discharge through the Yucatan Channel reasonably well, but they do underestimate the variability in Yucatan Channel flow.

He showed how projected changes in projected SST anomalies in his RCM almost follows the bathymetry on the west coast of Florida (i.e. the shallow bathymetry allows for the water column to be heated more in this area than in more open ocean areas). In contrast, CCSM4 does not capture that due to the presence of those blank (empty) zones that are in neither the atmospheric or ocean components of the model.

Dr. Misra showed us how his RCM when driven by boundary conditions from CCSM4 predicts that the Florida shelf becomes very warm with a deepening of the 26°C and 20°C isotherms. This could intensify storms passing through the area similar to what happened with Hurricane Michael when observed SST anomalies lined up against the Florida shelf caused it to rapidly intensify. Due to a reduction in the Loop Current during the mid-21st century (around 2060), his model predicts a drying of the wet season. In contrast, the global CCSM4 model predicts an insignificant to moderate increase in mid-21st century rainfall. This is one story from one model.

"A hybrid dynamical-statistical analog downscaling technique to efficiently explore changes in extreme precipitation" – Dr. Luke Madaus, Jupiter Intelligence.

Dr. Madaus started his presentation by talking about the Jupiter Floodscore Planning predictive services product, which provides physical flood risk information at street-level resolution. He also talked about the physical compounding issues in South Florida such as coastal surge, seasonal king tide effects, and extreme rainfall. The goal is to determine how extreme precipitation events are expect to change in frequency and magnitude in the future climate. The right methodology for determining this is not the same everywhere.

There are five (5) main steps for doing this: (1) Definite criteria for candidate extreme precipitation events, (2) Run dynamically-downscaled simulation at ~1-km resolution for historical events, (3) Project changes in event frequency with analog method, (4) Project changes in event magnitude with statistical scaling, (5) Produce climate statistics and feed into flood models.

In selecting the extreme events, one must determine how much rainfall is required to result in flooding in different areas of South Florida. They chose all events where either Miami Dade or Miami Beach ASOS/GHCN stations show at least 30 mm of precipitation in 24 hours. This criterion is based on analysis of NCEI/NCDC flood reports which shows a threshold of 100 mm in 24 hours after which reports of flooding increase dramatically. A smaller level of 30 mm/24 hours was chosen with flood reports being very rare below this level.

The WRF model was used for downscaling simulations. It is a nested series of model grids telescoping into Miami Dade County area with approximately 1-km resolution there and a sub-daily timestep. WRF was tuned to better match the South Florida precipitation distribution. A 1-km land cover dataset was used, which can have feedbacks on the local atmospheric circulations. The idea is to choose configurations/schemes for WRF that are best suited to the South Florida climate (e.g. warm rainfall processes dominate in South Florida and the Goddard Microphysics model is good for that). It was found that 1-hour precipitation histogram simulated by WRF it is similar to the histogram of observations, but WRF underestimates the most extreme events in the tail. The relationship between the simulated and observed hourly precipitation from a quantile-quantile plot is used to bias-correct the WRF simulation. The 24-hour precipitation in WRF shows similar skill as the hourly.

An analog technique is then used for event frequency matching. The CESM-LENS GCM ensemble is used to match future days to historic ones. The assumption is that if their large-scale patterns are similar, then the small-scale patterns should be similar too. The selection is based on a Machine Learning algorithm using a cross-validation technique to optimize the prediction for the analog finding. Often, analog finders are run one day at a time individually. They are looking into using multi-day analog finding. Most extreme rainfall events in South Florida are 1-2 day long with a few 7-day events. They have found that the performance of the analog finder is good as it samples a wide variety of extreme events. Analog re-sampling alone does not find an increase in annual frequency of extreme precipitation events in the future (from 24 in the 1920s to 27 events in the 2050s). Most extreme precipitation events in South Florida are determined by localized thunderstorms/convection and not by large-scale atmospheric patterns.

Analog-based sampling only samples historical events. Dr. Madaus showed us a paper from Liu where the period 2000-2013 was simulated with WRF at 4-km for the entire US including Hurricane Katrina's effects in South Florida in 2005. Then the same 13-year run of WRF was repeated using future projections from GCM output. This shows the behavior of the *same sequence* of weather events in a warmer and moister atmosphere. Their findings show a similar spatial pattern and location of rainfall for Hurricane Katrina in South Florida, but there was more rainfall in the region under a wetter and warmer atmosphere.

Changes in event magnitude can be obtained from statistical scaling techniques. For example, their future scaling results show an increase in wetter events on the tail of the distribution based on the end of the century simulations when compared to the simulated current climate.

When analog and scaling methods are combined the results show fewer precipitation days than in the current climate with the number of days with more than 30 mm/day of rainfall increasing by 2-3% by there are lots of variability in the predictions. These results can then be fed into hydrologic and hydraulic models (e.g. HEC-RAS) to translate precipitation changes into changes in flood risk. Instead of looking at events with > 30 mm/day of rainfall, this method can be used to analyze changes in the frequency of design storms. In addition, any GCM can be swapped into the analog finder.

"Precipitation is part of the story" – Barclay Shoemaker, US Geological Survey

Mr. Shoemaker started his talk by mentioning how evapotranspiration (ET) is the "invisible giant" with ET exceeding precipitation near the coast and at lakes. He talked about the difference between precipitation and ET, called the available water, does the work of hydrology and is important for water management issues such as water supply, spring flow, and saltwater intrusion. He showed how the median 2001-2015 annual precipitation in the St. Johns River Basin has a small range of spatial variability; however, annual ET is much more spatially variable which results in a highly spatially-variable available water (P-ET). He mentioned how the available water is expected to change with time due to climate change, land use changes, etc.

Mr. Shoemaker pointed us to 30 years of ET data now available from the USGS with potential evapotranspiration (PET) and reference evapotranspiration (RET) available as well. The USGS has a new initiative to computing actual ET (AET) which uses gridded solar radiation data from GOES satellites. He showed us the results of a 1996-2011 calculation of available water in the state (Precipitation from PRISM minus PET from the USGS). Over Lake Okeechobee, PET (~1,800 mm/year from Bowen ratio ET station LZ40) exceeds precipitation (~1,500 mm/year) due to increased solar radiation due to decreased cloud cover on the lake from atmospheric circulation that forms on and around the lake due to differential heating capacities of water and land. He showed us how the net radiation at station LZ40 on Lake Okeechobee is about twice the net radiation at a marsh station nearby. In other words, there is much less ET at the perimeter of the Lake than at its interior.

The USGS is currently evaluating the use of North Atlantic Regional Reanalysis (NARR) dataset or the Advanced Weather Research and Forecasting Model (AWRF) to provide meteorological data for PET and RET calculations (in addition to the solar radiation which comes from GOES satellites). He showed us some tables with the seasonal correlation of data from these products with measured data at 57 stations across the state. The worst performance is for the daily maximum relative humidity (RHmax); however, PET and

RET are not very sensitive to it. AWRF is much more computationally-intensive than NARR. They have found that solar radiation and albedo are the two controlling variables for PET estimation; while, for RET other variables matter as well—this makes RET much more spatially variable than PET.

Dr. Obeysekera mentioned that many GCMs and RCMs do not capture cloud cover well in Florida, particularly over Lake Okeechobee. This results in an overestimation of PET and RET.

"Evaluation of future climate change and water use scenarios on regional hydrology" – Dr. Wendy Graham, University of Florida

Dr. Graham has a project with Tampa Bay Water to look at how well GCMs reproduce retrospective temperature and rainfall in the Tampa Bay region. Future projections from these GCMs are then fed into the Integrated Northern Tampa Bay (INTB) hydrologic model which is then used to evaluate changes in hydrologic conditions and the relative effects of climate change and water management on the water resources of the region. They used eight (8) GCMs for RCP8.5 (the business-as-usual Representative Concentration Pathway). Those were combined with eight (8) water use scenarios and three (3) RET estimation methods (Priestly-Taylor which is solar-radiation-based, Penman-Monteith which includes effects from many meteorological variables, and Hargreaves which is temperature-based). They looked at one retrospective period and two future periods (future 1: 2030-2060, future 2: 2070-2100) and evaluated the hydrologic response using the INTB hydrologic model, which has a 2-km resolution.

Dr. Graham performed separate univariate bias-correction of precipitation and RET and found it to be equivalent to multi-variate bias-correction albeit simpler. Her team developed the Bias-Correction Stochastic Analog (BCSA) statistical downscaling method, which reproduces the spatio-temporal correlation of rainfall better than the US Bureau's BCCA and the University of California's LOCA statistically-downscaled methods. They used the North American Land Data Assimilation System (NLDAS-2) 1/8th degree gridded dataset observational data for this analysis. BCCA and LOCA were found to produce too spatially homogeneous rainfall with sort of drizzle everywhere, and underestimate the frequency of wet spells longer than 5 days. BCSA does a better job than BCCA, SDBC, and LOCA. The US Bureau's BCSD is too coherent; it has too little spatial variability in rainfall compared to observations based on a variogram analysis. She mentioned that even RCMs need to be bias-corrected although they reproduce the spatio-temporal structure of rainfall.

In terms of RET, all GCMs predict the maximum to occur in the middle of the year; however, observations show the maximum happens in May due to cloud cover reducing solar radiation and RET in summer months. Therefore, ET from all GCMs have to be bias-corrected. All retrospective GCM runs do a reasonable job at reproducing observed inflows in the INTB model once precipitation and RET are bias-corrected. Projected future monthly changes in RET show slightly higher mean monthly values especially in the future 2 period evaluated, but also very large model to model variability. The difference of precipitation minus RET show a future potential drying in the summer months especially in the far-future. There is a large change in the projections depending on the GCM used and the RET method used.

In addition to changes in precipitation and RET, her team modeled eight different 2045 water use scenarios. They did not consider changes in land use but ran the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) model to determine future agricultural water use based on future GCM projections. For the business-as-usual (BAU) scenario, which uses the same agricultural regulations as today and RET based on the Hargreaves method, they found a small change in the mean streamflow for the future 1 period with respect to observations, but a decrease in streamflow in the summer months with lots of spread from model to model in future 2. They also found lower mean groundwater levels at monitoring well NWH-RMP-08s especially in future 2 simulation under BAU.

Results from a global sensitivity analysis found that more than 90% of the spread in the streamflow projections were due to GCM variability with less influence exerted by the choice of RET method and water use scenario being simulated. The local groundwater levels were found to be sensitive firstly to GCM variability and secondly to the water use scenario being simulated.

In terms of changes in water availability from the Hillsborough River, they found small changes from the observational period regardless of water use scenario. When changes are classified by GCM they found that the two wet and warm GCMs projected an increase, while the six drier GCMs projected a decrease.

In terms of changes in groundwater (quantified as changes in the percent of time that groundwater is above the target level), they found small changes from observations for all water use scenarios, except for the case when wellfield pumpage is turned off. As expected, the two wet GCMs meet the groundwater standard more often, while the six drier GCMs are about the same as current.

They also performed a scenario discovery analysis where they found that the number of GCMs that say that Tampa Bay Water can meet their 2045 demand and also meet environmental regulations (e.g. maintaining levels in sensitive wetlands) increases as the reuse percentage increases. They found that the only way to satisfy all constraints was to only use surface water to meet demands and not use the groundwater. Five-six of the eight GCMs projected decreases in water availability. Even with 40% reuse and active conservation (no groundwater pumping), water supply demands cannot be met while meeting environmental regulations in four of the eight GCMs.

Dr. Obeysekera mentioned that he had found a decrease in summertime precipitation and an increase in early dry season precipitation in his evaluation of GCM projections, which is consistent with Dr. Graham's findings.

"Considerations for the design and use of scenarios that inform robust decisions" – Dr. Casey Brown, University of Massachusetts

Dr. Brown started by talking about the differences between the common decision model and the concept of decision making under deep uncertainty. The common decision model starts with climate science, makes predictions, and prompts action. Decision making under deep uncertainty starts from the bottom up by first framing the decisions, then identifying vulnerabilities, and finally evaluating options which is when climate science comes in. He underscored that this is needed because uncertainty cannot be quantified by a single probability distribution because we are not simply dealing with predictions but with projections.

The typical methodology for vulnerability assessment is to start with emission scenarios to drive GCMs. Since these GCMs are too coarse to be useful at regional and local scales, observations are used to bias-correct and downscale the model output to higher resolutions. The statistically-downscaled model output is then fed into a hydrologic model, which can feed a water resource system model to give us the performance of the water system under different scenarios. Dr. Brown showed us a scatter-plot of projections of temperature changes and percentage changes in precipitation for South Florida, with every dot representing a single GCM projection. He mentioned how these GCMs are often highly correlated due to having being derived from the same original model or having similar physics, etc. Due to this high correlation, it is possible that the uncertainty in future changes in temperature and (especially) precipitation may be even wider than seen in the plot he showed us. Sub-sampling a subset of these GCMs would be advisable.

Dr. Brown highlighted how the GCM scenarios were designed to explore forcing uncertainty, but not to explore adaptation uncertainty. The GCM scenarios are not true scenario analyses nor predictions of the future. What we want to arrive at is a plausible and consistent set of scenarios in a systematic way to identify vulnerabilities. He recommends a Climate Informed Decision Analysis or a scenario-neutral approach, a multi-dimensional stress-testing approach, where climate scenarios enter at the end of the analysis to prioritize decisions and actions.

With decision scaling, the analysis is framed for actionable science by considering the 4 C's: unCertainties (climate is not always the top source of uncertainty), Consequences, Connections, and Choices. Under this approach the stress test can consist of a climate weather generator to systematically sample the range of precipitation and temperature changes that we want to explore. Then a hydrologic model can be run with or without policy and system changes. The resulting map shows a measure of system vulnerability as a surface which is function of changes in temperature and precipitation. In the example, he showed us, each dot represents the results of average California's State Water Project (SWP) deliveries based on 550 years of simulation sampled from observations using a weather generator.

The advantage of this approach is that the vulnerability map will not change as new GCM, RCM, and statistically-downscaled data becomes available. When these become available one can plot the pairs of predicted temperature and precipitation changes by each model and generate some joint pdf to plot on top of the vulnerability map to see in which part of the vulnerability map, we might find ourselves in in the future. In other words, the climate scenarios inform the level of risk or vulnerability. Changes in the pdf through time can also be animated. For the specific vulnerability map he showed us, the findings are that no future changes in precipitation would still result in large changes in future SWP deliveries because of their high dependence on snowpack which is function of temperature.

Dr. Brown briefly talked about how can we assure that stormwater design standards will be robust and prudent based on the uncertainty. For example, we do not know exactly how the 3-day in 25-year rainfall event will change in the future. We know from Clausius-Clapeyron relationship that it will increase. He suggests looking at the cost of infrastructure improvements needed to handle design rainfall total increases of 10-20% against the cost of inaction and potential risks associated with that.

Breakout Sessions

During the afternoon portion of the workshop, attendees were divided into three groups and were given the following prompts to guide the group discussions:

- Discussion of what you heard in the morning (promising approaches?)
  - Future rainfall patterns
  - Extreme rainfall (intensity-duration-frequency, IDF curves)
- What are the research gaps?
- What scenarios should be used for resiliency planning in the:
  - Short-term (next 5-10 years)
  - Long-term (beyond 10 years)
- What is the best strategy for the development of climate scenarios?
- How should that be funded

Each group was asked to select a lead facilitator to manage the time and facilitate all the questions, and a rapporteur to provide the report at the plenary session. Below is a summary of the presentations given by the rapporteur for each group.

Group 1 – Rapporteur: Robert Burgman

Group 1 was mainly composed of climate modelers. This group identified the following research gaps:

- Quantifying uncertainty on timescales of up to 10 years. Must quantify the range of internal climate variability which can be larger than the trend at least in shorter timescales.
- Looking at uncertainties associated with each downscaling methodology. Some have issues with capturing trends, others have issues with internal variability.

Group 1 suggested the following strategy:

- Do not use climate change projections for local near-term needs.
- Start with decision support needs. Talk to engineers to figure out what products and metrics they need. The needs of different regions may be different but tied together by their water resources. It is important to use the appropriate metrics that are relevant to the kind of water management or planning project. Finally, this group highlighted that a certain level of uncertainty comes from communication gaps between decision makers and scientists.

This group also suggested FLDEP and the state water management districts as potential funders for this project. They mentioned that Sea Grant has matching funds for this type of research.

Group 2 – Rapporteur: Dr. Wendy Graham

Group 2 was mainly composed of hydrologic modelers. The group highlighted the finding from future projections of a shift to less rainfall in south Florida and more rainfall in the north with a dividing line around Lake Okeechobee. The group thought this was an interesting finding and whether it can be confirmed and the physics of it explained. They found it curious that the retrospective GCM model mean for JJA underestimates historical precipitation throughout the state especially in the southern portion of the peninsula. Could this be related to the predicted future changes in JJA precipitation? They also found the onset/demise of the wet season as an interesting metric for model performance.

The group identified the following promising approaches for improving future rainfall projections: (1) using a variable grid size in GCMs for increase resolution in areas of interest, (2) development of regional ocean-atmosphere coupled models. The group discussed the need for more information about future IDF curve changes especially for sub-daily timescales. The group thought that the climate stress-test or decision-scaling approach may be a good screening tool but wonders how we could generate stochastic climate sequences to generate the vulnerability maps. They found the analog-finder technique to be intriguing but needs more investigation. Different scenarios and different downscaling methods may be different for different applications.

The following research gaps were identified:

- Identifying changes in extreme precipitation is needed, especially for sub-daily timescales
- Information on the spatial distribution of future rainfall changes is also important along with identifying physical-drivers behind these changes.
- Bias-correction and downscaling of the full suite of climate data (i.e. other meteorological variables beyond temperature and precipitation) is needed.
- Related to the above, the incorporation of cloud cover and solar radiation as part of model validation is important due to their impact on RET rates.
- Need statewide climate scenarios tailored to the specific problem. These scenarios may be different depending on whether they are to address water supply, flood control, water quality, ecosystem restoration concerns, among others. For example, water supply is more concerned with longer timescales, while flood control problems need data at short-term timescales.
- The team liked the approach from the Netherlands where scenarios are defined in terms of climate drivers in 4 distinct quadrants. A similar approach could be used in Florida. This may require additional research in identifying what the local climate drivers are (e.g. Loop Current, sea level rise, urbanization and land use changes, socioeconomic, ocean/sea breeze influence on rainfall, SST effects on the sea breeze, what drives tropical cyclones, etc.). Sensitivity analyses of climate models of the sort presented by Dr. Misra may help clarify some of these.

The group suggested the following strategy for future rainfall scenario development:

- Expert elicitation to identify the tools and scenarios which includes the following:
    - Defining metrics for each problem
    - Recommending models and methods for each metric to come up with climate scenarios or climate stress drivers (problem-based GCM selection). These could be a combination of GCMs, downscaling, analog-search and/or weather generators.
- In addition, there is a need for rapid assessment of output from new climate models and derived products as they are released. Alternatively, one could start with a rapid assessment of the vulnerabilities to decouple the metrics/vulnerabilities from the GCMs.

In terms of funding, the group thought that the project could be funded jointly by the public and private sector. Specifically, the Chief Science Officer and the Chief Resilience Officer for the state should be involved.

Group 3 – Rapporteur: Akin Owosina

Group 3 was predominantly composed of hydrologists, water managers, and planners. This group identified the following needs:

- A stress-test approach is needed. Some sort of matrix based on the stress-test approach should be developed, similar to what has been done with sea-level rise. Instead of trying to determine exactly what will happen during a certain year, let's focus on impacts of the scenarios; i.e. If it gets 10% wetter, what would be the impact? This could be a product.
- There is a need of long-term (>50 year) and event rainfall data and the interaction between the two. When we say it will get 10% wetter, how will that be distributed in time? Will all events be increased by that amount or will it come in the form of more extreme events? Will the characteristics of the event change such as having larger extents, event moving slower, etc.?
- For level of service projects at the SFWMD, design events are important. Although antecedent conditions immediately before an event are important, they do not need to know what was happening 2 weeks before.
- Changes in the length and spatial extent of dry spells are important for planning of water supply projects at the SFWMD.
- Long-term data is important for planning critical projects.
- There is a need for short-term (shock) and long-term temperature data beyond what is needed for modeling and planning purposes. Stakeholders are also concerned about heat indexes and air quality. From a climate science perspective, temperature is much easier to downscale than precipitation.
- There is a need of predictions of changes in parameters driving RET.
- The data is needed in a spatially-distributed format. For example, the 2-mile by 2-mile grid resolution used by the SFWMM.
- There are a variety of users that would need this data.

    - Water supply planners need to look at wet and dry periods and sequencing of events, while flood control managers need to look at short-term events for a variety of durations.
    - Palm Beach County is concerned about pluvial flooding and impacts on agriculture.
    - Future rainfall is also needed for road design. There are 5 classes of roads and all have different design criteria.
    - There is also a potential for higher winds from hurricanes, which may affect design standards.
    - Changes in groundwater and surface water levels may affect the Finished Floor Elevation of households.
    - Changes in IDF curves would also affect design standards.
    - Some stakeholders are concerned with responsiveness planning during extreme events.
- Scenarios are needed for short-term (20-year horizon), middle term (50-year horizon), and long-term (100-year horizon).
- Different parts of the state may need to use different models or scenarios.
- A lot of communities that are doing vulnerability analysis. They look at stressors (long-term) and shocks (acute events).

Their strategy for both event and long-term data consists of:

- Define reliable observational datasets.
- Decide which models to use (e.g. BCCA, Hyperion, LOCA, CORDEX), which may be different depending on the kind of question being asked and for different regions of the state.
- Decide which scenarios to use and what components or metrics they should include. Scenarios may be different depending on location, need and level of risk associated with the metric and potential adaptation measures. It might be prudent to recommend a different type of safety factor for shocks. Sensitivity testing is a key part of this decision. The length of time associated with each metric would be different depending on its purpose (e.g. for crops it may be 10-15 years, but 30-50 years for water supply).
- How to do bias-correction and downscaling? How do we fit a pdf to the data? This must be evaluated region-wide.
- There may be a need to do additional bias-correction.
- How to project for the future?

The group highlighted the need to be pragmatic and develop an initial set of scenarios that could be adjusted or revisited over time. They pointed to the state (DOT, WMDs, FLDEP) and federal government (e.g. USACE) as drivers of the effort. NSF grants could be looked into as well as private philanthropies who might want to fund it. The state legislature could fund it through the Chief Resilience Officer. Counties and cities should at least be stakeholders. A statewide assessment initiative driven by the state would help with buy-in on the scenarios.

The group recommended that this initiative be part of the state-wide climate assessment for Florida. Once we get a Chief Resilience Officer for the State, we could have a statewide climate assessment and a review of the ongoing efforts happening now, and then formulate a 5-year climate action plan for the state. There is already a bill in legislature for statewide climate assessment.

Plenary Session

After presentations from the individual groups, there was a plenary discussion on the needs, strategies and funding for the project. It was discussed that the funding question may need linkage between the science and the socioeconomics. For example, insurance companies may be interested in becoming funding partners. There was a discussion on the two distinct approaches for future planning under uncertainty. First, there is the traditional scenario-driven, and second, there is the vulnerability or stress-test approach which was favored by many attendees.

A critical part in ensuring the success of this project is how to improve the communication and understanding between climate modelers and stakeholders. Dr. Kirtman made the point that the CMIP models (even downscaled) were not intended for answering regional adaptation problems, but were developed for mitigation purposes. They are "What if" type of experiments and should not be considered as predictions. They are driven by economics and have large uncertainties. He suggested that stakeholders start identifying the questions that need answering and then perform the modeling scenarios that would answer these questions at the relevant scales. This would help identify whether we need telescoping grids, couple models, etc.

Mr. Owosina suggested that we start with a bottom-up approach of identifying vulnerabilities for future restoration work. For regulatory and planning needs, one would need agreed upon scenarios. For sizing infrastructure, we need some scenario data points (e.g. what SLR scenario to choose depends on the vulnerability and risk of the feature being designed).

Dr. Reed mentioned that CMIP provides a range and a sign of change. He mentioned how historical simulations with and without greenhouse gases (GHGs) are used in attribution studies to derive information on how the probability of a specific event has changed due to climate change. From these runs one can extract large-scale conditions and see how a specific storm would change under different GHG emission scenarios.

It was also discussed how a model could get the past correct for the wrong reasons. Therefore, understanding the physical conditions leading to certain events is important. The multi-model ensemble mean usually does a better job than each individual model.

Some climate modelers suggested that one can use historical data for planning for the next 10 years. However, it is not clear how to plan for longer-term planning. Having one consistent solution for the entire state which agrees across boundaries is important. The tool to use depends on the type of question that needs to be answered which includes its temporal and spatial resolution.

Dr. Sukop mentioned that we have the same broad needs as engineers, which are short-term and long-term climate predictions as well as sea level rise predictions. The CMIP scenarios can bracket things, so they are still useful.

Mr. Owosina suggested that for higher risk projects one could use a broader range of scenarios, while for lower risk projects they can be narrowed down. One set of road guides is needed across the state. There would be challenges due to inconsistencies in short distances if different water management districts were to use different climate models.

Dr. Maran gave an example of a specific issue, which is how they developed a progressive map for the minimum floor elevations in Broward County and yet it has recently been surpassed by FEMA curves. Some water control structures are already operating at small head gradients and there is a need to plan for improvements now, not later when models may be more refined.

Dr. Obeysekera closed the plenary session by mentioning that a DRAFT report of the workshop will be developed and then shared with attendees to get their input. The report should be a consensus document that lists research gaps and identify areas where money needs to be invested immediately. In addition, immediate next steps need to be identified.

Workshop Summary

The workshop brought many of the key researchers with experience in working on climate projections in the State of Florida. While the focus of the workshop was largely on rainfall, the issues that were raised are equally applicable to other climate change variables of interest such as temperature. Sea Level Rise was not discussed as it is being addressed through other means. Following is a high-level summary of the findings, issues, and suggestions from the workshop participants

SFWMD's mission includes a broad range of water management objectives which include flood protection, water supply, water quality protection and natural system protection and enhancement. To date, future planning of comprehensive water management projects have assumed "stationarity" which, as its basis, assumes that the future climate regime will be similar to what has been observed historically. In view of impending climate change, this assumption may no longer be valid and planning of projects cannot ignore the potential for a "nonstationary" climate which is expected to evolve over the 21st century and beyond. Large investments being planned by SFWMD for programs such as Everglades and Restoration, and the Level of Service for both flood protection and water supply will need to incorporate non-stationarity into the planning process. SFWMD and some academic partners have already invested some efforts towards the evaluation of available climate projections which has revealed strengths and limitations of both global and regional models (both statistically- and dynamically downscaled) and their uncertainties. Advancements in academic efforts have included development of more efficient downscaling techniques and the use of regional climate models which have been constrained by historical observations specific to the State of Florida. Unfortunately, such efforts have not resulted in consensus on data sets and/or models that should be used for future planning. A prudent strategy for using the existing models and data sets, and for developing regional climate models designed to capture important climatic processes important for Florida needs to be developed. Because the planning efforts cannot wait for the development of new tools, this strategy needs to address both short- and long-term needs.

Research to date reveals some important issues that must be addressed in this strategy. First, it appears that there is a disconnect between the stakeholder needs and the design of climate modeling exercises. This gap may be due to a lack of communication among the users and climate modelers and/or the inadequacy of user requirements that have been published. This finding leads to the need for a co-production approach involving users and climate modelers in the future.

Second, when climate model data are appropriately compared with historical data, temperature projections appear to perform better than those of rainfall. In particular, both statistically and dynamically downscaled climate data exhibit large biases in extreme rainfall. Some research suggests that the spatial and temporal resolution of existing climate data may not be adequate to represent the spatial patterns of both mean state and extremes in Florida. Furthermore, the reproduction of the correlation between natural variability, an important characteristic that must be simulated in future projections, and the climate phenomena external to Florida (e.g. ENSO) via teleconnections appears to require a higher-resolution climate models than what is available for the state. Future mean state of rainfall across the state appears to have a unique signature north and south of Lake Okeechobee. The question is, is this an artifact of downscaling or is there a physical basis for such a distinct pattern. Research also show that the rainfall in Florida may be affected by sea surface temperatures in the vicinity and other phenomena such as the Loop Current suggesting the importance of coupled ocean-atmosphere models for predicting rainfall adequately.

Third, the climate modelers are concerned that the current suite of climate models and scenarios are not being used appropriately for future planning. The concern among the modelers is that model data sets were never meant as future potential realizations but rather, they were “what if” scenarios associated with variations in drivers of climate change. This is an important issue since the users may need to rethink the way they use climate model projections. The “Decision Scaling” or the “Stress Test” approach that was discussed appears to be promising as an alternative approach for the proper use of climate model data, although such an approach has its own challenges. Alternatively, the Dutch approach of developing a limited number of scenarios based on important drivers of regional climate from a large ensemble of global and regional climate model data sets may be employed.

Strategy

Based on the research and the recommendations by the workshop participants, a two-pronged strategy to meet both the short-term and long-term needs is proposed.

1. Short-Term (0 – 5 years)

SFWMD should first develop and publish a document which describes specific climate information needs for its various programs and project. For example, the specific design-rainfall information (intensity, duration, frequency) necessary for protecting infrastructure associated with the Level of Service (LOS) or Everglades Restoration must be out documented in a manner that is unambiguous to climate modelers.

Similarly, it needs to document the spatial and temporal resolutions necessary for hydrologic/hydrodynamic modeling associated with long-term simulations of projects associated with water supply planning and Everglades Restoration. Ideally, this must be developed using a co-production approach involving both users and climate modelers.

There are several candidate data sets that are available for short-term planning. They include, LOCA, BCCA, BCSA, and CORDEX which have been published by various governmental agencies and academic institutions. The strategy suggests that the SFWMD complete the evaluation of data sets, select one for short-term planning, and develop an ensemble of realizations that may be used as input to hydrologic/hydrodynamic models used for planning. This effort may require developments of input time series for hydrologic variables that depend on climatic data (e.g. Potential Evapotranspiration, water demand). Although, it is feasible to run the hydrologic models using the entire ensemble, that may not be necessary. The use of "Stress Testing" approach should be fully explored to identify a subset of model datasets that are relevant to the project objectives. The identification of the subset may also use the Dutch approach of uncertainty reduction by investigating important drivers of regional climate.

Because of the biases in extreme rainfall, the use of available climate datasets for projects requiring design rainfall is challenging. A separate evaluation of the best available data sets to inform the extreme rainfall scenarios for the future should be conducted. A scenario approach may be the best alternative to plan future LOS projects for flood protection until reliable tools for regional climate models become available.

2. Long – Term (0 to 15 years)

Recent research presented at the workshop has revealed that the current climate models do not have sufficient skills to predict future rainfall patterns, particularly the extremes. More importantly, existing regional climate models may not have the resolution necessary to predict effects of local meso-scale phenomena and teleconnections associated with El Nino Southern Oscillation (ENSO), the Atlantic Multi-decadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO). A reliable tool is necessary to explore simulation experiments to answer key questions that would influence planning and operation of the water management system. Examples of such questions are:

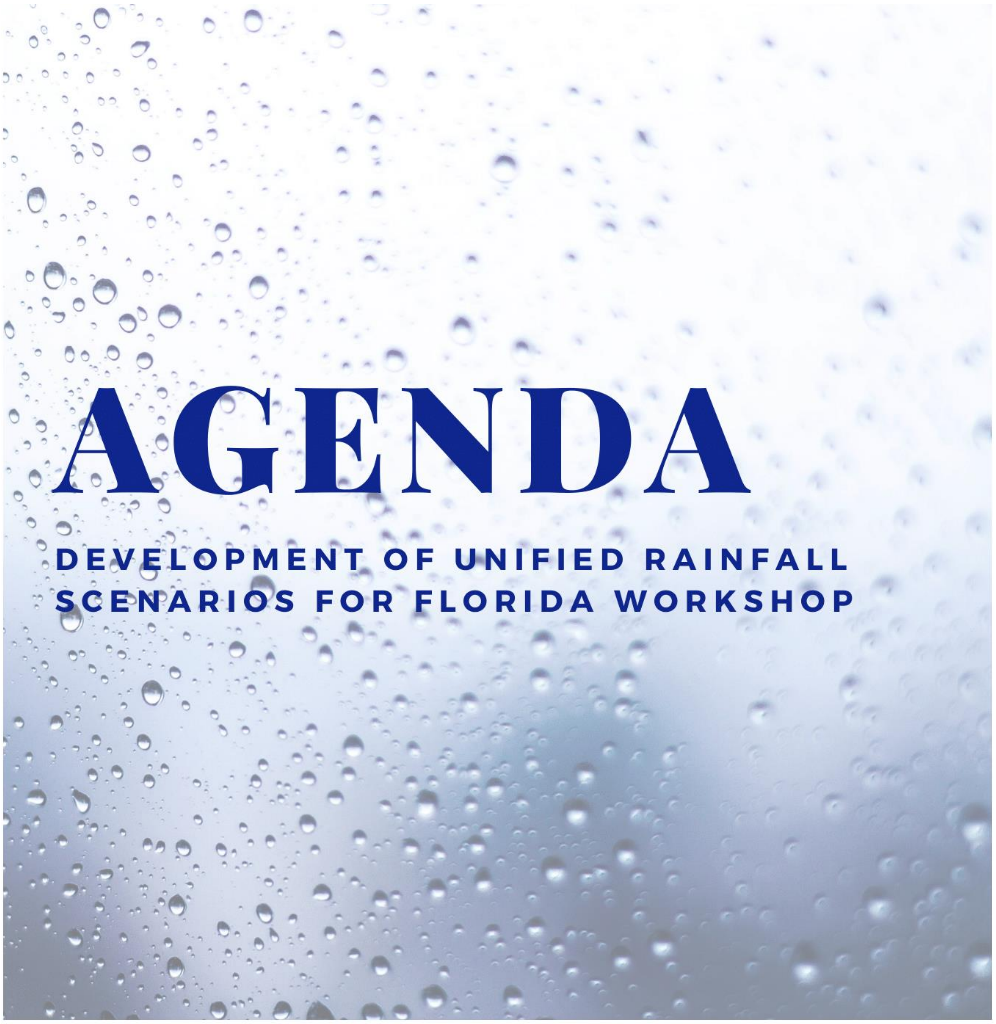
- Will the future 100-year events change within the next 30-40 years given that the RCPs do not make much of a difference until after 2050? A series of experiments may help us understand the natural variability inherent in the regional climate system. This would be useful for the Flood Protection Level of Service planning guidance.
- How will the long-term and seasonal rainfall change? This would be useful for long-term planning of water supply and environmental restoration projects.

SFWMD (possibly with other WMDs) should issue a call for proposals to develop one or more regional climate models appropriate for the State of Florida. Such a proposal should also include key stakeholder questions that should be addressed through simulation experiments to be conducted as a part of the project.

Acknowledgments

This is publication number 23 of the Sea Level Solutions Center in the Institute of Water and Environment at Florida International University.

Appendix A. Workshop Agenda



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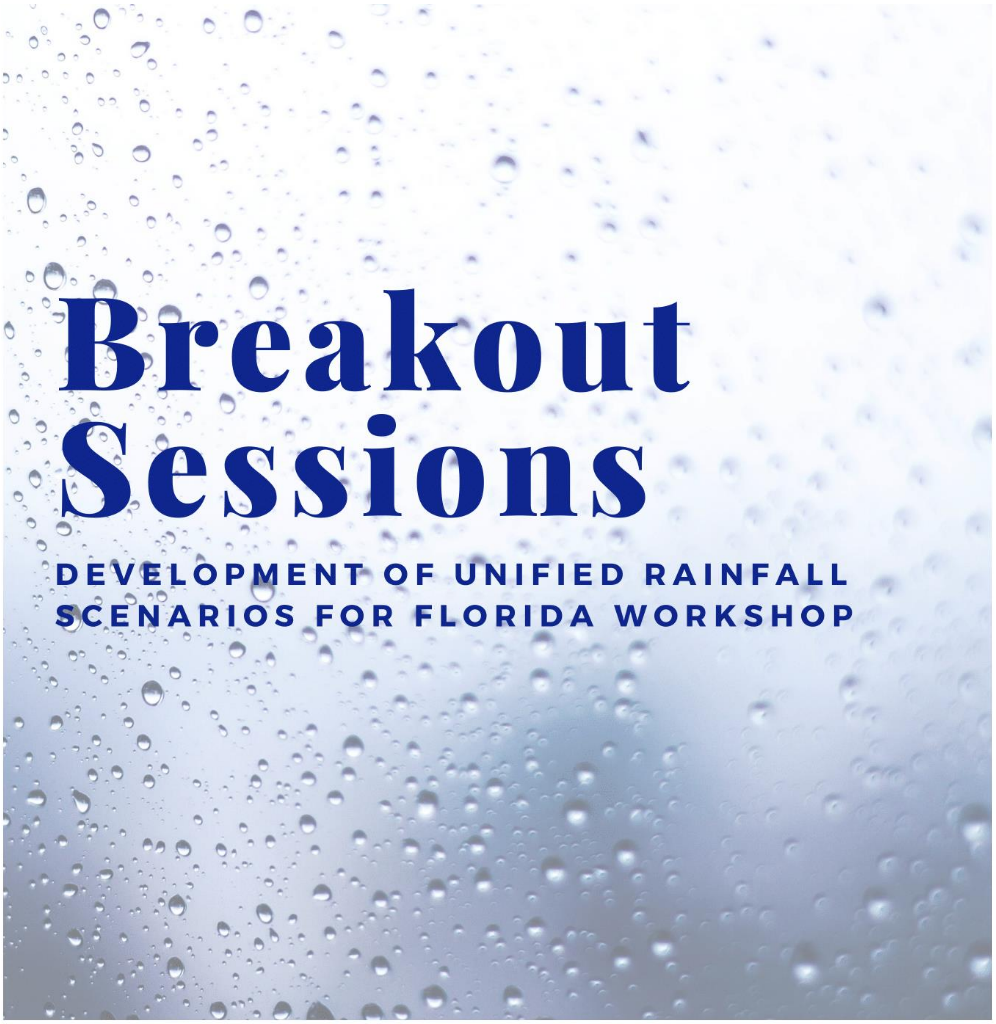
SCHEDULE

8:00 - 8:15	Registration
8:15 - 8:30	Welcome Remarks: Todd Crowl, FIU InWE; William Anderson, FIU ORED
8:30 - 8:40	Welcome Remarks: South Florida Water Management District
8:40 - 9:00	Progress to date by SFWMD
9:00 - 9:20	**"Rainfall variability over Florida: Opportunities and Challenges"**, Vasu Misra, Florida State University
9:20 - 9:50	**“Aggregated climate change scenarios for the Netherlands: their construction and stakeholder uptake”,** Bart van den Hurk, on behalf of Rijkswaterstaat, KNMI, Deltares, The Netherlands
9:50 - 10:00	**BREAK**
10:00 - 10:20	**“High-resolution and low resolutions climate model predictions for south Florida and southeast United States drought”,** Ben Kirtman; **"Constraining model projections of regional precipitation change",** Brian Soden; **“The AMO and Florida rainfall”,** Amy Clement, and Jeremy Klavans, all from University of Miami
10:20 - 10:40	**“An Integrated Evaluation of the Simulated US Hydroclimate System: Focusing on Extreme Rainfall”** Hyperion Project (funded by Department of Energy), Kevin Reed, Stony Brook University
10:40 - 11:00	**"A hybrid dynamical-statistical analog downscaling technique to efficiently explore changes in extreme precipitation",** Jupiter Intelligence, Luke Madaus, Boulder, Colorado
11:00 - 11:20	**“Evaluation of future climate change and water use scenarios on regional hydrology”** Wendy Graham, Water Institute, University of Florida, Tirusew Asefa, Tampa Bay Water
11:20 - 11:40	**“Statewide Trends in Rainfall minus Potential ET”,** Barclay Shoemaker, David Sumner, US Geological Survey (USGS)
11:40 - 12:00	**“Considerations for the Design and Use of Scenarios that Inform Robust Decisions”,** Casey Brown, University of Massachusetts, National Academy, CISRERP Committee of the Everglades
12:00 - 1:00	**LUNCH BREAK**
1:00 - 2:30	Breakout sessions: Needs, strategies, and funding (for both short-term & long-term)
2:30 - 3:30	Presentations by Breakout groups
3:30 - 4:30	Plenary Discussion
4:30 - 5:00	CLosing Remarks



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BREAKOUT SESSIONS

OBJECTIVES

- Review the state-of-the-art in downscaling (both statistical and dynamical) rainfall for the State of Florida (morning)
- Develop a strategy for the development of statewide series of climate scenarios that may be used for resiliency planning (afternoon)
  - The primary focus of this workshop is on rainfall (both extremes and averages)
  - Research Gaps
  - Short-term and long-term
  - Execution strategy
  - Potential funding options

GENERAL INFO

- Discussion of what you heard in the morning (promising approaches?)
  - Future rainfall patterns
  - Extreme rainfall (Intensity-duration-frequency (IDF) curves
- What are the research gaps?
- What scenarios should be used for resiliency planning in the:
  - Short term (next 5-10 years)
  - Long term (beyond 10 years)
- What is the best strategy for the development of climate scenarios?
- How should that be funded?

PROCESS

- Select a lead facilitator
  - Manage time to facilitate all questions
- Select a rapporteur
  - Provide the report at the plenary session

Appendix B. Workshop Attendance

Table 1. List of workshop attendees and contact information.

First Name	Last Name	Email
Candice	Allouch	callouch@fiu.edu
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Appendix C. Links to Climate Datasets

LOCA: http://loca.ucsd.edu/

BCCA: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

BCSA precipitation: http://ufdcimages.uflib.ufl.edu/IR/00/01/05/42/00001/BCSA_pr.zip

CORDEX: https://www.cordex.org/data-access/

Appendix D. Workshop Presentations