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2017 Coastal Master Plan

Attachment C2-3: Precipitation and Evapotranspiration

Report: Version I

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Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration master plan.

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Executive Summary

Climate scientists have developed numerous future climate projection datasets at various spatial and temporal scales. General circulation models (GCMs) have been widely used to analyze the impact of greenhouse gas emissions on future climate, and are increasingly used to develop regional models of future climate. Recent efforts by the United States Geological Survey (USGS) have made various regional climate projections available for use by the general science and engineering communities. Three of these available regional climate projections, all dynamically downscaled via the RegCM3 regional climate model, were used to determine a range of future precipitation and evapotranspiration scenarios across coastal Louisiana. These three datasets were developed by setting the boundary conditions of RegCM3 equal to output from three GCMs (GFDL, ECHAM, and GENMOM) that were all run on the A2 emissions scenario, as analyzed in the Intergovernmental Panel on Climate Change's Fourth Assessment Report. In addition to the future projections of climate, historic records of precipitation and historic monthly mean potential evapotranspiration rates (calculated via Penman-Monteith) were included in the development of future climate ranges.

After comparing the historic records to the RegCM3 datasets to ensure that seasonal patterns are maintained by the regional climate datasets, the following ranges are proposed for use in the 2017 Coastal Master Plan modeling effort:

Precipitation: The historic rainfall record for coastal Louisiana will be used as a middle-range value of future climate. The historic rainfall will be bounded on the lower end by the RegCM3 dataset driven by the GENMOM boundary conditions. The upper bound on future precipitation will be set by the RegCM3 dataset driven by the ECHAM boundary conditions.

Evapotranspiration: The middle-range of future evapotranspiration will be set by the ECHAM-driven RegCM3 dataset. The lower range of ET will be set by the GENMOM RegCM3 dataset, and the upper bound will be the Penman-Monteith mean monthly evapotranspiration from historic climate records.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BATS	Biosphere-Atmosphere Transfer Scheme
CPRA	Coastal Protection and Restoration Authority
ECHAM5	Max Planck Institute for Meteorology ECHAM5 general circulation model
ET	evapotranspiration
GCM	general circulation model
GENMOM	USGS and Portland State University GENMOM general circulation model
GFDL	NOAA's Geophysical Fluid Dynamics Laboratory Climate Model 2.0
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
MSY	New Orleans International Airport
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
RCM	regional climate model
RegCM3	NCAR's Regional Climate Model - 3rd generation
USGS	United States Geological Survey
NARCCAP	North American Regional Climate Assessment Program

1.0 Introduction

1.1 Overview of Climate Projections

The recent availability of regional climate model (RCM) datasets, produced by a downscaling process from general circulation model (GCM) climate projections, provides an opportunity to estimate a range of future precipitation and evapotranspiration (ET) scenarios. These scenarios will be considered for usage in the 2017 Coastal Master Plan (master plan). The ability to include climate change scenarios into the master plan will provide a sound basis for quantifying a range of future precipitation and evapotranspiration projections, as well as help understand how climate change could impact Louisiana's coastal restoration and protection planning efforts.

GCMs are developed and used by climate scientists to simulate how global climate will respond to changes in greenhouse gas (GHG) concentrations. In general GCMs simulate both precipitation (dynamic and convective) and temperature at the global scale; however, regional effects on climate driven by topographic (and other physical) elements are not captured in GCMs. Therefore, in order to utilize future GCM climate projections in regional analyses, such as the master plan, GCM climate projections are used to define the boundary conditions of RCMs, which better capture these local effects on climate than the GCMs (Hostetler et al., 2011).

Downscaling GCM scenarios can be used to obtain locally relevant future predictions of climate parameters. Various methods exist for downscaling GCM data (e.g., statistical and dynamical downscaling) and may introduce systematic errors into the hydrological forecast (Bastola & Misra, 2014). Regional climate models can also be nested in GCMs to study climate processes at higher resolutions and model system dynamics at regional scales, but require quality driving data (i.e., boundary conditions) and high computational resources (Rummukainen, 2010).

1.2 Downscaled Datasets Used in this Analysis

Three publically available datasets for projected precipitation and evapotranspiration for coastal Louisiana were used for this current analysis. These datasets were prepared by the USGS with the Regional Climate Model (RegCM3) using three GCMs to define boundary conditions. The three GCMs used in preparation of these datasets were: the Max Planck Institute for Meteorology ECHAM5 model, NOAA's Geophysical Fluid Dynamics Laboratory Climate Model 2.0 (GFDL), and the USGS and Portland State University GENMOM model. All three GCMs were run assuming the A2 emissions scenario from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Currently, these publically-available regional climate datasets are only available for GCMs run using the A2 scenario; projections from other emissions scenarios were not available.

The authors acknowledge the existence of other downscaled climate datasets and models. However, these three RegCM3 datasets were identified not to imply that they cover all the possible future projections; rather they would provide a consistent and representative subset of possible future projections of precipitation and ET conditions over the model domain. It is also acknowledged that analysis of these RegCM3 and other downscaled climate models at the regional scale remain to be investigated and will be considered for possible inclusion in future master plan efforts. Another reason for selection of these specific RegCM3 datasets is that they provide both precipitation and ET, which may not be available with other options.

Since the Fourth Assessment Report was published, the IPCC has updated the emissions scenarios used in their analyses. Therefore, the A2 emissions scenario is no longer actively being used in assessing future climate projections. While it may be no longer used in global climate modeling efforts under the auspices of the IPCC, regional climate model data developed from these global datasets still, by and large, rely on the A2 model runs to define boundary conditions. The publically available RCM datasets available from both USGS and the North American Regional Climate Assessment Program (NARCCAP) all rely on the A2 emissions scenario to drive modeled boundary conditions for future projections of climate (Hostetler et al., 2011; Mearns, 2012). While new downscaled datasets could be developed from different GCM scenarios for the 2017 Coastal Master Plan, this document focuses on existing science and readily-available data. Undertaking a task to downscale GCM datasets from other emissions scenarios would be a very extensive effort, well outside the scope of this report. A more in-depth discussion of the A2 scenario, and its impact on precipitation and ET projections, is provided in the following section.

The three downscaled RCM datasets covered the same spatial extent, but were run for overlapping, but not identical, time periods. All data were downloaded in NetCDF format from the USGS's online Geo Data Portal (USGS, 2013), and processed into a database using a NetCDF extraction tool (Davies, 2013) within the Python environment. Table 1 summarizes the hindcast and projection time periods downloaded for each model.

Table 1: Time periods of downscaled RCM data used in this analysis.

GCM used as boundary in RegCM3	Hindcast Period	Projected Period
GFDL	1970-1999	2040-2069
ECHAM	1970-1999	2020-2099
GENMOM	1980-1999	2020-2080

1.3 A2 Emissions Scenario

The A2 emissions scenario corresponds to a high emissions scenario with a "best estimate" of global temperature change of 3.4°C from 1999 to 2099, and is the only future scenario used to develop the downscaled precipitation and ET data available from the USGS's online Geo Data Portal. Numerous other emissions scenarios have been analyzed by the IPCC, and the Fifth Assessment Report (released in 2014) no longer uses the A2 scenario. However, the IPCC states that the A2 scenario is similar, in terms of radiative forcing as the RCP8.5 scenario used in the IPCC's Fifth Assessment Report (Moss et al., 2008). The RCP8.5 scenario corresponds to the 90th percentile of projected greenhouse gas emissions if baseline conditions (i.e. current emission levels) persist throughout the next century. This is the 90th percentile of projected emissions reported in the scientific literature (not calculated from a frequency distribution). It serves as a useful upper estimate on radiative forcing in GCMs. In other words, this "business-as-usual" RCP8.5 scenario represents the likely upper range of projected climate change scenarios (Sankovich et al., 2013; Moss et al., 2008).

Due to these similarities between the A2 and RCP8.5 scenarios, the A2 scenario remains a reasonable upper estimate on future climate change, in terms of GHG emission rates and the associated increase in radiative forcing, and is still frequently used in climate analyses (Sankovich et al., 2013; Mearns, 2012; Hostetler et al., 2011). While the A2 emissions scenario remains a useful upper estimate of projected GHG emissions and climate change, it is important to recognize that the upper range of projected emissions does not necessarily translate to the upper range of precipitation projections. In fact, Liu et al. (2011) analyzed the range in precipitation projections from an ensemble of downscaled GCM runs for the southeastern U.S., and concluded that the A2 scenario returns the lowest precipitation projections of the three scenarios they examined (Figure 1). The other two scenarios both had lower emission projections than A2, but resulted in more precipitation.

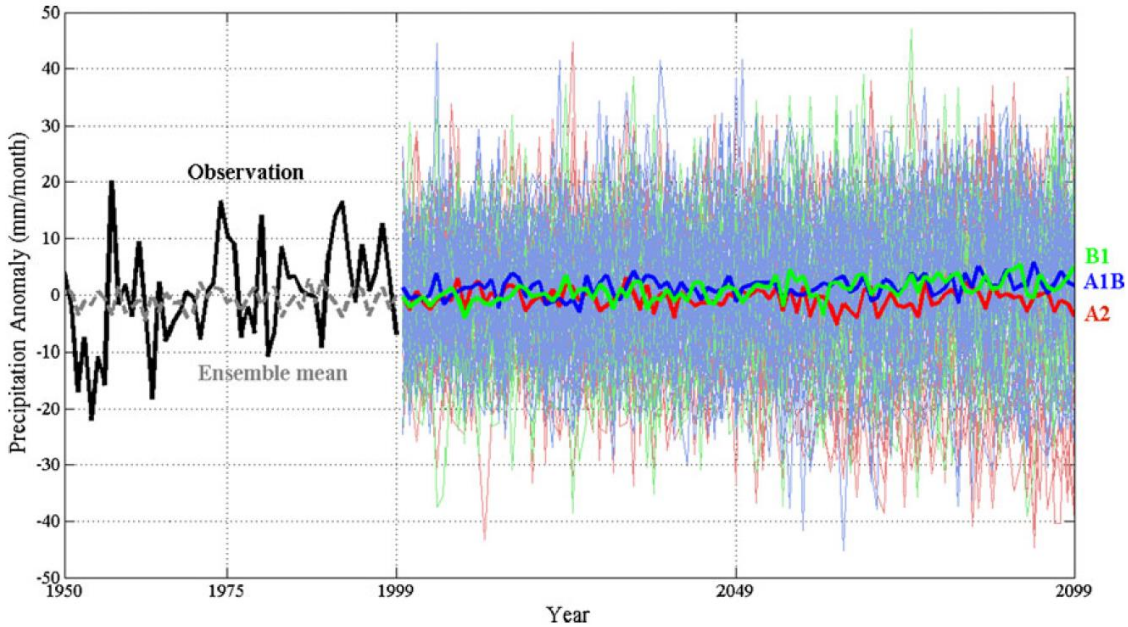

Figure 1: Projected precipitation anomalies in the southeastern U.S. from ensembled downscaled datasets for three emission scenarios. These data are relative to 1950-1999 mean in the southeastern U.S. from ensembled downscaled datasets for three emission scenarios as follows: A2 = high emissions path, A1B = middle emissions path, B1 = low emissions path (from Liu et al., 2012).

Error! Reference source not found. (Liu et al., 2012) shows the projected monthly preciptation nomalies for the southeastern U.S.; it is evident that during all months, except October,the A2 scenario is the driest of the three projections. The two lower emissions scenarios, A1B and B1, both project that all months will be wetter than current averages; the A2 scenario projects a drier first half of the year than current averages.

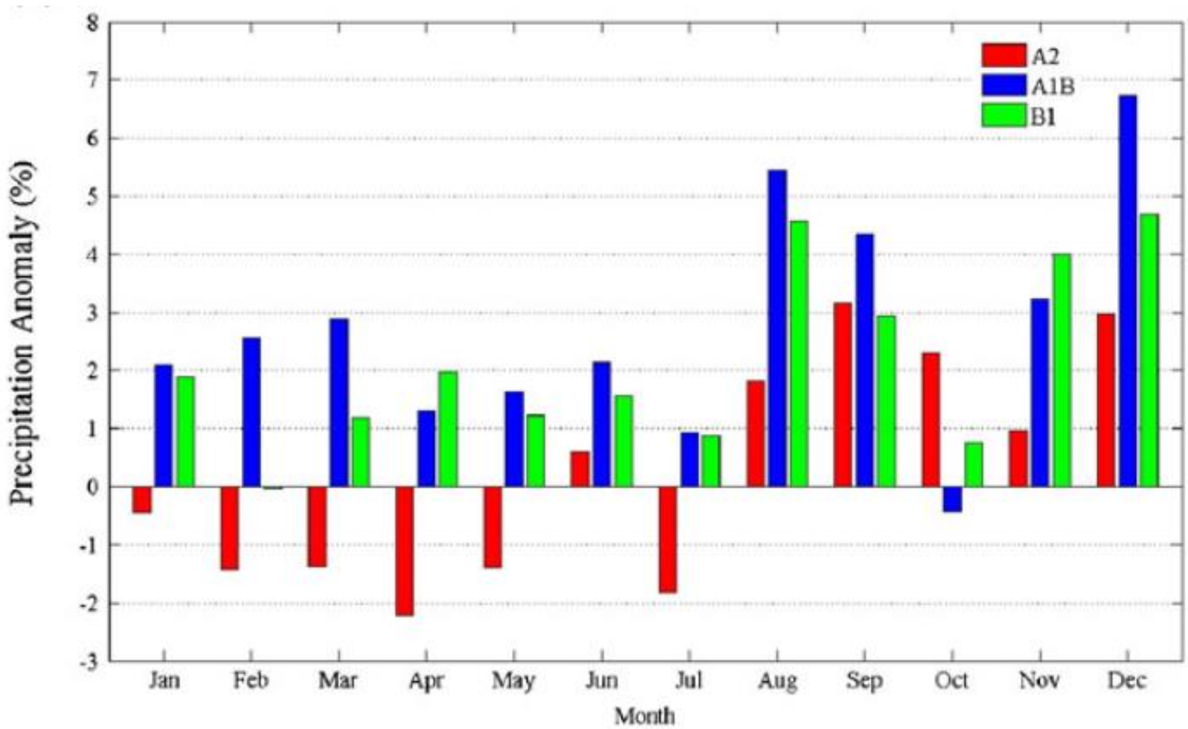

Figure 2: Projected monthly precipitation anomalies in the southeastern U.S. from ensembled downscaled datasets for three emission scenarios. These data are for 2000-2099 period, relative to 1950-1999 from ensembled downscaled datasets for three emission scenarios as follows: A2 = high emissions path, A1B = middle emissions path, B1 = low emissions path (from Liu et al., 2012).

In addition to the projected precipitation scenarios, Liu et al., (2012) also report comparisons in projected temperature increases between the three emissions scenarios, which can be used, in conjunction with precipitation to infer differences in ET projections between the different emission scenarios. ET is influenced by surface characteristics, vegetative cover and micrometeorological factors such as precipitation, temperature, cloud cover, humidity, and wind ((Drexler et al., 2004; McKenney & Rosenberg, 1993). As a result, change in climate, land use and land cover will have a significant impact on ET and subsequently, the global hydrological cycle. For instance, increasing temperatures, radiation and wind speed, and decreasing precipitation, cloudiness, and humidity can all contribute to increases in ET (Abtew & Melesse, 2013).

As previously discussed, of the three emissions scenarios examined by Liu et al. (2012), A2 is the driest. Of these three scenarios, A2 also has the highest projected rise in mean temperatures (Figure 3: Projected surface temperature anomalies in the southeastern U.S. from ensembled downscaled datasets for three emission scenarios.). Due to the A2 scenario being the hottest and driest of the three emissions scenarios and the fact that the other drivers of ET were not quantified in this comparison of scenarios, it is assumed that the A2 scenario is likely to produce the largest increase in ET of the different emissions scenarios. This finding holds with recent models that suggest a future decrease in the available water resources for the lower Mississippi River region as a result of land use and climate change impacts on river flow and ET (Caldwell et al., 2012; Hagemann et al., 2012). These findings are particularly important when designing future scenarios for the 2017 Coastal Master Plan, since it is likely that these model results will be most sensitive to the driest future conditions, which correspond to the A2 emissions scenario in southeastern U.S.

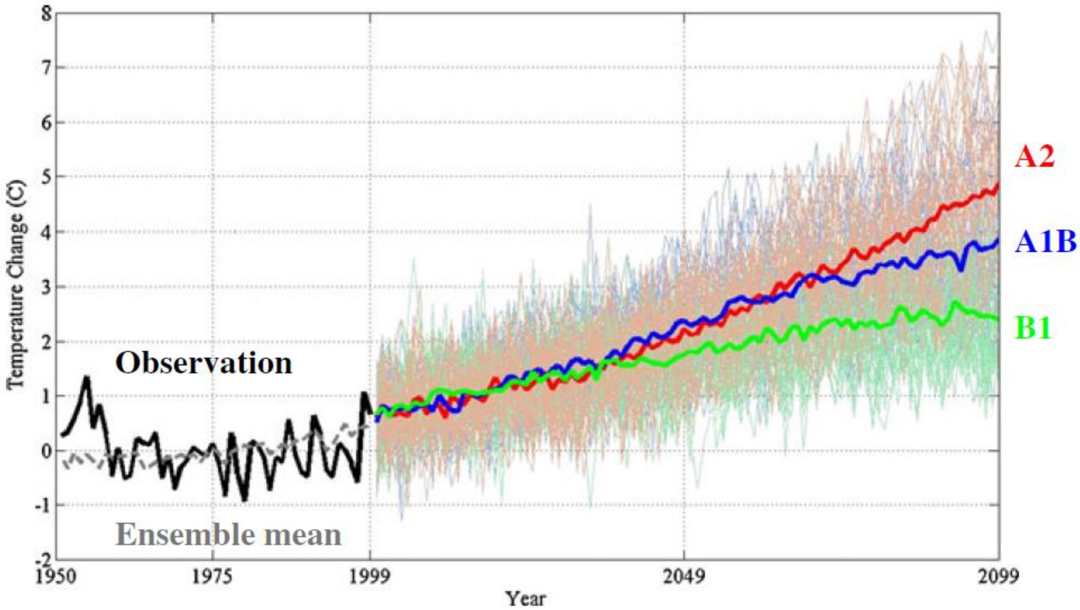

Figure 3: Projected surface temperature anomalies in the southeastern U.S. from ensembled downscaled datasets for three emission scenarios. These data are relative to 1950-1999 mean from ensembled downscaled datasets for the following three emission scenarios: A2 = high emissions path, A1B = middle emissions path, B1 = low emissions path (from Liu et al., 2012).

2.0 Comparison of RegCM3 Datasets to Observed Records

In addition to providing datasets of future precipitation and ET projections, the three downscaled models also produced hindcast data. This resulted in several decades where the RCM datasets could be compared against observed precipitation records in coastal Louisiana. By comparing these models to observed precipitation and calculated average ET rates, the models' ability to reproduce seasonal variability in precipitation and ET can be determined.

2.1 Precipitation Comparison

An overlay of the master plan coastal basins with the three RCM datasets resulted in a data coverage area of 3,690 km^2, with spatial resolution equal to the 15 km grid cell used by the RegCM3 model. Across this area covered by the master plan, there were seven precipitation gages operated by the NOAA's National Climatic Data Center (NCDC) that provided continuous precipitation time-series throughout the three model's hindcast periods (Table 2). The locations of these seven gages were projected onto the grid coverage and a RegCM3 grid cell was associated with each precipitation gage location (Figure 4). The data from each of these seven gages was then compared to the respective grid cell for each of the three hindcast RCM datasets.

Table 2: Precipitation gages used in this analysis.

Precipitation Gage Name	NCDC Gage #	Location # in Figure 4
Port Arthur, TX	GHCND:USW00012917	1
Lake Charles, LA	GHCND:USW00003937	2
Rockefeller, LA	GHCND:USC00167932	3
Abbeville, LA	GHCND:USC00160007	4
Morgan City, LA	GHCND:USC00166394	5
Galliano, LA	GHCND:USC00163433	6
New Orleans Int'l Airport (MSY)	GHCND:USW00012916	7

To determine how well each of the three datasets matched observed precipitation records, the long term monthly average precipitation and evapotranspiration depths were compared between the model results and the observed records. Due to the different hindcast periods used by the GENMOM-based dataset (Table 1), two different long term monthly averages were developed for the observed precipitation records; one from 1970-1999 for comparison to ECHAM and GFDL, and one from 1980-1999 to match GENMOM.

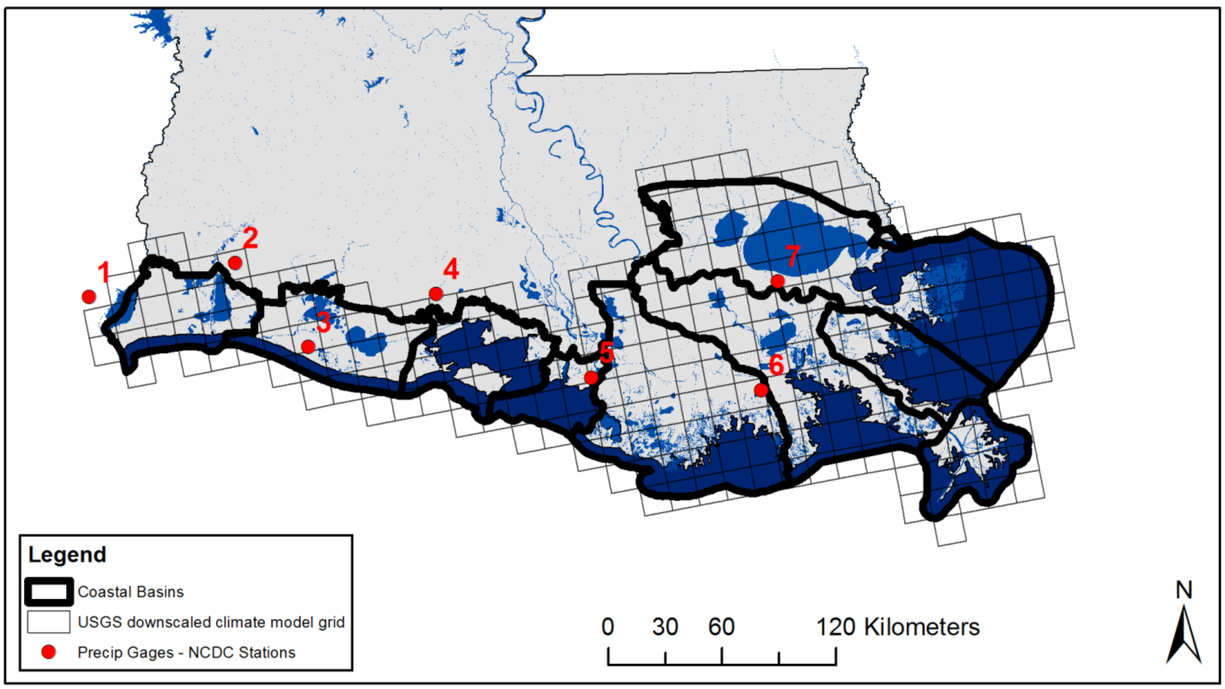

Figure 4. RegCM3 dataset domain and NCDC gage locations.

For comparison purposes, several plots of monthly precipitation values were developed for each of the seven gage locations. The first plot (Figure 5) analyzed the average monthly precipitation for the 1970-1999 period. For ease of comparison, the 1980-1999 monthly averages for GENMOM were also included on this plot. However, a second plot was also generated at each location comparing the GENMOM results to the observed means for the 1980-1999 period (Figure 6). The results from the New Orleans International Airport gage (MSY) are provided in Figure 5 and Figure 6 as an example; however the plots from all seven gage locations are provided in Appendix A.

The three RCM datasets match observed seasonal trends fairly well. For any given month (with less accuracy in late summer), at least one of the three models predicts the monthly precipitation reasonably well at each gage location. At MSY, for instance, Figure 5 shows that the GFDL model closely matches the monthly observed precipitation in January, February, March, May, and November and ECHAM matches best in April, October, and December. The GENMOM model is the best match at MSY for the months of June, July, and August. None of the models perform particularly well at MSY for the month of September. Table 3 provides the percent error of each RCM dataset's monthly average, as compared to the monthly averages from the observed record.

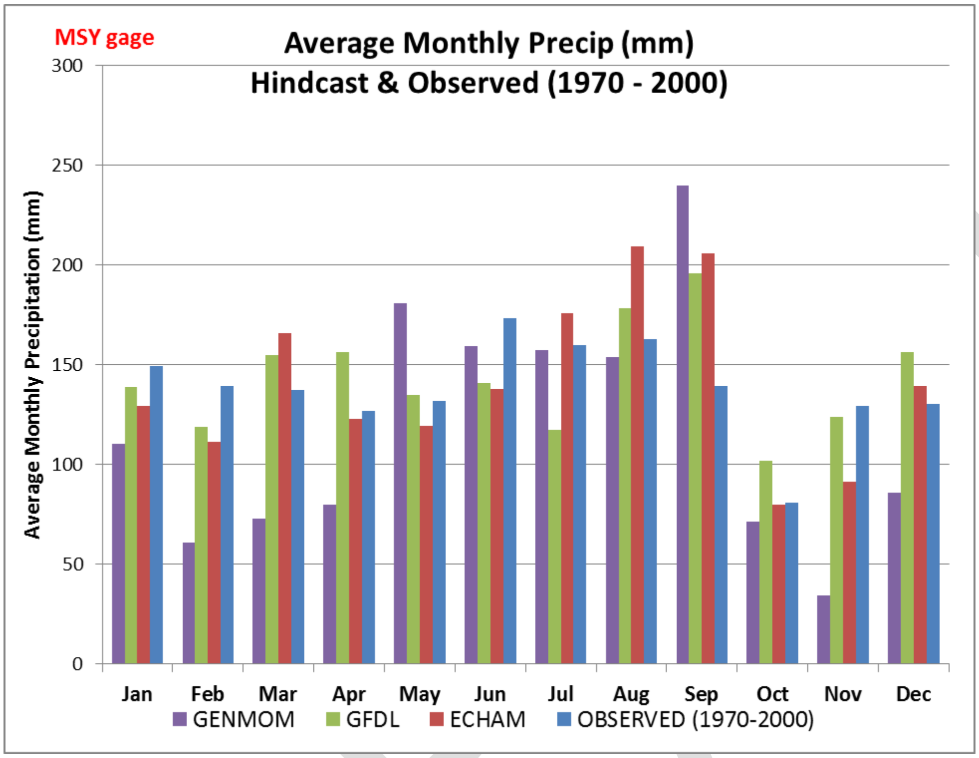

Figure 5: Monthly mean precipitation for the New Orleans International Airport gage, as compared to the three downscaled hindcast datasets. Note that the GENMOM means are only from 1980-2000 (see Figure 6 for the observed means from this same period).

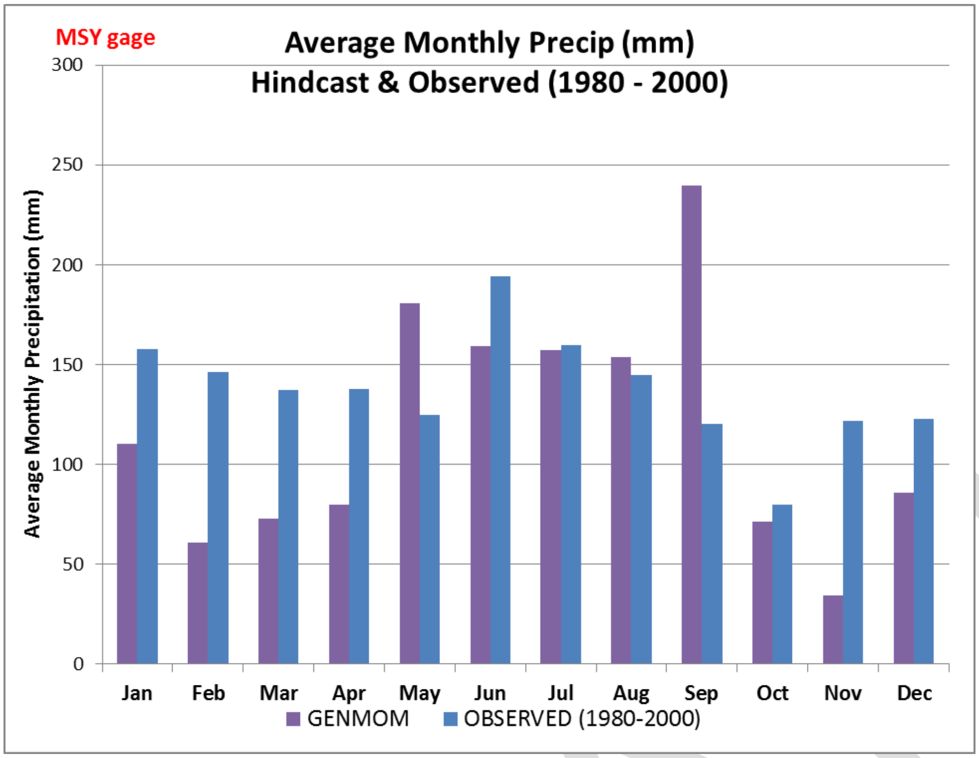

Figure 6: Monthly mean precipitation for the New Orleans International Airport gage, as compared to the GENMOM hindcast period from 1980-2000.

Overall, each month has one GCM model that slightly outperformed the other two models. However, a different model best matched the observation from month to month and from one location to another. In general, it is evident from the plots and tables provided in Appendix A that, as a suite, the RegCM3 data adequately captures the historical seasonal variability of non-tropical-storm precipitation in coastal Louisiana (see Figure 7).

Table 3: Monthly precipitation percent error at MSY gage location.

	1980- 1999	1970-1999	
	GENMOM	GFDL	ECHAM
Jan	-30%	-7%	-14%
Feb	-58%	-15%	-20%
Mar	-47%	13%	21%
Apr	-42%	23%	-3%
May	45%	2%	-9%
Jun	-18%	-19%	-20%
Jul	-2%	-26%	10%
Aug	6%	10%	29%
Sep	99%	41%	48%
Oct	-11%	26%	-1%
Nov	-72%	-4%	-29%
Dec	-30%	20%	7%

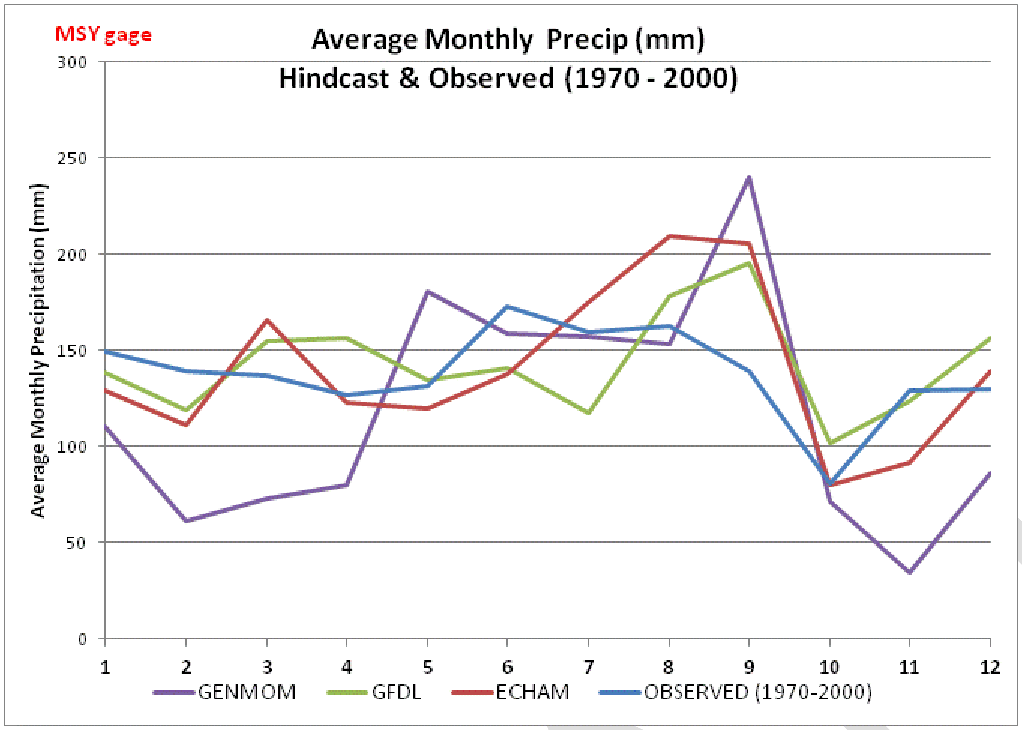

Figure 7: Range in monthly mean precipitation records for the New Orleans International Airport gage.

2.2 Evapotranspiration Comparison

The ET datasets generated by the USGS were analyzed in the same manner as the precipitation data. However, unlike precipitation, observed ET data were unavailable for this analysis. Instead, monthly average ET values, used as input in the 2012 Coastal Master Plan models, were used as a reference ET record. The RCM data that was extracted at the NCDC precipitation gage locations was utilized for this analysis, and compared to a potential ET calculated via the Penman-Monteith method and provided in the International Water Management Institute's World Water and Climate Data Atlas (IWMI, 2014).

The IWMI ET data were provided in a gridded dataset, and in a manner analogous to the extraction of the RCM downscaled data, the NCDC gage locations were projected onto the ET grid surface and a single grid value was extracted at each NCDC gage location. Therefore, there are four locations where the IWMI Penman-Monteith ET data are compared to the three RegCM3 ET datasets (Figure 8).

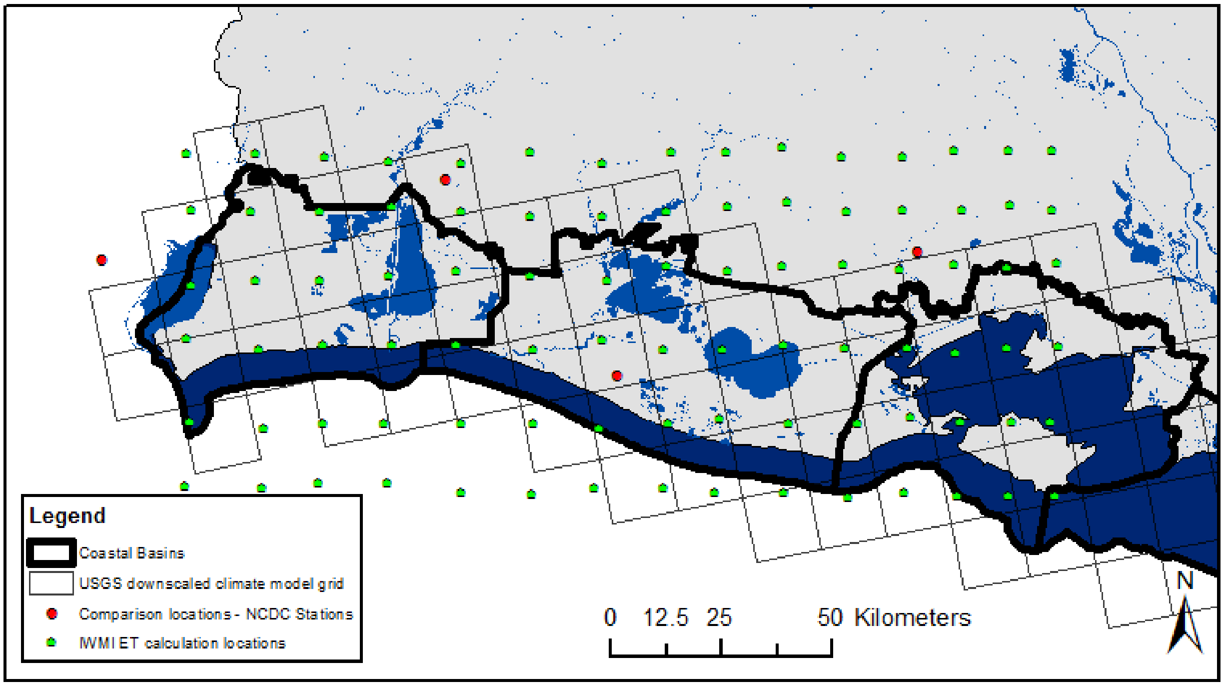

Figure 8: IWMI-calculated potential ET dataset used in the 2012 Coastal Master Plan.

As Figure 9 shows (see Figure B 1 through Figure B 12 provided in Appendix B for plots from other gage locations), the RCM datasets match the seasonal variability of ET well in the southwestern portion of the state; however, the RCM's tend to under-predict ET as compared to the IWMI climate atlas ET calculations. Like the precipitation results, for each month there is at least one RCM that is reasonably close to the Penman-Monteith ET, although the RCM datasets tend to perform equally well in some months. All of the RCM models tend to under-predict ET as compared to the IWMI ET dataset, which is likely due to the fact that the IWMI Penman-Monteith calculates a potential ET rate, whereas the RegCM3 models calculate actual ET via the Biosphere Atmosphere Transfer Scheme (BATS) model.

The Penman-Monteith potential ET calculations are derived for conditions that assume wet surface areas (e.g. open waterbodies and vegetation surfaces that are wet from water vapor diffusion). These conditions are clearly not met for all periods of time, and therefore potential ET rates can be reduced to actual ET rates based upon numerous variables; however, if short vegetation has access to an "adequate" soil moisture supply, actual ET rates generally match evaporation rates from open water (e.g., potential ET; Brutsaert, 2005). Based on these conditions, the IWMI Penman-Monteith ET rates will be unadjusted when determining possible ranges of future ET.

BATS does not use a standard ET approach (e.g. Hargreaves, Priestley-Taylor, Penman-Monteith, etc.). Rather, BATS utilizes physically-based equations which separately calculate: evaporation from water bodies (as a function of surface aerodynamics, relative humidity, wind speed, temperature gradients), a reduction from the water surface evaporation rate based on water flux through soil layers, and actual transpiration from vegetation (Dickinson et al., 1993; Yang and Dickinson, 1996).

It should be noted, that while the percent error values presented in Table 4 are somewhat higher than the precipitation errors, the absolute error (in millimeters) remains less than that of the precipitation estimates, which infers that errors in the mass balance of atmospheric-sourced water in the 2017 Coastal Master Plan may be more sensitive to uncertainty in precipitation projections than the uncertainties of ET projections. The higher percent error values correspond to the periods of lowest ET. Refer to Appendix B for the corresponding figures and tables for the other ET locations (Table B 1 and Figure B 1 through Figure B 12).

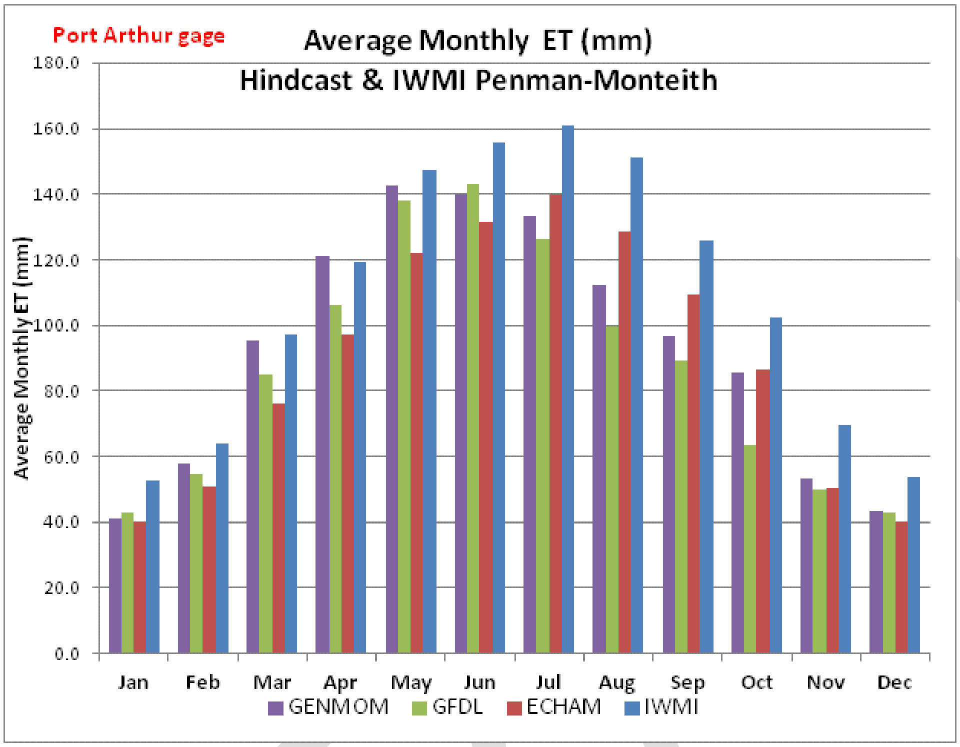

Figure 9: Monthly mean ET for the Port Arthur gage location.

Table 4: Monthly ET percent error at Port Arthur gage location.

	1980-1999	1970-1999	
	GENMOM	GFDL	ECHAM
Jan	-22%	-19%	-24%
Feb	-10%	-15%	-21%
Mar	-2%	-12%	-21%
Apr	2%	-11%	-18%
May	-3%	-6%	-17%
Jun	-10%	-8%	-16%
Jul	-17%	-21%	-13%
Aug	-26%	-34%	-15%
Sep	-23%	-29%	-13%
Oct	-16%	-38%	-15%
Nov	-23%	-29%	-28%
Dec	-19%	-20%	-25%

3.0 Rationale for Identifying Plausible Ranges

This analysis was conducted to determine a plausible range of future precipitation and evapotranspiration rates for coastal Louisiana. While the application of downscaled global climate projections will potentially provide further insight into master plan project sensitivities, the availability of regional climate model data developed from a single emissions scenario does introduce some limitations. Previous IPCC Assessment Reports did not provide any guidance if some emissions scenarios are "more likely" than others (Huntington et al., 2014). This coupled with the fact that only one emission scenario is available for "off-the-shelf" data, presents the need to incorporate further datasets in the precipitation and evapotranspiration to complement the RCM projections. To address these issues, it is proposed that a plausible range of future climate projections be developed by including the historic observations of precipitation and the Penman-Monteith ET with the RegCM3 datasets to analyze possible future scenarios.

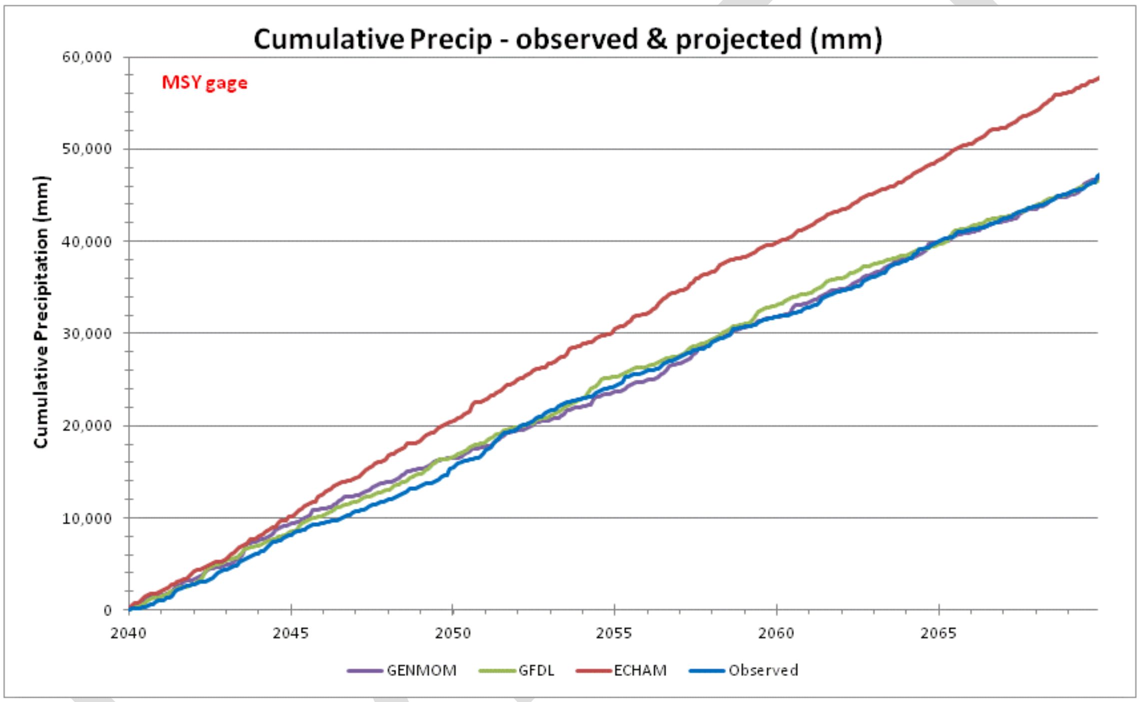

Figure 10: Projected cumulative precipitation (mm) for the New Orleans International Airport gage - RCM data compared to a repetition of the observed record. For comparison purposes, this plot only shows the cumulative precipitation from 2040 through 2069. This is the period where data is available for all three RegCM3 datasets.

At any given time, a single downscaled dataset may not strongly match historic records; however, when taken as whole, these three RCM datasets tend to follow seasonal precipitation and ET trends across coastal Louisiana fairly well. It is proposed to combine these three RCM datasets with the historical observations to develop future precipitation and ET scenarios for use in the 2017 Coastal Master Plan. While large uncertainties still remain in projections of future climate, utilizing data derived from GCM scenarios allows for a range of precipitation scenarios to be implemented, which bracket the observed historic records. The previous ranges used for precipitation scenarios in the 2012 Coastal Master Plan were derived solely from historic observations, and drier or wetter futures were predicted by simply adding or subtracting a standard deviation to the observed record. However, if downscaled RCM data is utilized, a range of drier or wetter futures (as determined by the RegCM3 models) will be gradually implemented over time. These wetter and drier projections envelop the historic observations and will result in variability of potential future precipitation scenarios as predicted by future climate projections, rather than past variability (as was done for the 2012 Coastal Master Plan model).

Similar to the precipitation projections, the RegCM3 downscaled ET datasets should provide means to incorporate projected climate variability into the 2017 Coastal Master Plan models for a more nuanced application of future ET scenarios than were modeled in the 2012 Coastal Master Plan. In 2012, average monthly ET values were used, however they were held constant throughout the model simulation; i.e. every January in the 50-year simulation period of the 2012 Coastal Master Plan was subjected to the same ET rate. Now that these downscaled datasets are available, and are driven by projected temperature and precipitation dynamics (that are also included in these updated future scenarios), the 2017 Coastal Master Plan model will include a range of ET rates, which will provide a better understanding of how the Master Plan models respond to future climate conditions.

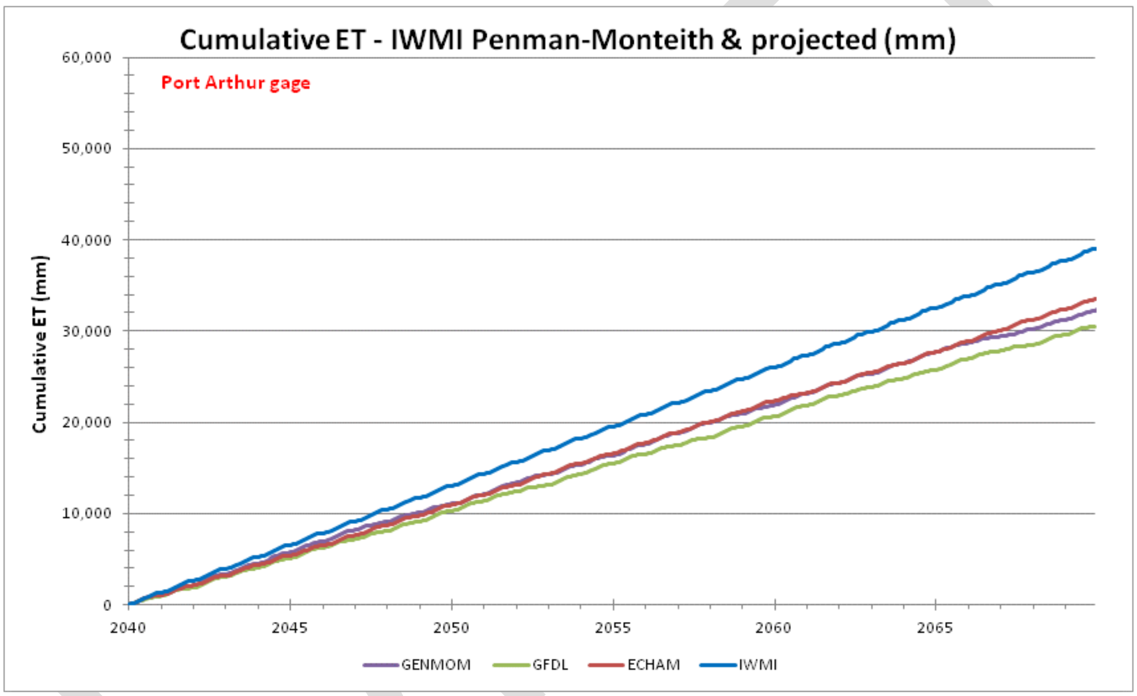

Figure 11: Projected cumulative ET (mm) for the Port Arthur gage location - RCM data compared to a repetition of the IWMI Penman-Monteith ET record. For comparison purposes, this plot only shows the cumulative ET from 2040 through 2069. This is the period where data is available for all three RegCM3 datasets.

4.0 Plausible Ranges

4.1 Range in Precipitation – lower bound

It is suggested, based on the future precipitation projections available from the USGS, that the dynamically downscaled RCM dataset derived from the GENMOM GCM be used as the low range of potential future precipitation. Based on cumulative rainfall totals at each of the seven gage locations, it is the driest projected future at all when compared to the ECHAM model, which also covers the entire 50-year simulation period of the 2017 Coastal Master Plan, and is drier than the GFDL dataset at three locations. Of the remaining four locations, the GFDL is noticeably drier than GENMOM at only one gage.

4.2 Range in Precipitation – upper bound

It is suggested, based on the future precipitation projections available from the USGS, that the dynamically downscaled RCM dataset derived from the ECHAM GCM be used as the high end of the range for potential future precipitation.

4.3 Range in Precipitation – mid-range

It is proposed that historic precipitation records be repeated into the future model simulation period to provide a mid-range value for precipitation projections. This historic precipitation was used in the 2012 Coastal Master Plan models, and it will again be considered as part of the plausible range. Rather than bracketing the observed precipitation with adjustments based on standard deviations, it is now bracketed by the two RegCM3 datasets listed above.

4.4 Range in Evapotranspiration – lower bound

The lower bound of the ET range is developed from the GENMOM dataset, which consistently predicts lower ET rates than both the Penman-Monteith and ECHAM datasets. Both of these datasets cover the entire future time period, unlike the GFDL data.

4.5 Range in Evapotranspiration – upper bound

The repeated IWMI Penman-Monteith record was substantially higher than all three downscaled datasets. Therefore, the ET records developed from the IWMI climate atlas, which was used in the 2012 Coastal Master Plan, will be used as the upper range of future ET scenarios.

4.6 Range in Evapotranspiration – mid-range

As stated above, the ECHAM dataset consistenly predicts higher cumulative ET throughout the 50-year simulation period than the GENMOM dataset. Therefore, the RegCM3 dataset developed from ECHAM boundary conditions will be used as a mid-range estimate of ET.

5.0 Discussion

5.1 Development of 50-Year Future Timeseries

The 2017 Coastal Master Plan modeling effort focuses on 50-year simulations, which will range from 2015 to 2065. This time period does not align with available future climate projection datasets, the earliest of which begin in 2020. Therefore, historic average precipitation and ET values will be used for 2015 through 2020. Following these initial years, the remaining 45 years will be simulated using the RegCM3 datasets or the historic records, as described in sections 4.1 through 4.6.

5.2 Tropical Storm Events

The downscaled datasets of future precipitation projections are known to have a shortcoming with respect to predicted rainfall from tropical storm events (e.g. tropical storms and hurricanes; Hostetler et al., 2011). While this is an important factor in seasonal rainfall patterns in coastal Louisiana, this will likely have a negligible impact on the 2017 Coastal Master Plan due to the fact that a suite of tropical storm rainfall records are being developed in parallel to this non-storm condition precipitation scenario.

Tropical storm effects will be modeled based on a synthetic suite of tropical events that will be ‘stitched’ into the input time-series of precipitation. Before this ‘stitching’ occurs, any tropical storm events will have to be filtered out of the downscaled datasets. By deciding to implement the synthetic storm suite in the master plan, CPRA has provided a means to improve upon one of the known weaknesses of these RegCM3 datasets. The environmental conditions provided by this suite of synthetic tropical events will include: wind speed and direction, storm track, and precipitation. This synthetic storm suite is being developed under a separate 2017 Coastal Master Plan Model Improvement Plan effort (see Attachment C3-3 Storms in the ICM Boundary Conditions in the 2017 Coastal Master Plan).

5.3 Spatial Simplification of RegCM3 Datasets

The RCM datasets downloaded from the USGS Geo Data Portal provide a gridded spatial coverage of precipitation and ET time series throughout the entire 2017 Coastal Master Plan model domain area. The historical comparisons conducted in this analysis were done on single grid cells extracted from the precipitation and ET ‘surface’ at NCDC gage locations. However, when implementing these datasets into the 2017 modeling effort, this extraction methodology can be easily improved upon.

Due to the availability of gridded precipitation and ET time series, extensive pre-processing of the downscaled data can be performed to assign mean precipitation and ET values to each compartment based upon the RCM grid cells that overlay each compartment. This method is analogous to using radar rainfall as model input data; however instead of gridded radar data the model would be using gridded RCM projected data.

There are potentially two approaches that can be taken to mapping the gridded datasets to the compartments. First, each compartment boundary could be used to determine the mean and variability of precipitation and evapotranspiration for each compartment. Due to the varied sizes of the compartments and the fixed size of the grid, it is likely that the variance of individual compartments may vary greatly from one compartment to another. However the ability to understand this variance per compartment would likely be of value during the uncertainty analysis that is to be conducted on the 2017 Coastal Master Plan Integrated Compartment Model.

An alternative approach would be to extract the gridded data at each compartment’s centroid. This approach would be slightly more straightforward to operationalize. However it would provide less rigorous information to analyze the spatial variability of model uncertainties with respect to these precipitation and ET datasets.

6.0 References

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Appendices

Appendix A: Precipitation Tables and Figures

Table 5: Percent Error - Monthly Precipitation.

		Port Arthur	Lake Charles	Rockefeller	Abbeville	Morgan City	Galliano	NO Int'l Airport
Jan	*GENMOM*	-18%	-17%	-18%	-20%	-11%	-11%	-30%
	GFDL	-32%	-19%	-30%	-37%	-28%	-28%	-7%
	ECHAM	-1%	-5%	-14%	-18%	-14%	-11%	-14%
Feb	*GENMOM*	-7%	-11%	-17%	-16%	-14%	-32%	-58%
	GFDL	8%	26%	7%	3%	-10%	-8%	-15%
	ECHAM	38%	31%	23%	27%	16%	9%	-20%
Mar	*GENMOM*	19%	1%	-1%	2%	-5%	-24%	-47%
	GFDL	70%	65%	55%	15%	25%	2%	13%
	ECHAM	122%	101%	88%	56%	54%	28%	21%
Apr	*GENMOM*	60%	33%	27%	5%	21%	10%	-42%
	GFDL	110%	109%	89%	51%	64%	49%	23%
	ECHAM	106%	87%	51%	45%	53%	45%	-3%
May	*GENMOM*	51%	3%	59%	42%	82%	35%	45%
	GFDL	29%	10%	34%	13%	22%	12%	2%
	ECHAM	43%	22%	55%	26%	35%	19%	-9%
Jun	*GENMOM*	32%	15%	32%	10%	18%	33%	-18%
	GFDL	-7%	1%	27%	0%	13%	13%	-19%
	ECHAM	5%	-17%	33%	-1%	11%	14%	-20%
Jul	*GENMOM*	-20%	-30%	-23%	-2%	-13%	-36%	-2%
	GFDL	-56%	-35%	-47%	-27%	-33%	-34%	-26%
	ECHAM	13%	-12%	0%	9%	-10%	-16%	10%
Aug	*GENMOM*	47%	58%	31%	44%	19%	11%	6%
	GFDL	-39%	-20%	-37%	-32%	-35%	-27%	10%
	ECHAM	32%	1%	6%	5%	-10%	-14%	29%
Sep	*GENMOM*	27%	11%	46%	35%	-3%	1%	99%
	GFDL	-54%	-51%	-48%	-38%	-57%	-54%	41%
	ECHAM	-45%	-52%	-34%	-33%	-56%	-49%	48%
Oct	*GENMOM*	-48%	-42%	-36%	-51%	-51%	-55%	-11%
	GFDL	-54%	-47%	-52%	-63%	-60%	-62%	26%
	ECHAM	-37%	-38%	-37%	-48%	-39%	-47%	-1%
Nov	*GENMOM*	-39%	-41%	-46%	-51%	-56%	-58%	-72%
	GFDL	-27%	2%	-6%	-27%	-31%	-36%	-4%
	ECHAM	21%	26%	12%	3%	-8%	-14%	-29%
Dec	*GENMOM*	-41%	-28%	-29%	-29%	-25%	-21%	-30%
	GFDL	-32%	-2%	-2%	-19%	-5%	17%	20%
	ECHAM	26%	43%	34%	17%	20%	49%	7%

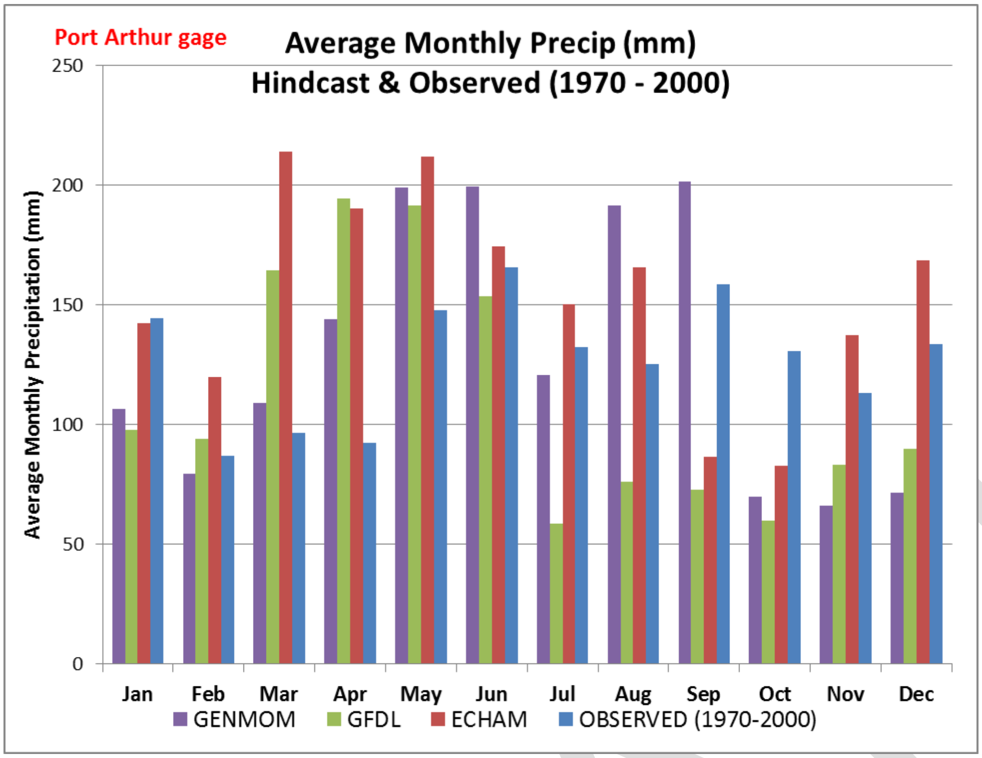

Figure 12: Monthly average precipitation (mm) for the Port Arthur gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

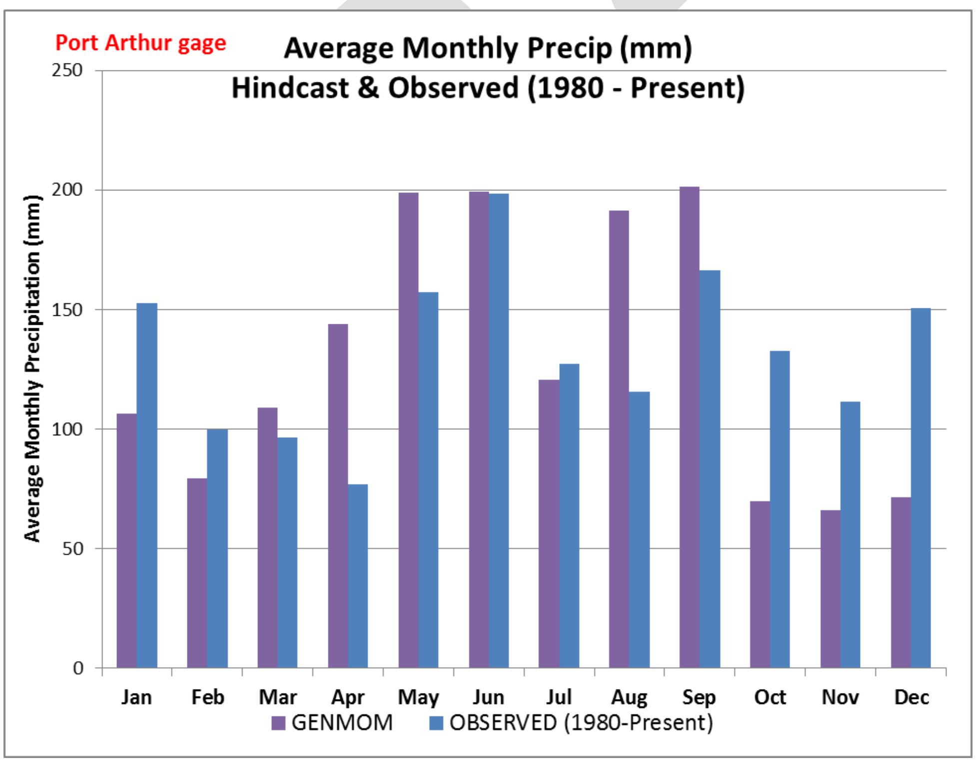

Figure 13: Monthly average precipitation (mm) for the Port Arthur gage location – GENMOM hindcast compared to observed record, 1980-2000.

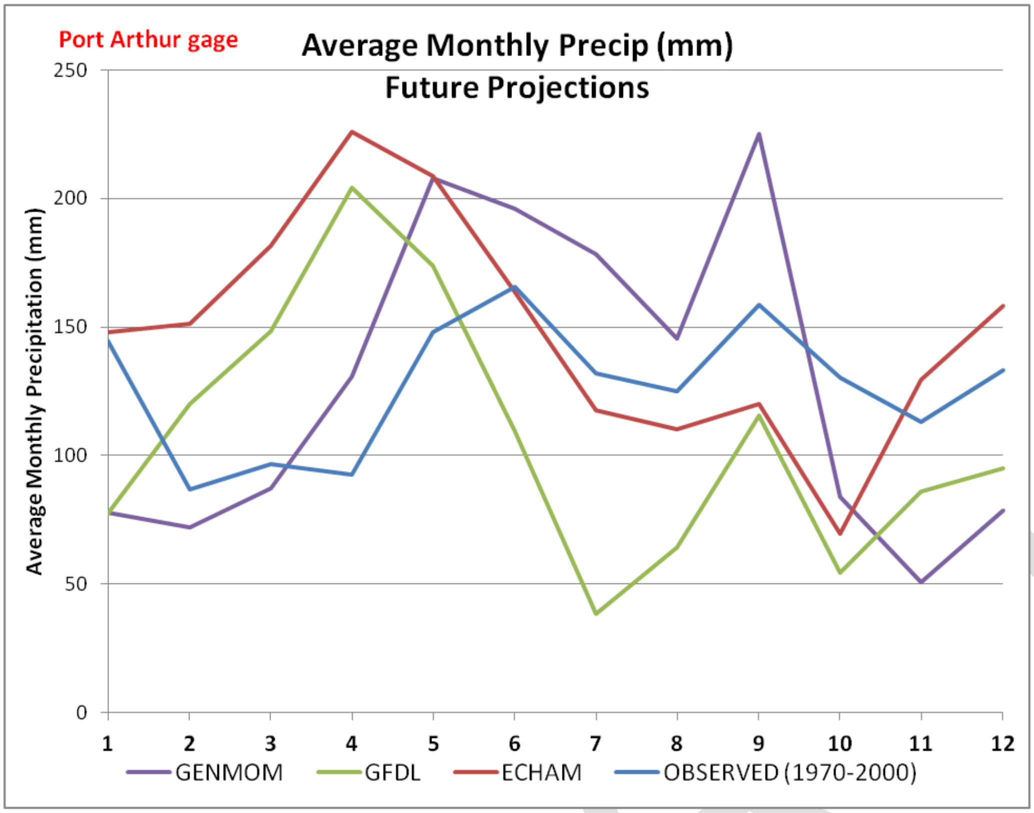

Figure 14: Range in downscaled monthly mean precipitation projections for the Port Arthur precipitation gage location.

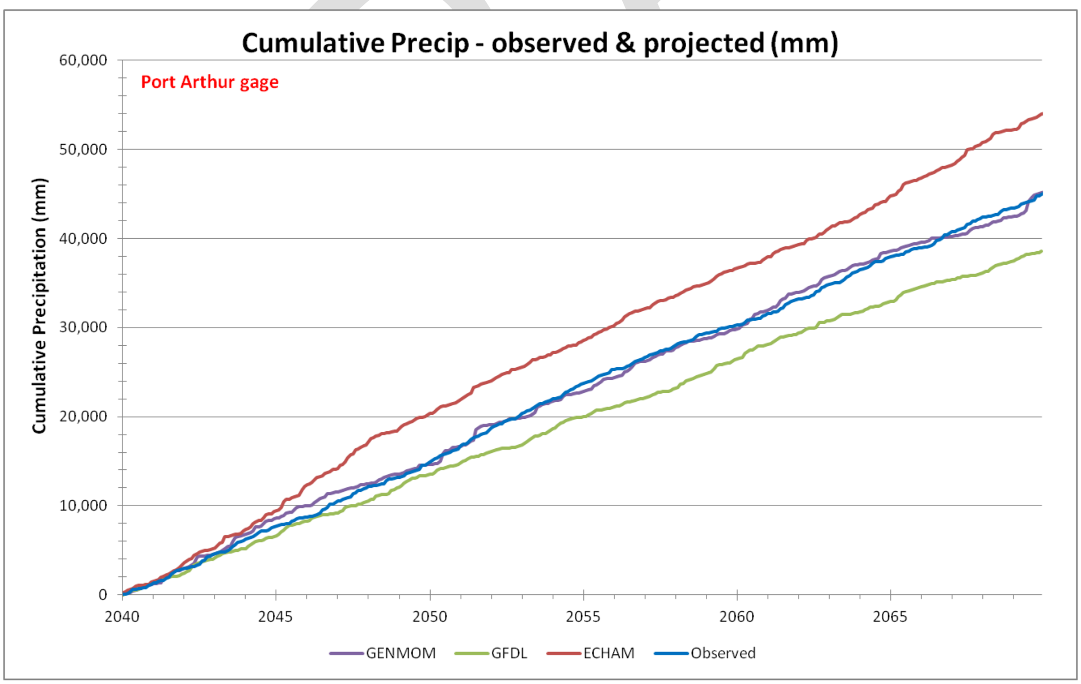

Figure 15: Projected cumulative precipitation (mm) for the Port Arthur gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

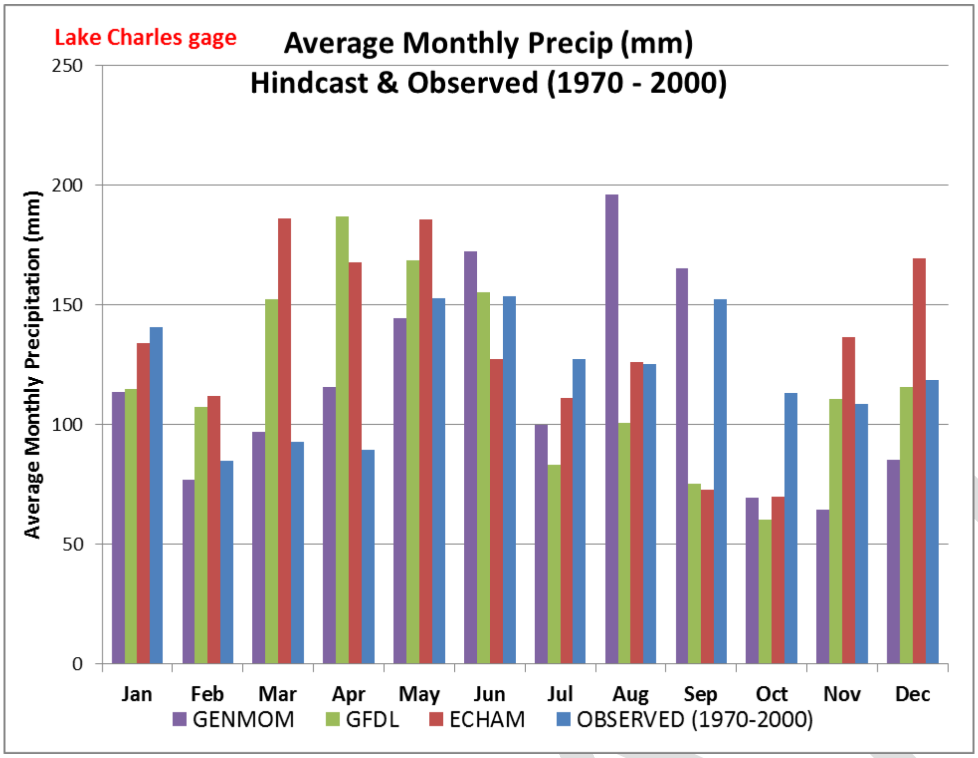

Figure 16: Monthly average precipitation (mm) for the Lake Charles gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

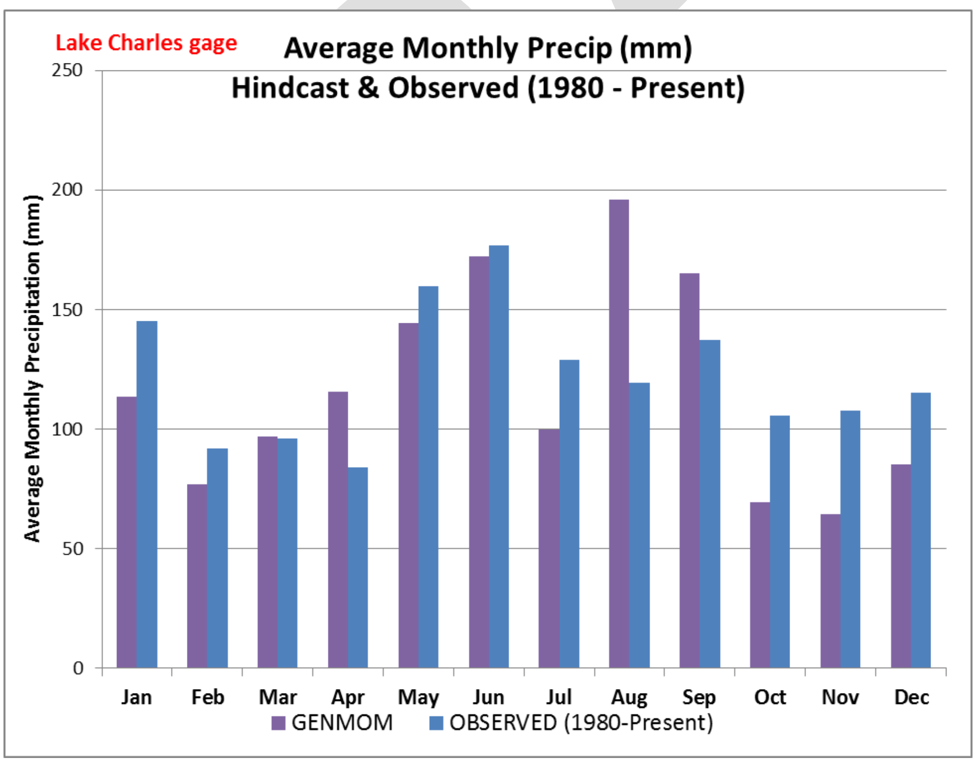

Figure 17: Monthly average precipitation (mm) for the Lake Charles gage location – GENMOM hindcast compared to observed record, 1980-2000.

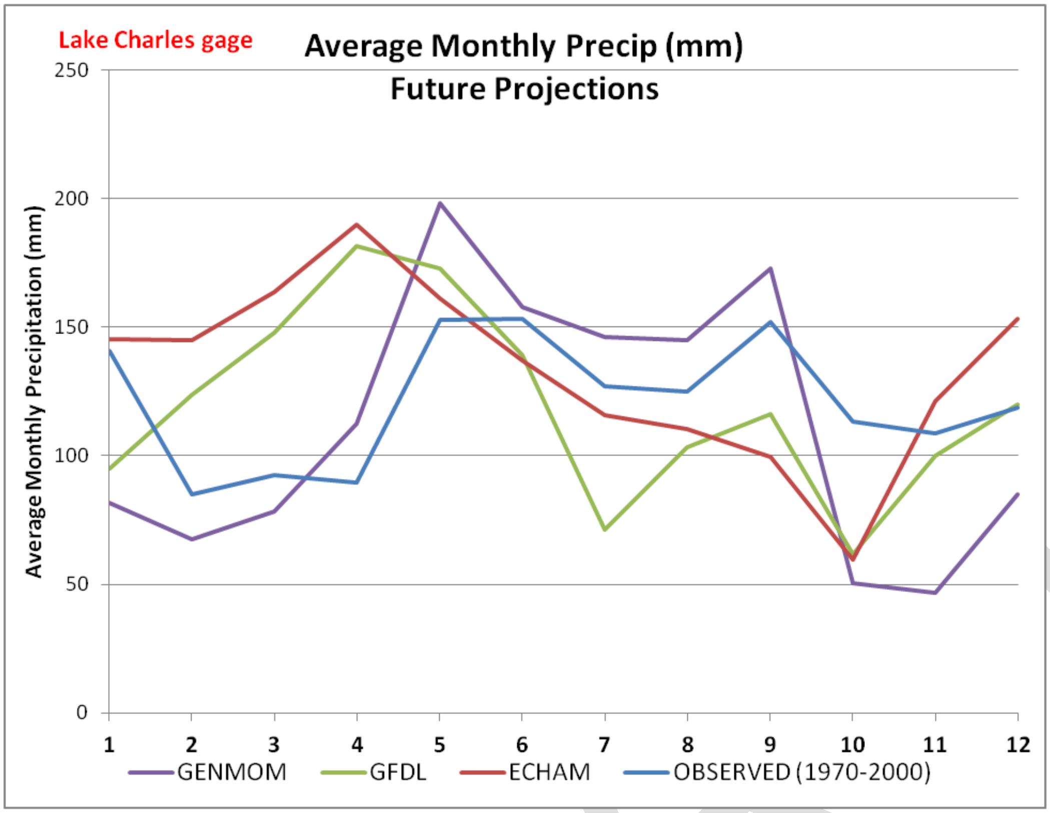

Figure 18: Range in downscaled monthly mean precipitation projections for the Lake Charles precipitation gage location.

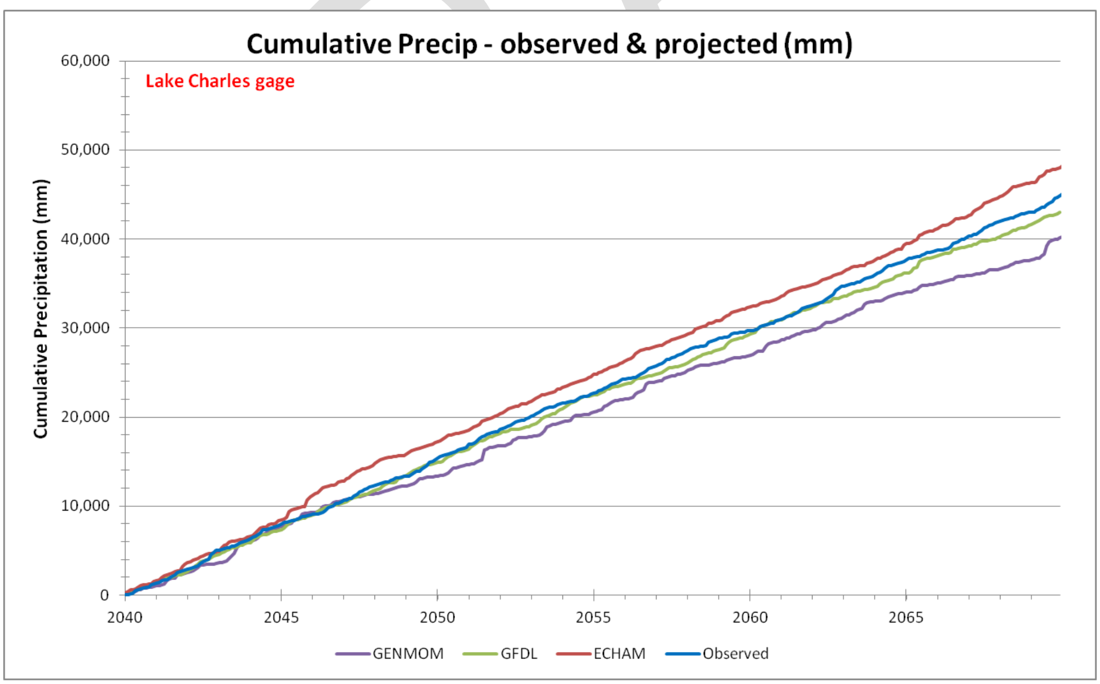

Figure 19: Projected cumulative precipitation (mm) for the Lake Charles gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

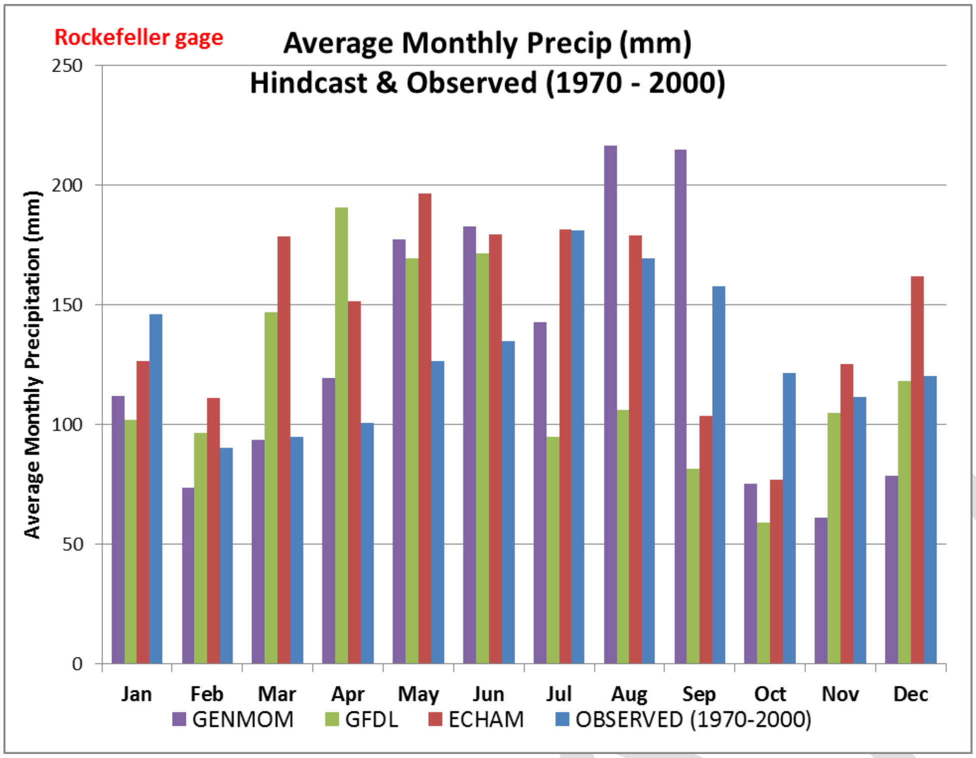

Figure 20: Monthly average precipitation (mm) for the Rockefeller gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

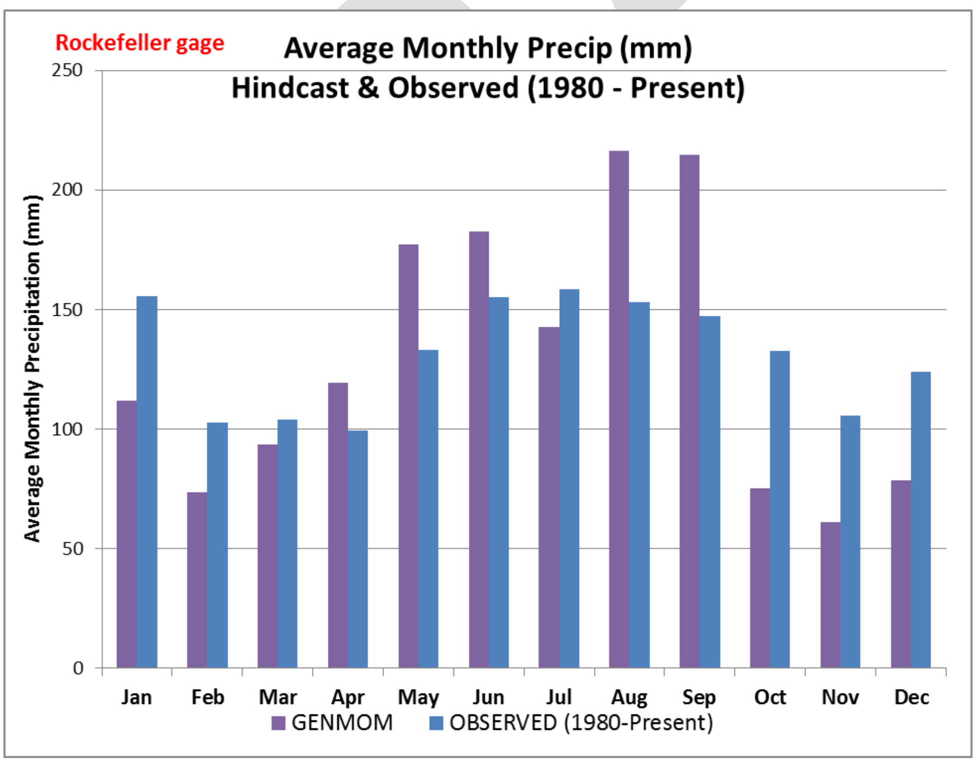

Figure 21: Monthly average precipitation (mm) for the Rockefeller gage location – GENMOM hindcast compared to observed record, 1980-2000.

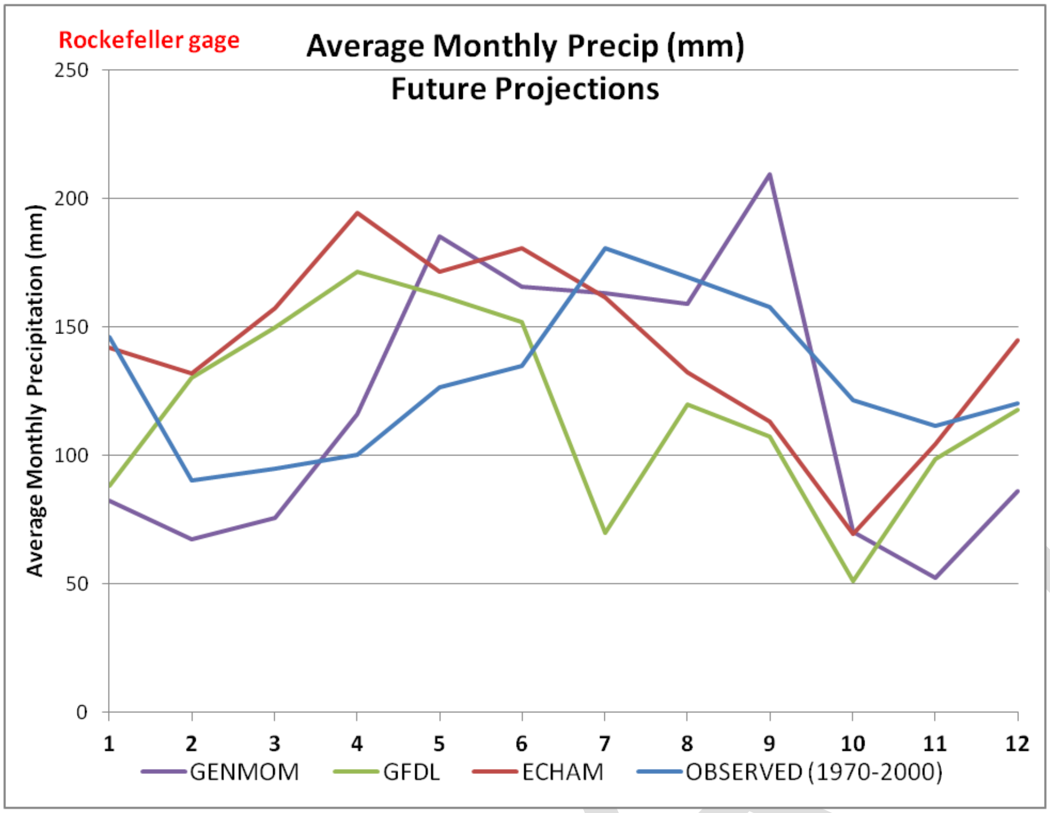

Figure 22: Range in downscaled monthly mean precipitation projections for the Rockefeller precipitation gage location.

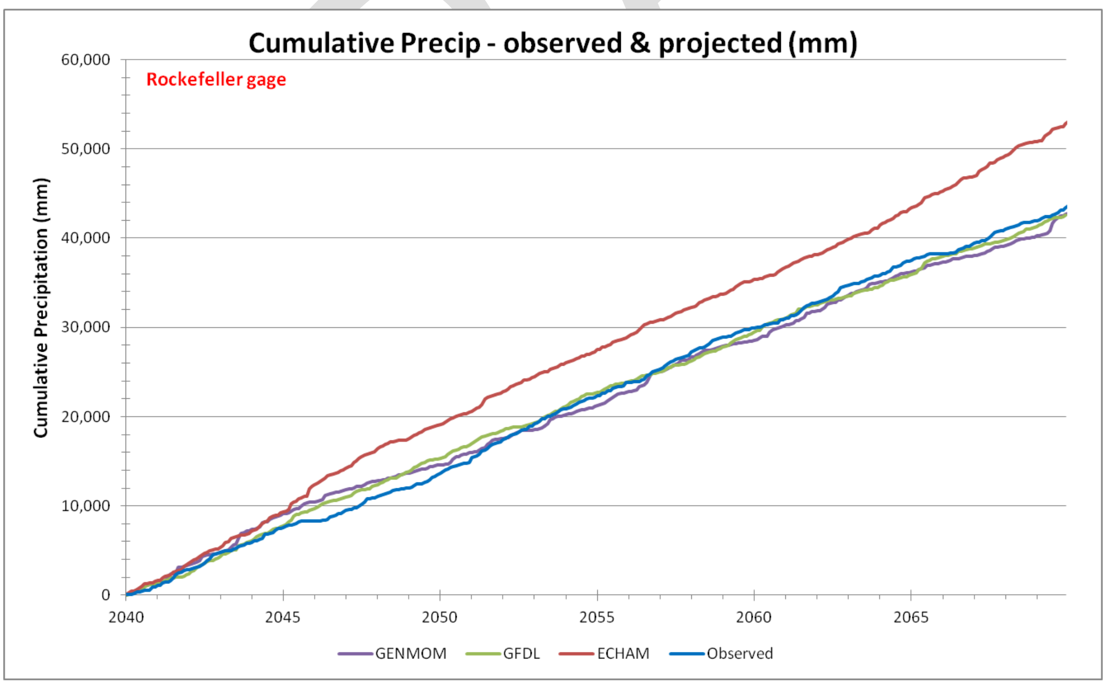

Figure 23: Projected cumulative precipitation (mm) for the Rockefeller gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

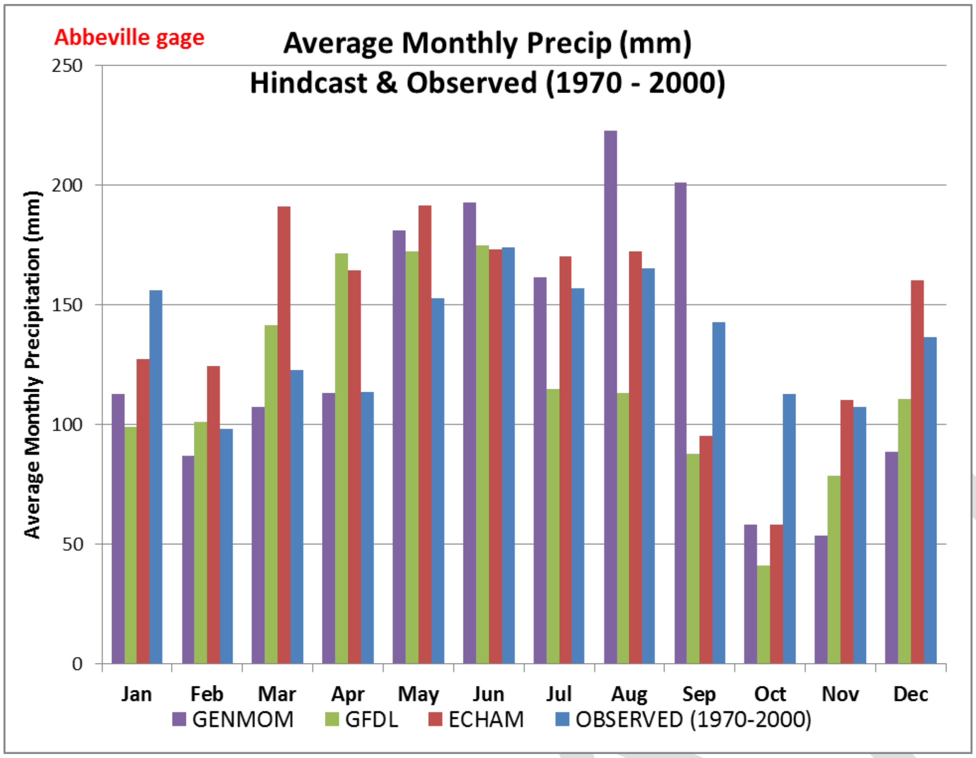

Figure 24: Monthly average precipitation (mm) for the Abbeville gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

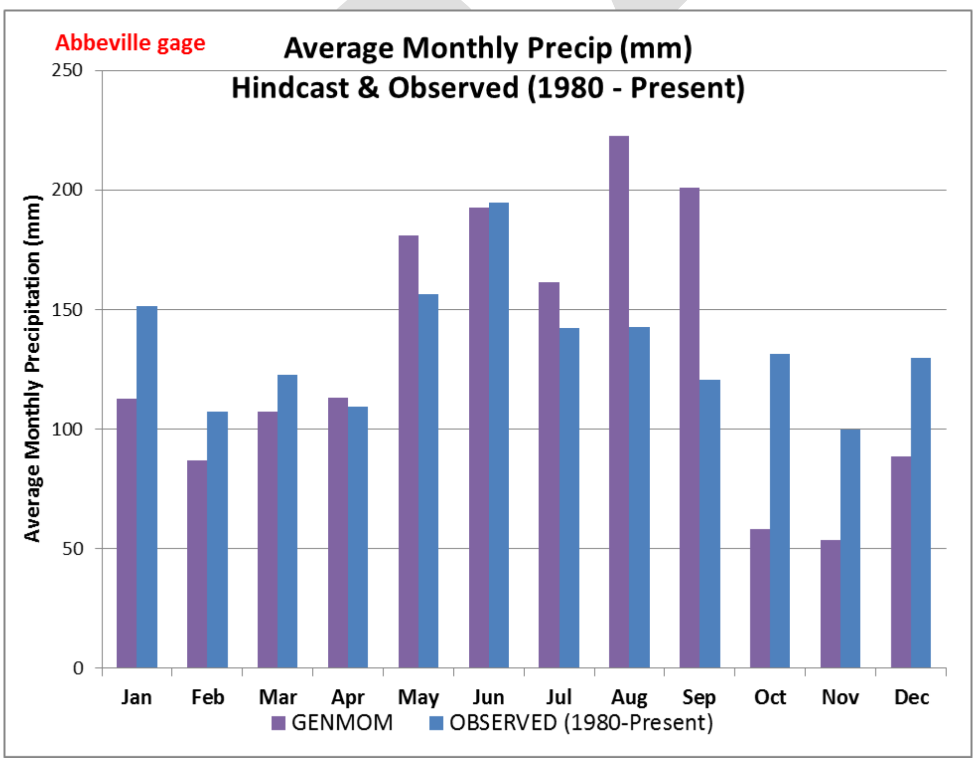

Figure 25: Monthly average precipitation (mm) for the Abbeville gage location – GENMOM hindcast compared to observed record, 1980-2000.

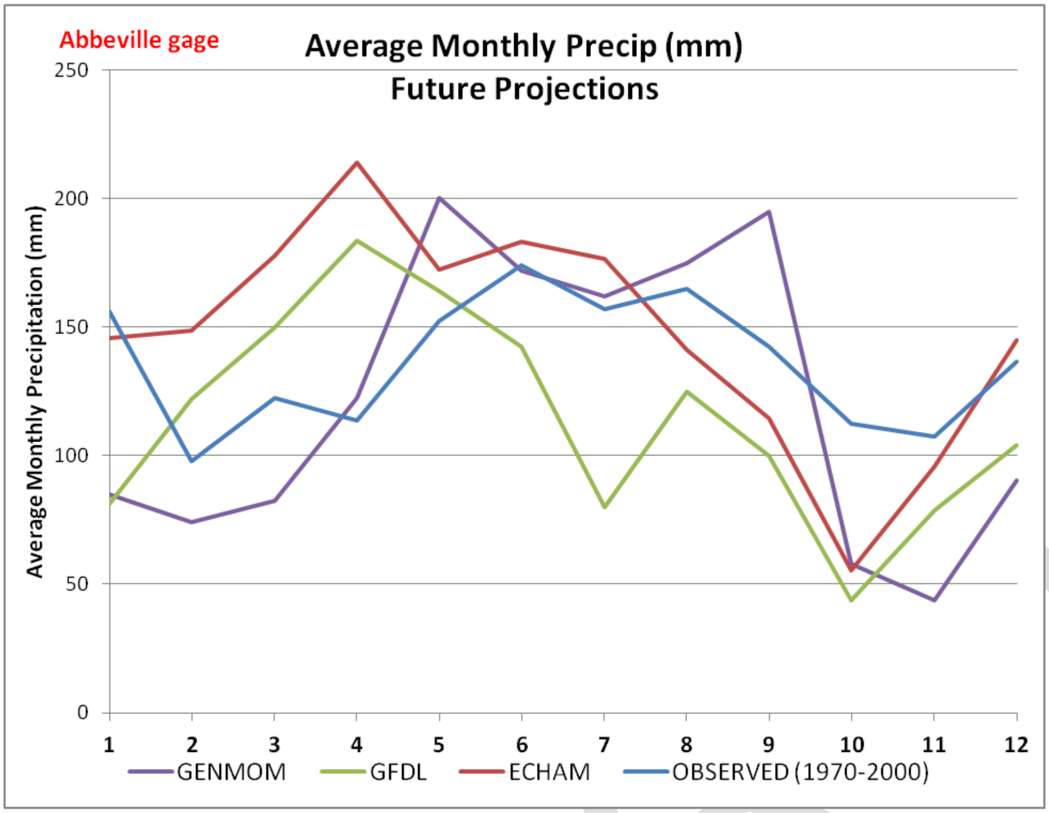

Figure 26: Range in downscaled monthly mean precipitation projections for the Abbeville precipitation gage location.

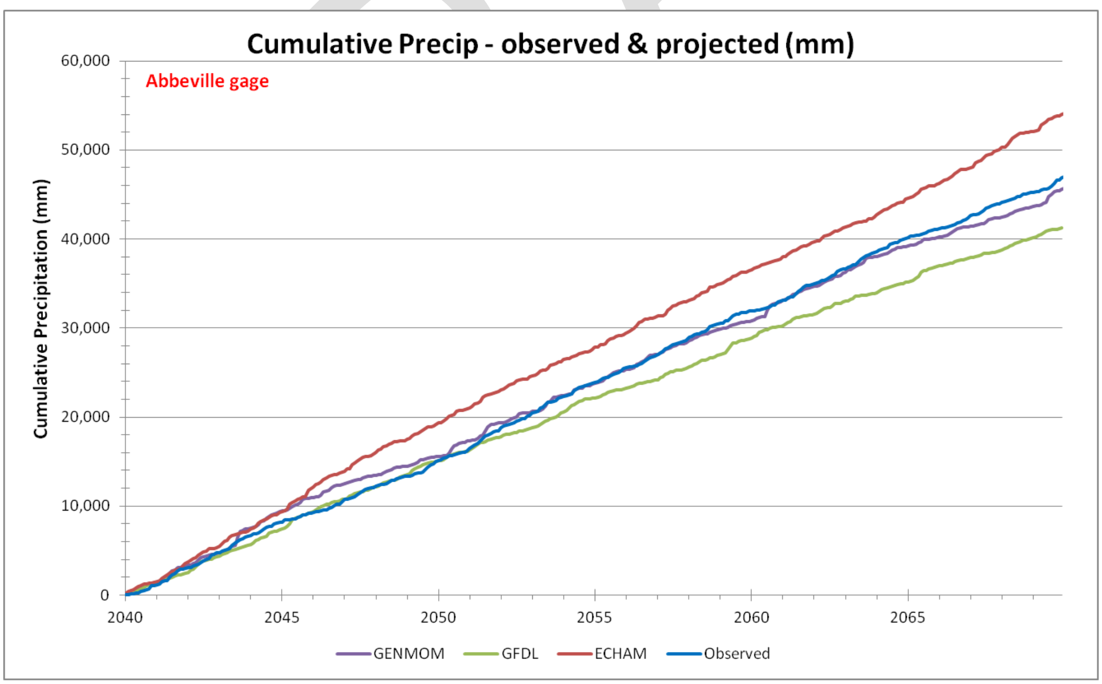

Figure 27: Projected cumulative precipitation (mm) for the Abbeville gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

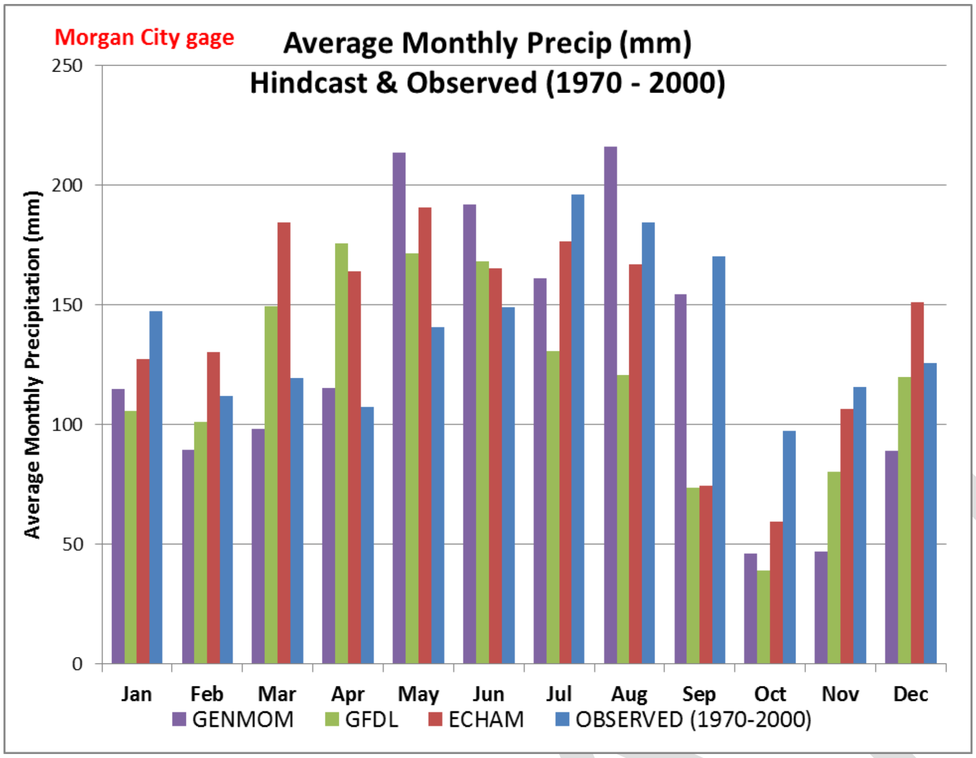

Figure 28: Monthly average precipitation (mm) for the Morgan City gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

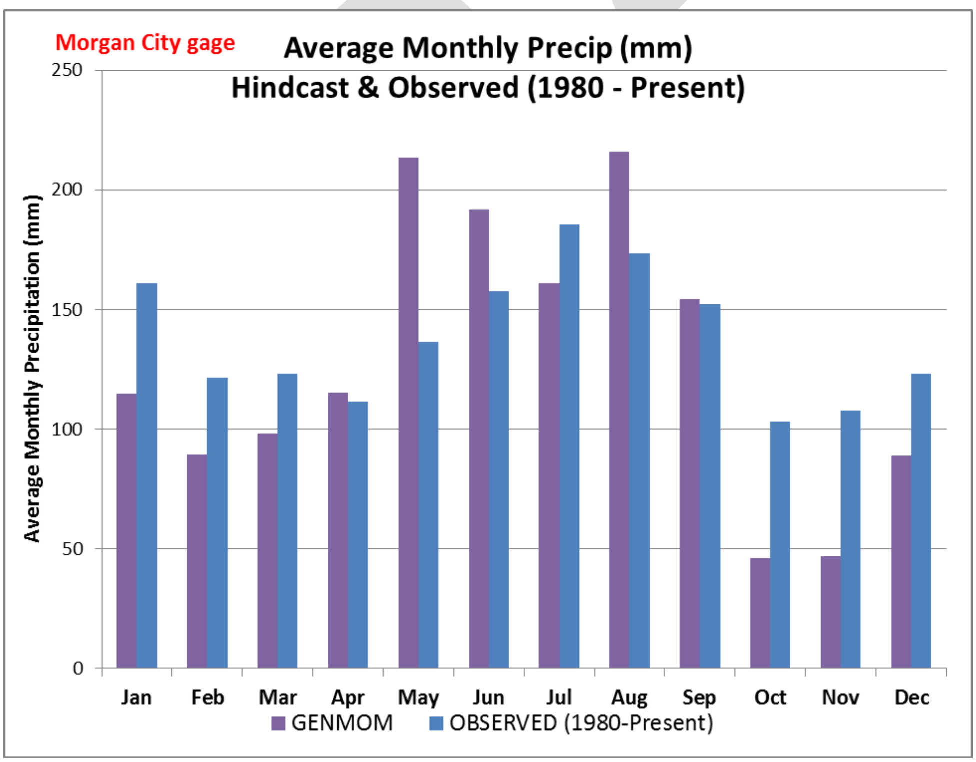

Figure 29: Monthly average precipitation (mm) for the Morgan City gage location – GENMOM hindcast compared to observed record, 1980-2000.

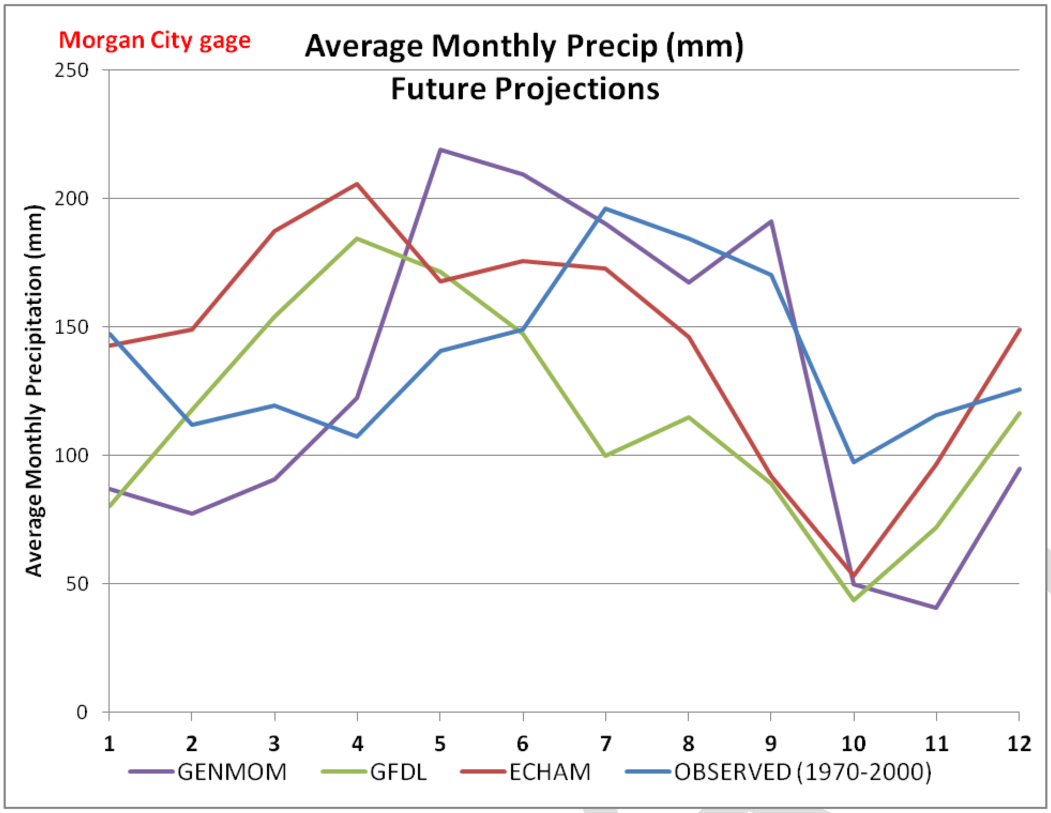

Figure 30: Range in downscaled monthly mean precipitation projections for the Morgan City precipitation gage location.

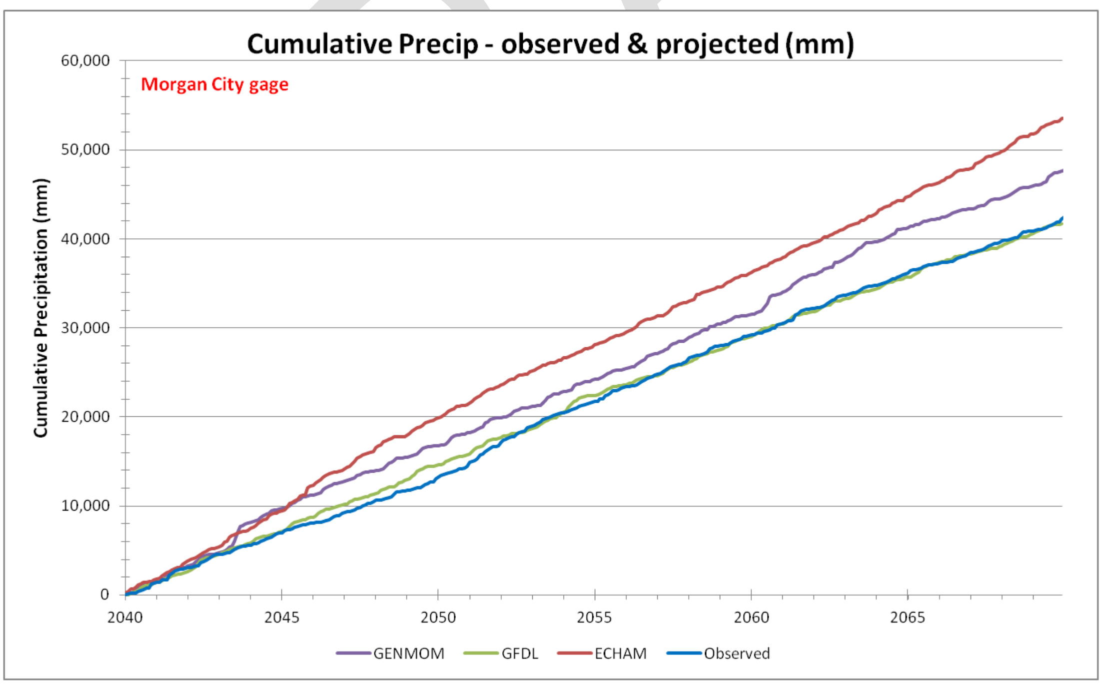

Figure 31: Projected cumulative precipitation (mm) for the Morgan City gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

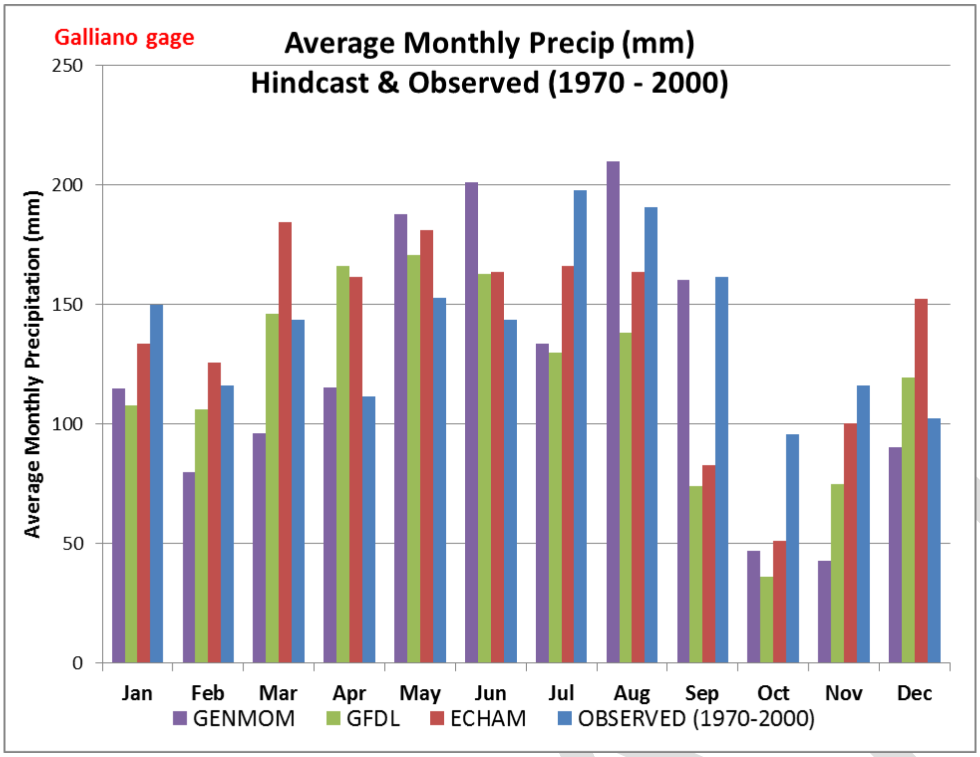

Figure 32: Monthly average precipitation (mm) for the Galliano gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM, which covered 1980-2000.

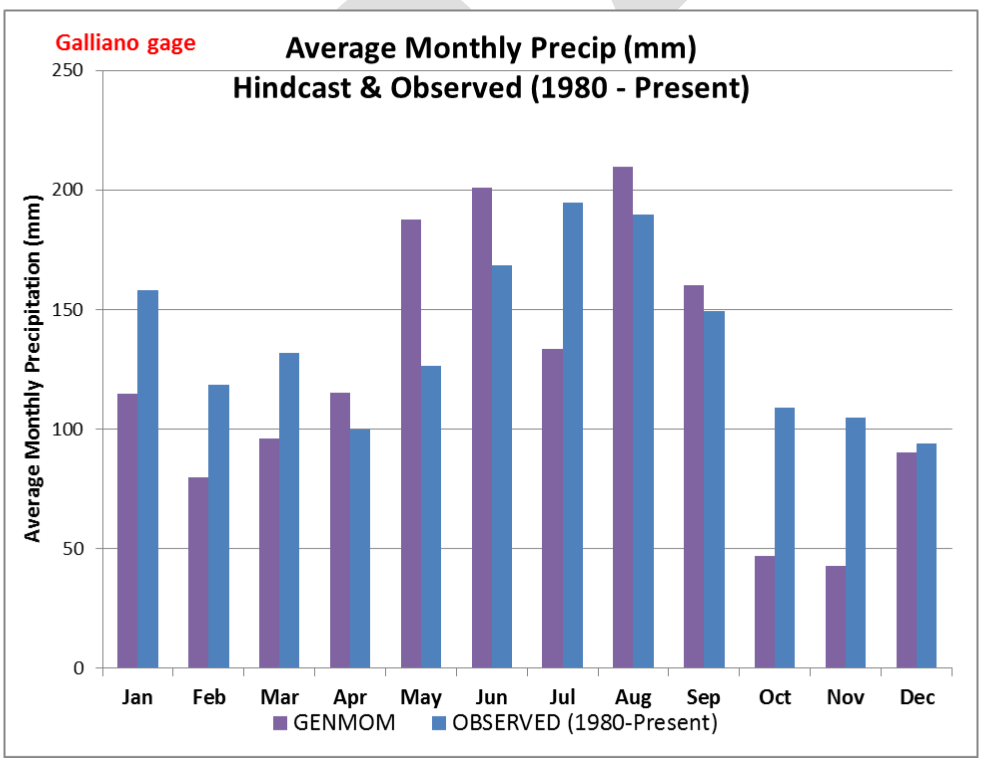

Figure 33: Monthly average precipitation (mm) for the Galliano gage location – GENMOM hindcast compared to observed record, 1980-2000.

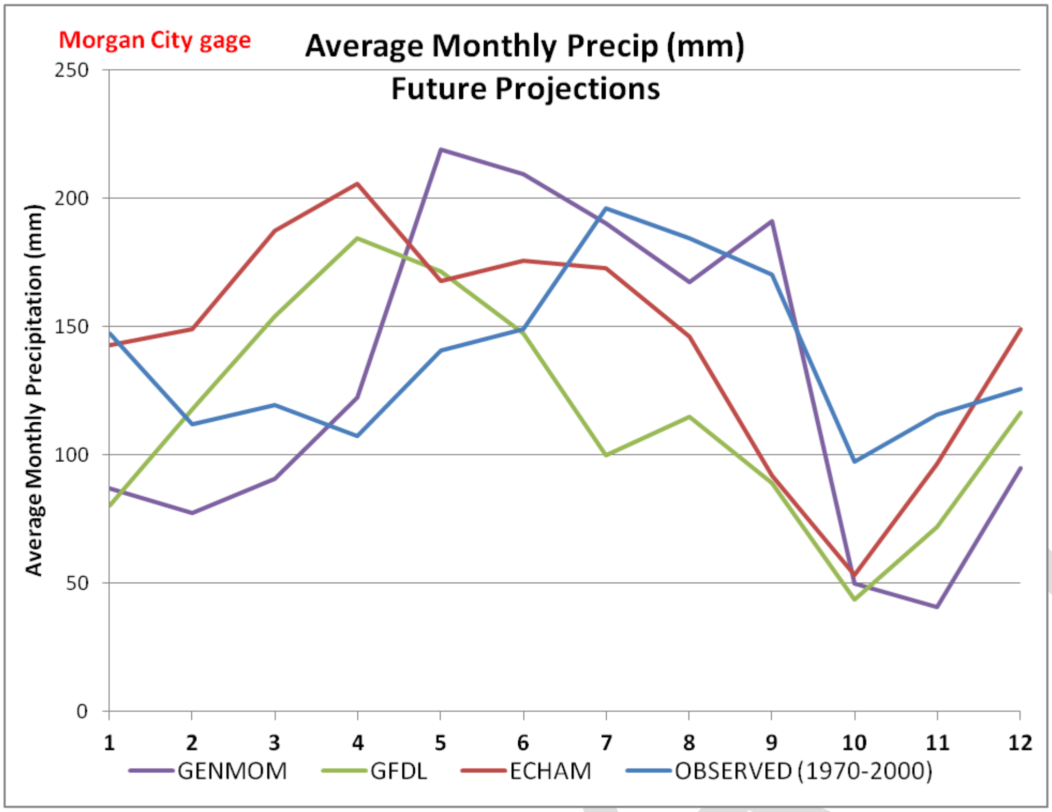

Figure 34: Range in downscaled monthly mean precipitation projections for the Galliano precipitation gage location.

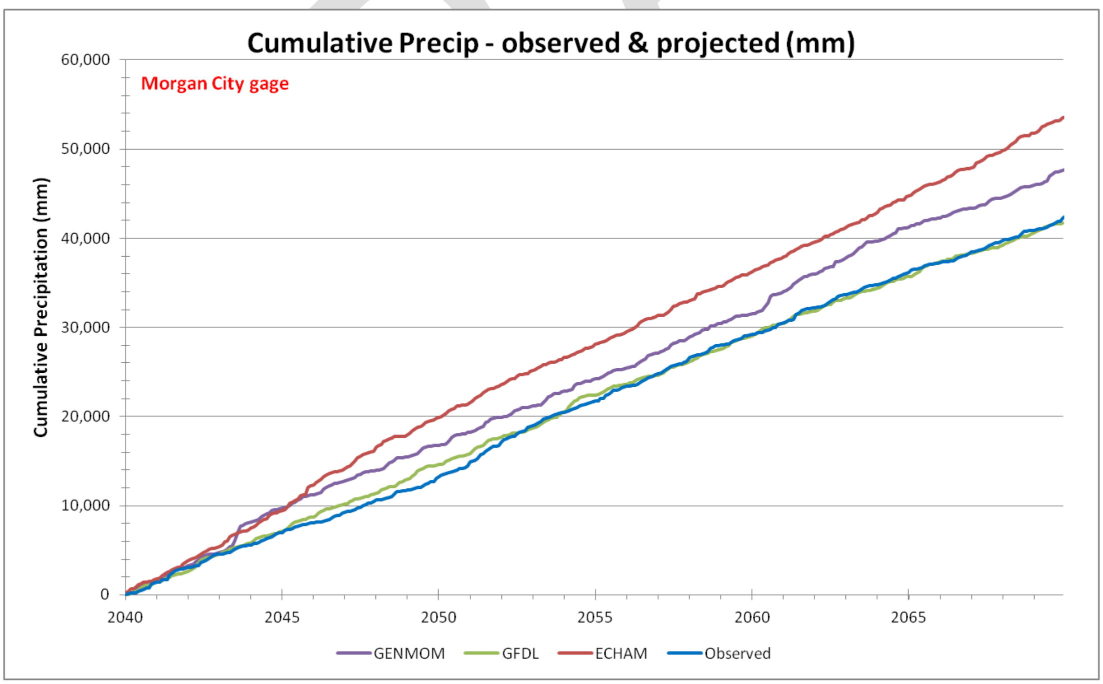

Figure 35: Projected cumulative precipitation (mm) for the Galliano gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

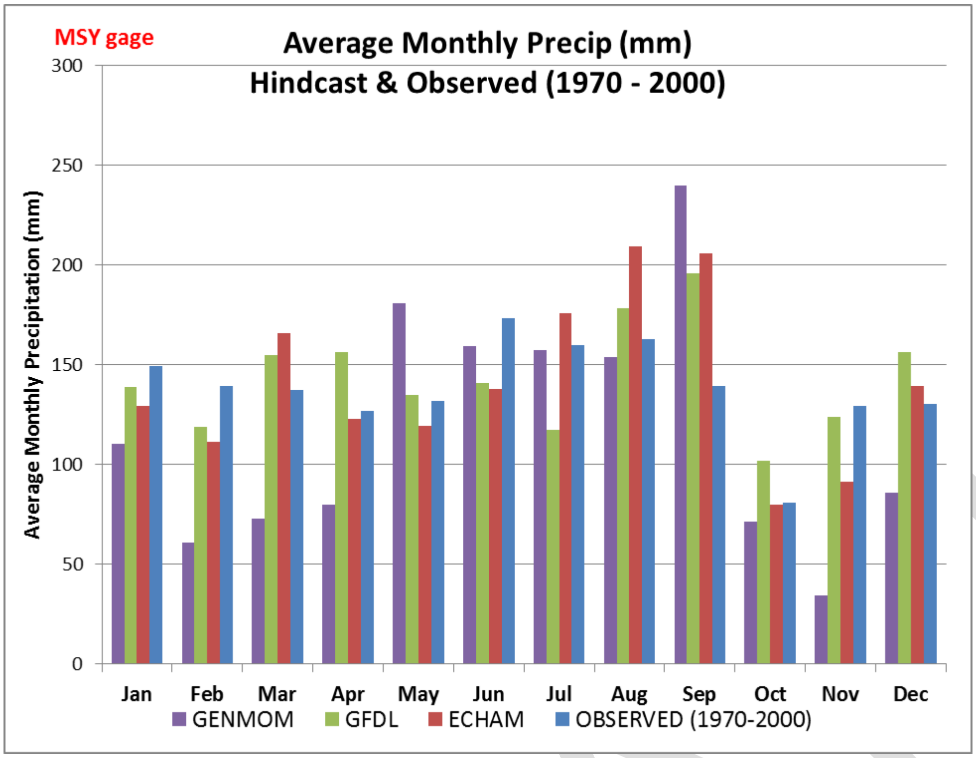

Figure 36: Monthly average precipitation (mm) for the NO Intl Airport gage location – RCM hindcast compared to observed record. All records were from 1970-2000, except GENMOM which covered 1980-2000.

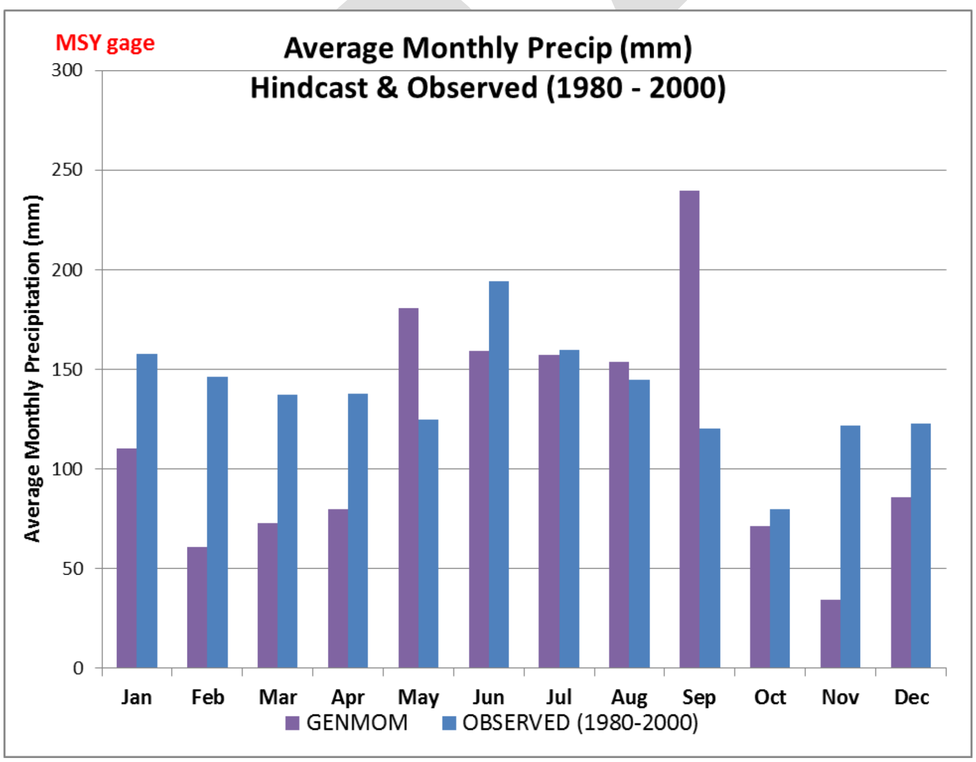

Figure 37: Monthly average precipitation (mm) for the NO Intl Airport gage location – GENMOM hindcast compared to observed record, 1980-2000.

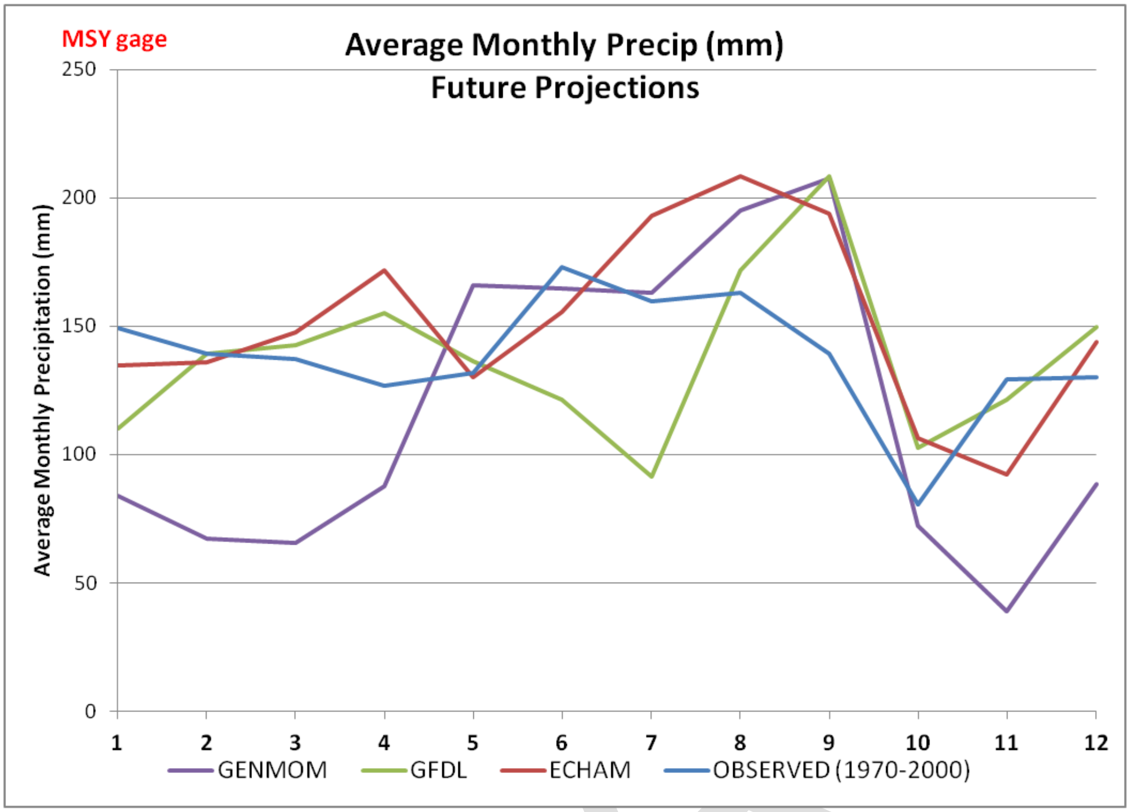

Figure 38: Range in downscaled monthly mean precipitation projections for the NO Intl Airport precipitation gage location.

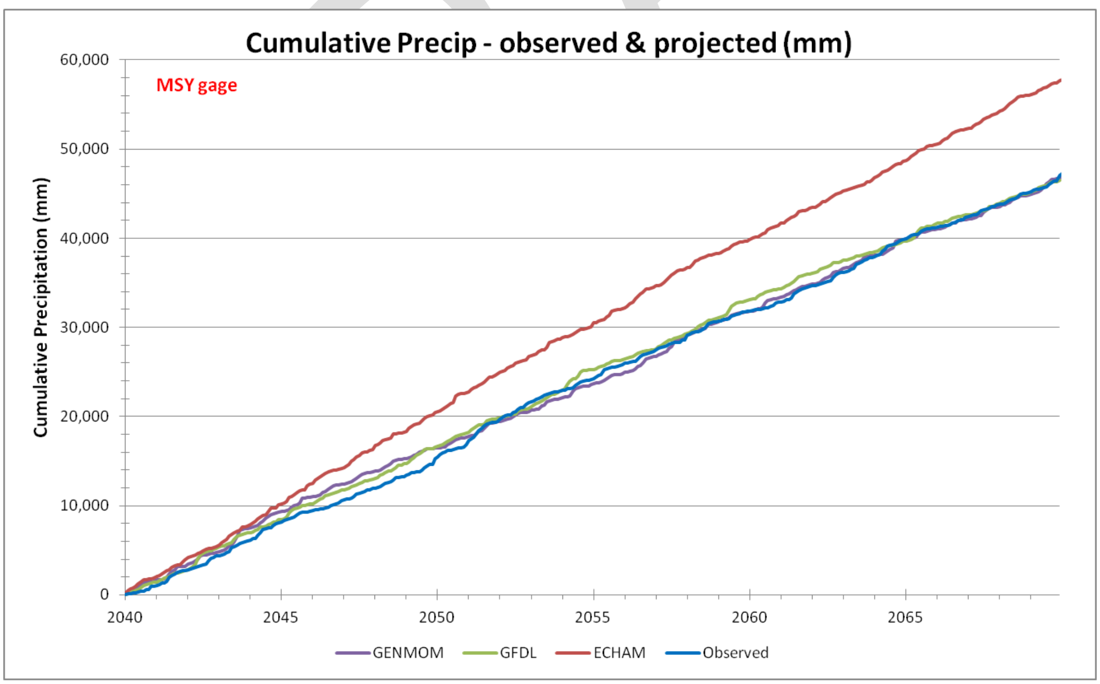

Figure 39: Projected cumulative precipitation (mm) for the NO Intl Airport gage - RCM data compared to a repetition of the observed record for the period where data is available for all three RegCM3 datasets.

Appendix B: Evapotranspiration Tables and Figures

Table 6: Percent Difference1 - Monthly Evapotranspiration.

		Port Arthur	Lake Charles	Rockefeller	Abbeville
Jan	*GENMOM*	-22%	-75%	-23%	-31%
	GFDL	-19%	-44%	-11%	-28%
	ECHAM	-24%	19%	-18%	-29%
Feb	*GENMOM*	-10%	-73%	-12%	-22%
	GFDL	-15%	-50%	-7%	-21%
	ECHAM	-21%	-3%	-18%	-26%
Mar	*GENMOM*	-2%	-75%	-7%	-14%
	GFDL	-12%	-53%	-9%	-21%
	ECHAM	-21%	-29%	-20%	-29%
Apr	*GENMOM*	2%	-58%	-6%	-9%
	GFDL	-11%	-42%	-12%	-21%
	ECHAM	-18%	-36%	-19%	-25%
May	*GENMOM*	-3%	-30%	-9%	-13%
	GFDL	-6%	-21%	-10%	-19%
	ECHAM	-17%	-38%	-20%	-26%
Jun	*GENMOM*	-10%	-23%	-11%	-15%
	GFDL	-8%	4%	-8%	-15%
	ECHAM	-16%	-37%	-16%	-21%
Jul	*GENMOM*	-17%	-16%	-16%	-16%
	GFDL	-21%	35%	-17%	-17%
	ECHAM	-13%	-23%	-13%	-17%
Aug	*GENMOM*	-26%	-7%	-21%	-16%
	GFDL	-34%	49%	-22%	-19%
	ECHAM	-15%	3%	-13%	-17%
Sep	*GENMOM*	-23%	-12%	-20%	-20%
	GFDL	-29%	53%	-18%	-16%
	ECHAM	-13%	41%	-9%	-12%
Oct	*GENMOM*	-16%	-44%	-11%	-15%
	GFDL	-38%	18%	-28%	-29%
	ECHAM	-15%	58%	-12%	-17%
Nov	*GENMOM*	-23%	-58%	-20%	-28%
	GFDL	-29%	-19%	-21%	-36%
	ECHAM	-28%	36%	-21%	-31%
Dec	*GENMOM*	-19%	-63%	-19%	-28%
	GFDL	-20%	-43%	-15%	-30%
	ECHAM	-25%	31%	-21%	-34%

[1]This is a comparison of different ET models, not observations. Therefore the term 'error' is used here to represent the change between the RCM datasets and the ET values used provided by the IWMI Climate Atlas and used in the 2012 Coastal Master Plan.

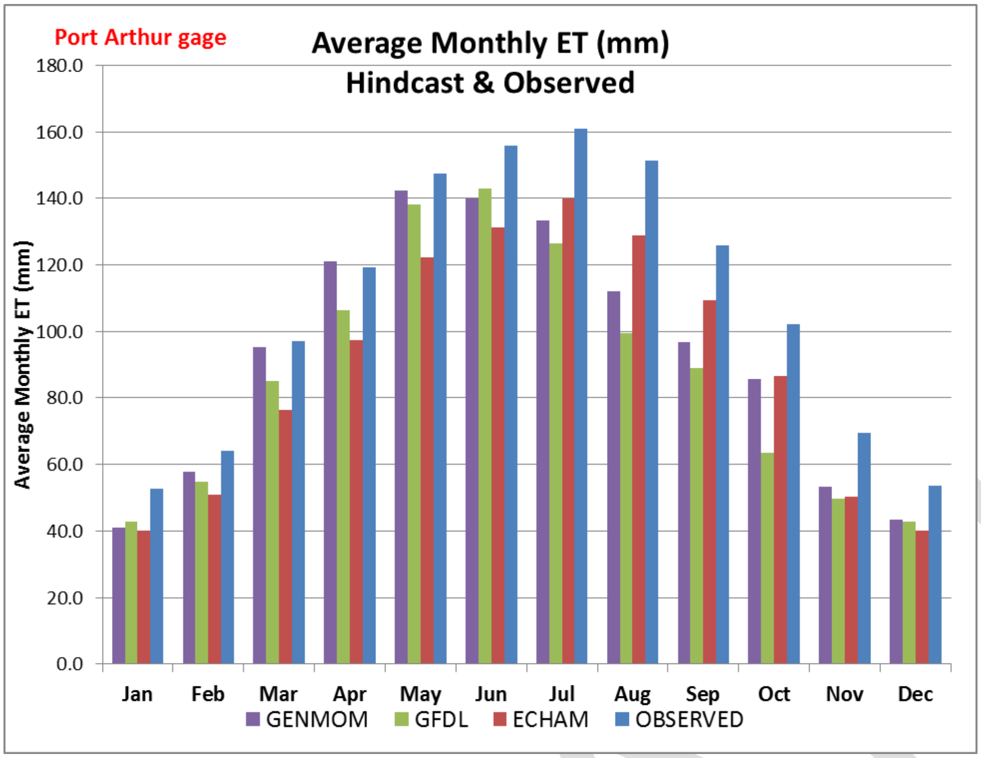

Figure 40: Monthly average ET (mm) for the Port Arthur gage location – RCM hindcast compared to "observed" monthly ET values used in 2012 master plan. All RCM records were from 1970-2000, except GENMOM which covered 1980-2000.

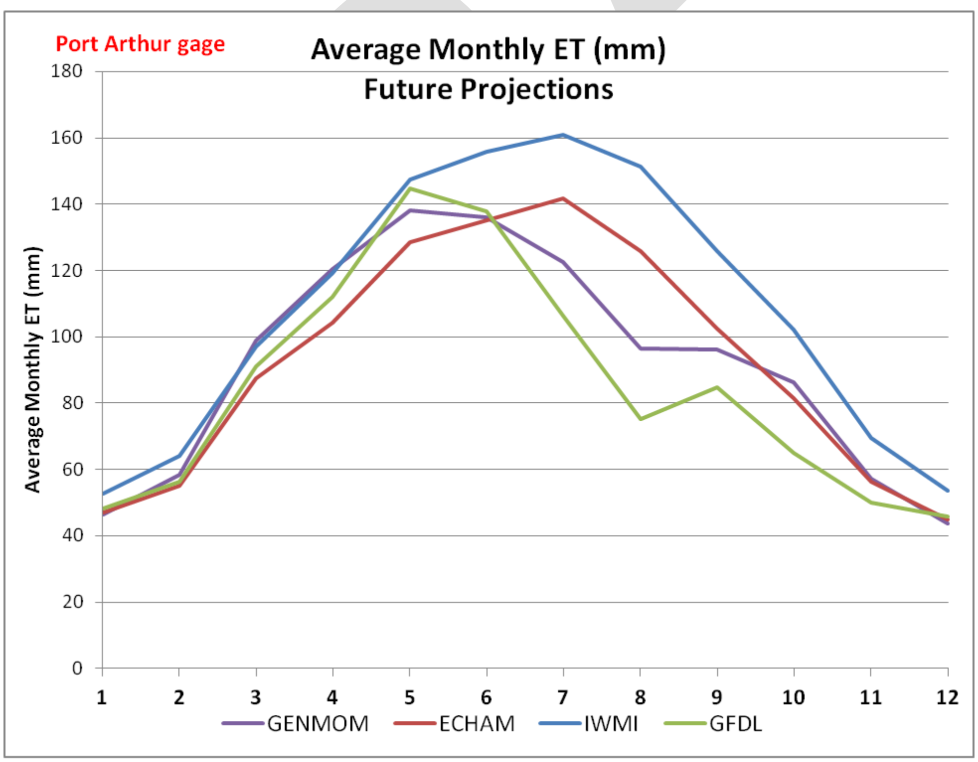

Figure 41: Range in downscaled monthly mean ET projections for the Port Arthur gage location.

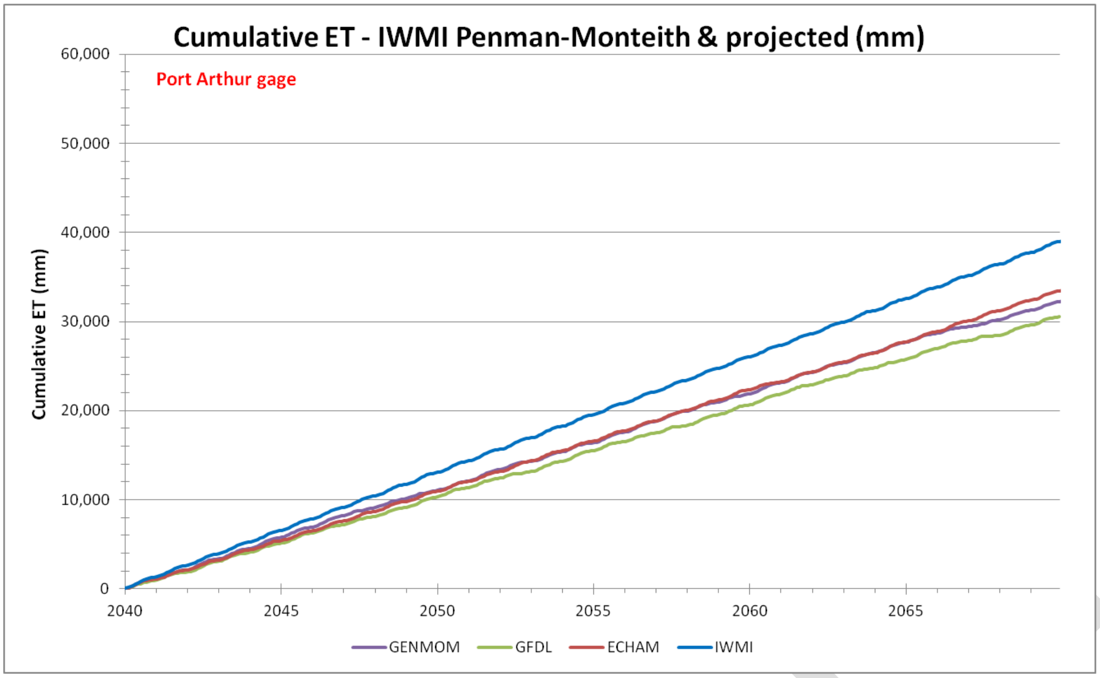

Figure 42: Projected cumulative ET (mm) for the Port Arthur gage - RCM data compared to a repetition of the IWMI record for the period where data is available for all three RegCM3 datasets.

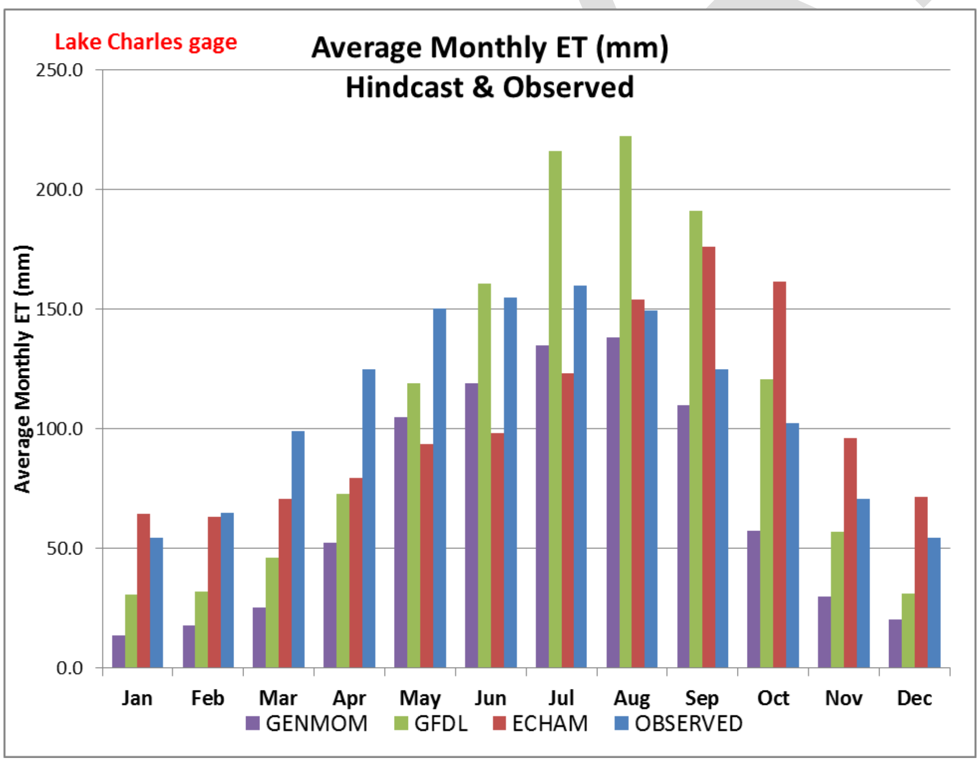

Figure 43: Monthly average ET (mm) for the Lake Charles gage location – RCM hindcast compared to "observed" monthly ET values used in 2012 master plan. All RCM records were from 1970-2000, except GENMOM which covered 1980-2000.

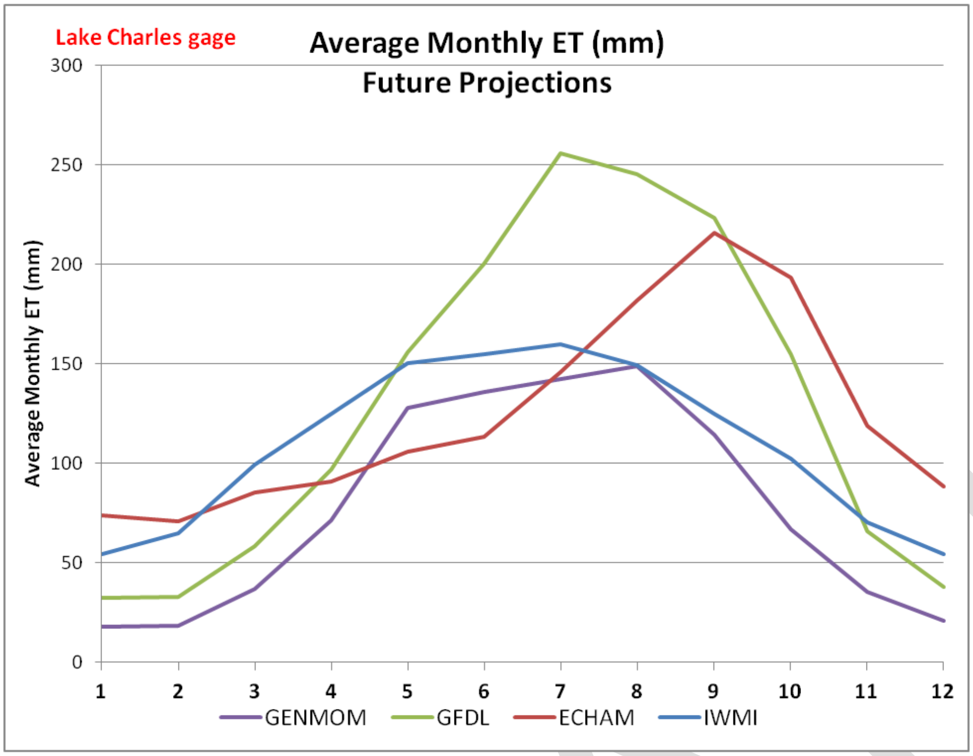

Figure 44: Range in downscaled monthly mean ET projections for the Lake Charles gage location.

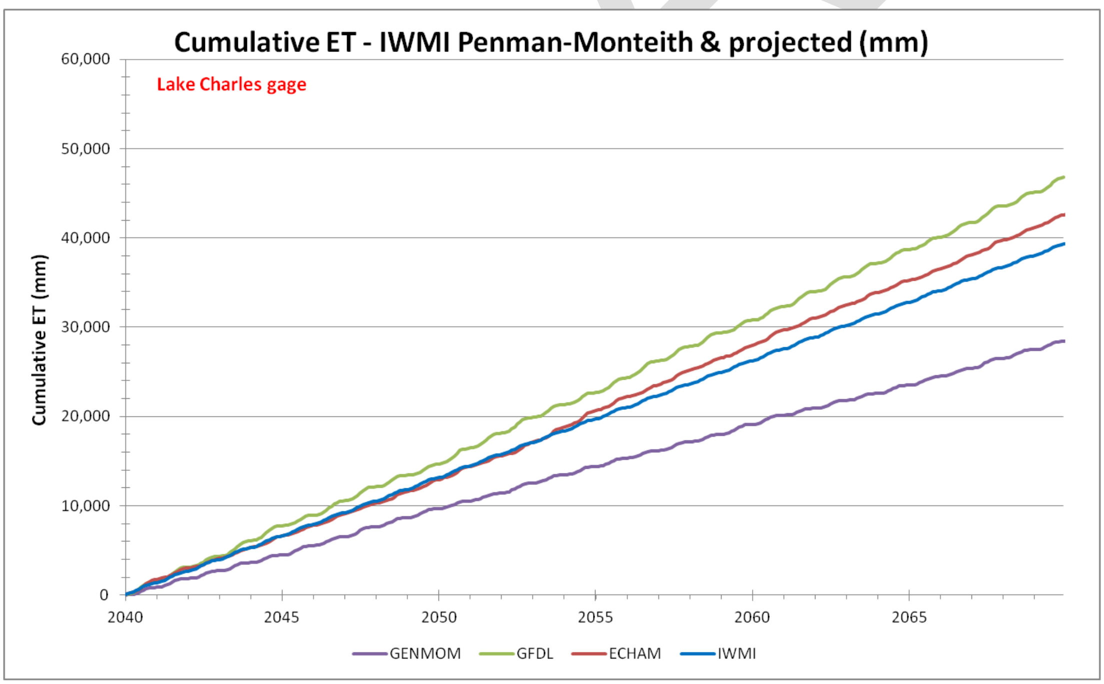

Figure 45: Projected cumulative ET (mm) for the Lake Charles gage - RCM data compared to a repetition of the IWMI record for the period where data is available for all three RegCM3 datasets.

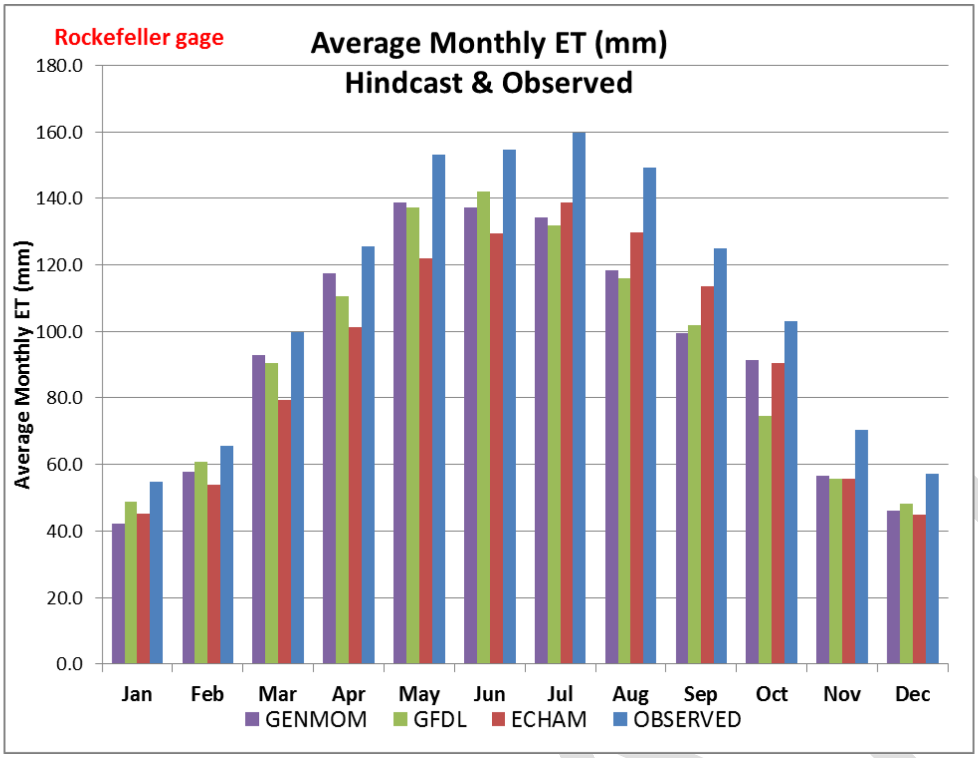

Figure 46: Monthly average ET (mm) for the Rockefeller gage location – RCM hindcast compared to "observed" monthly ET values used in 2012 master plan. All RCM records were from 1970-2000, except GENMOM which covered 1980-2000.

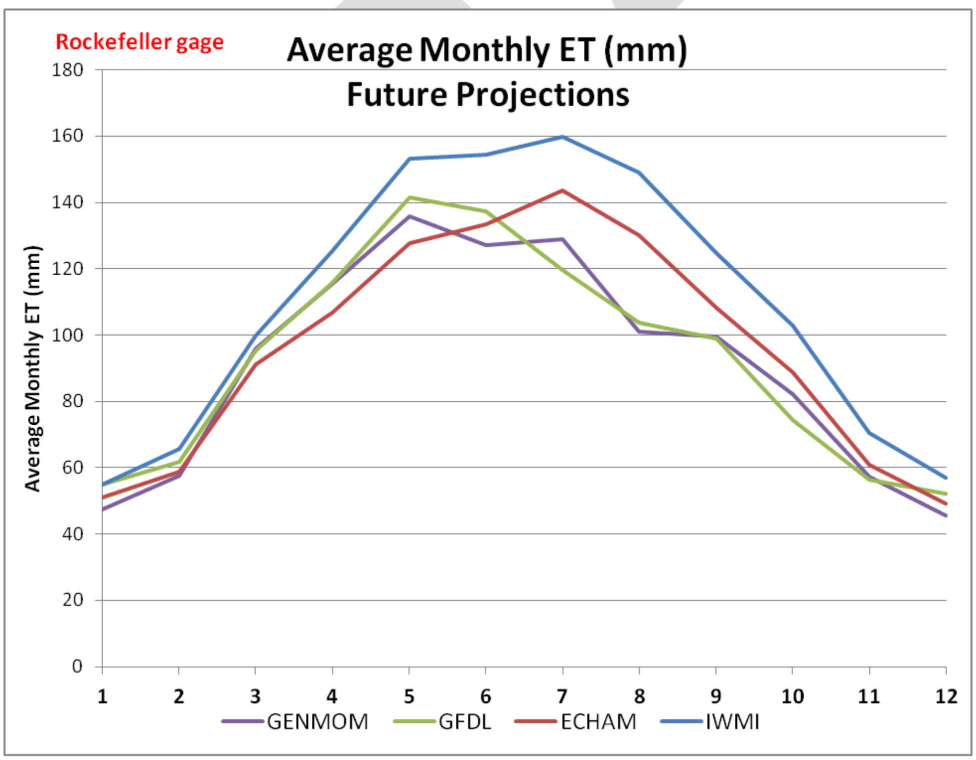

Figure 47: Range in downscaled monthly mean ET projections for the Rockefeller gage location.

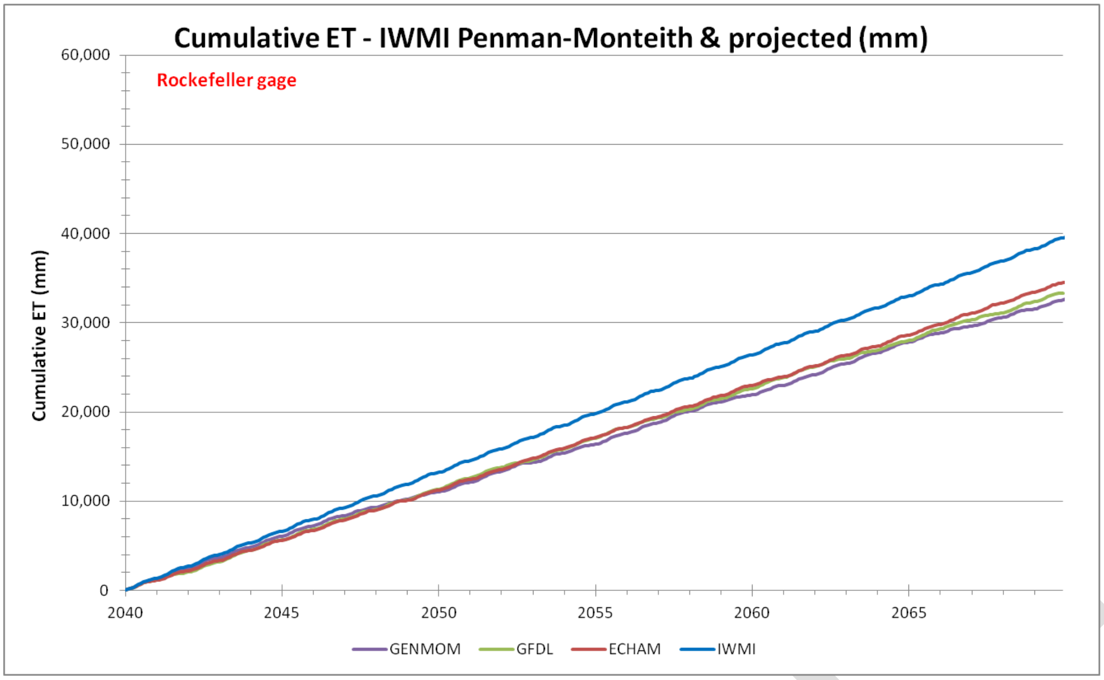

Figure 48: Projected cumulative ET (mm) for the Rockefeller gage - RCM data compared to a repetition of the IWMI record for the period where data is available for all three RegCM3 datasets.

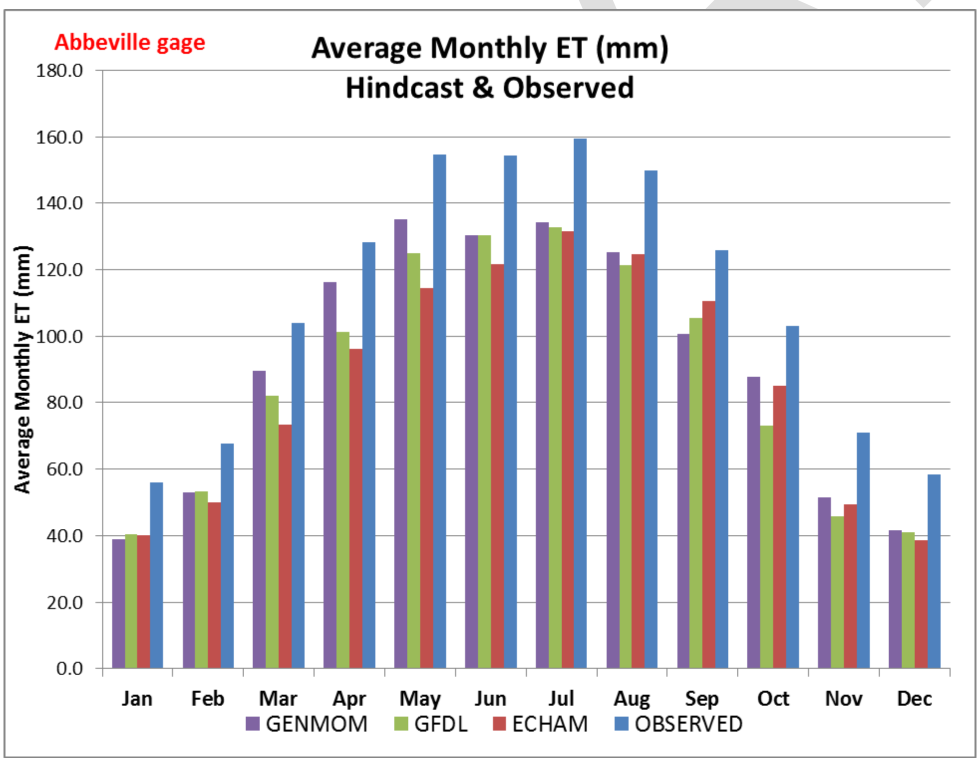

Figure 49: Monthly average ET (mm) for the Abbeville gage location – RCM hindcast compared to "observed" monthly ET values used in 2012 master plan. All RCM records were from 1970-2000, except GENMOM which covered 1980-2000.

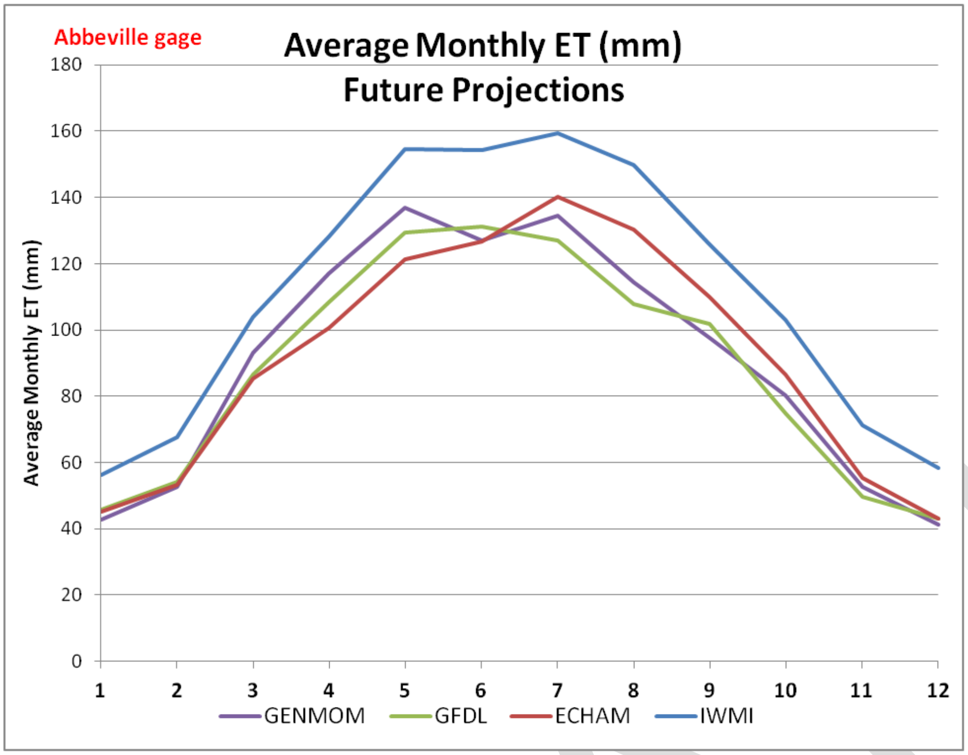

Figure 50: Range in downscaled monthly mean ET projections for the Abbeville gage location.

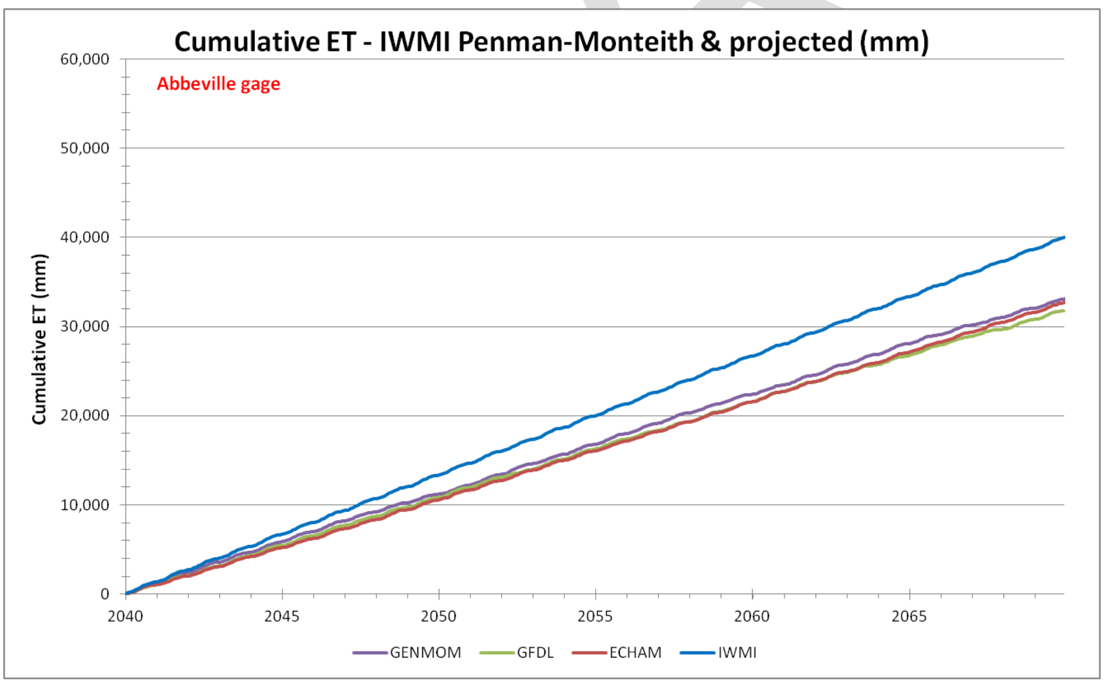

Figure 51: Projected cumulative ET (mm) for the Abbeville gage - RCM data compared to a repetition of the IWMI record for the period where data is available for all three RegCM3 datasets.