August 15 2017: Final Report:

Climate Change Impact Assessment in the Upper Santa Cruz River Basin

A consultation service to the Water Resources Research Center, University of Arizona

Eylon Shamir Ph.D.

Scope of Work

The research developed by the University of Arizona Water Resources Research Center (WRRC) is part of the Transboundary Aquifer Assessment Program (TAAP) for the San Pedro River and Santa Cruz River binational aquifers, which are specified as priority aquifers by Public Law 109-448. Previous TAAP efforts have revealed gaps in knowledge, particularly as applied to climate impacts and effective dissemination of scientific understanding. With this project, the WRRC intends to fill in some of the gaps related to climate assessment in the Santa Cruz River Aquifer.

The objective of this project was to analyze future projections of precipitation for the Upper Santa Cruz River Basin (USCRB) (Figure 1) and prepare precipitation time series that can be used for hydrologic impact assessment of the projected climate and groundwater modeling. The project included the completion of the following four tasks that are outlined in Table 1.

Table 1. Description of the project's tasks

Tasks #	Task Description
1	Subset the DD time series for the region of interest and create precipitation time series 1950-2100.
2	Evaluate the skill of the precipitation time series for the study region by comparing to the models simulations of the historic period, observed record and the WRF reanalysis dataset.
3	Analyze the projected changes in precipitation for 2020-2059. The changes will be evaluated for the summer and winter seasons and for characteristics that dominate the hydrologic characteristics of the region.
4	Using the Weather Generator that was developed for the Nogales region (Shamir et al., 2015) to generate ensembles of hourly precipitation that represent the historic and projected future (2020-2059), as found in task 3.

Task 1: Subset the DD time series for the USCRB

The analysis presented herein is of the state-of-the-art dynamically downscaled (DD) simulations from selected two CMIP5 Global Climate Models (GCM). Precipitation simulation for 1950-2005 and 2006-2100 at ~25 km horizontal spacing from two CMIP5 RCP8.5 dynamically downscaled models were received from Dr. Castro's group from the Hydrology and Atmospheric Sciences Department, University

of Arizona. These simulations were conducted as part of the North-America Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) program (https://na-cordex.org/), which is a World Climate Research Program (WCRP) initiative that aims to provide regional climate downscaling data for regional climate change adaptation and impact assessment.

The two selected GCMs were the HadGEM2-ES (Global Environmental Model, Version 2) from the United Kingdom Meteorological Office the Hadley Centre and the MPI-ESM-LR from the Max Planck Institute for Meteorology. These models were downscaled for the domain of the NA-CORDEX program using the Advanced Research version (ARW) of the Weather Research and Forecasting (WRF) Model (Version 3.1) as the Regional Climate Model (RCM). The WRF configuration is described in Castro et al. (2017). The simulations are available at 3 and 6-hour intervals for the WRF-HadGEM2-ES and WRF-MPI-ESM-LR, respectively. The DD simulations were selected for the study domain as indicated in Figure 1.

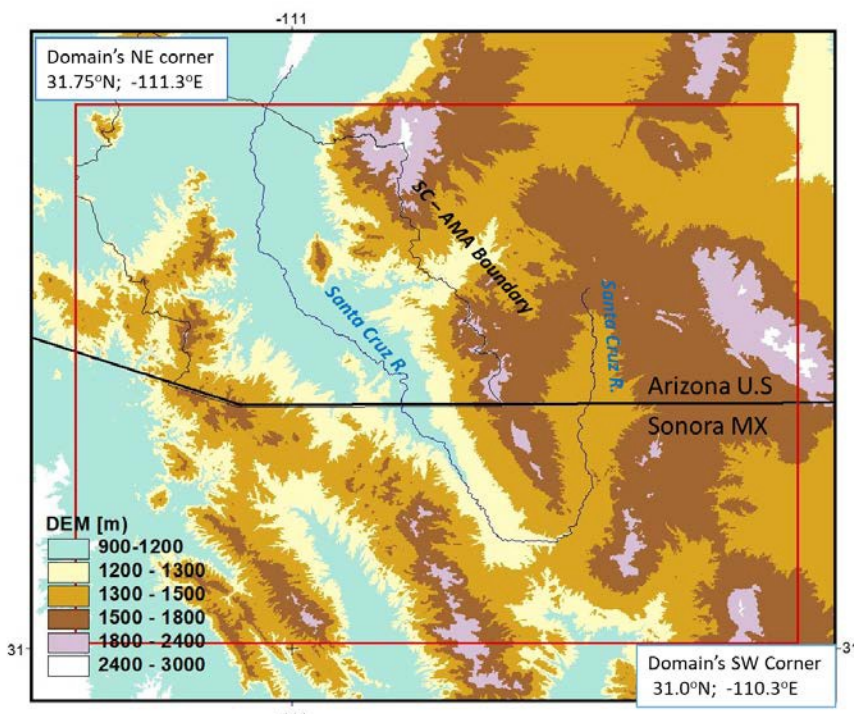

Figure 1: A regional map. The red outline indicates the domain of the analysis

Task 2: Evaluate the skill of the CMIP5 dynamically downscaled to simulate precipitation

A comparison of the average monthly total precipitation between the DD simulations of the historical period (1950-2005) and a gridded product that was interpolated from historical observations (Livneh et al. 2013) is shown in Figure 2. It is seen that although biased high during the summer months, both models captured well the temporal distribution of the annual precipitation.

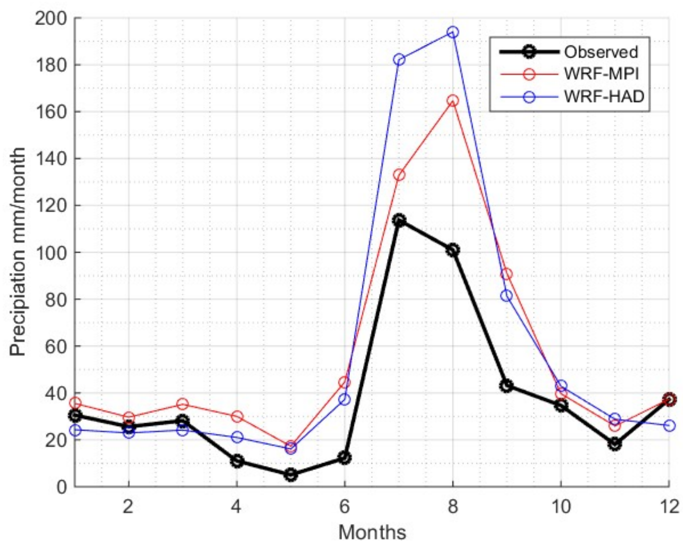

Figure 2: Average monthly totals of the DD simulations and observation for the study domain (1950-2005)

As of July 25, 2017, the WRF reanalysis simulations for the historical period were yet to be received. A comparison between the WRF reanalysis to the observed record is missing from this report. The WRF-reanalysis is a dataset that was produced by forcing the boundary conditions of the WRF model, at the same configuration as used for the DD simulations, with the historical observed based reanalysis dataset. Thus, this high-resolution reanalysis dataset produced by the WRF can be used to determine the skill of the WRF to simulate the climate features of interest in the study area.

Task 3: Analysis of the projected future changes in precipitation

The projected precipitation changes (if any) of the WRF MPI and WRF-HAD simulations are examined below. The DD simulations of the total 1950-2099 winter and summer precipitation are shown in Figures 3 and 4, respectively for the WRF-MPI (left panels) and WRF-HAD (right panels). The red dashed lines in these figures mark the 33.3 and 66.7 quantiles for the historic period (1950-2005) and two future horizons (2020-2059 and 2060-2099).

For both winter and summer seasons there is a lack of agreement between the projections of two GCMs. The WRF-HadCM3 simulation shows an increase frequency of wet and dry winter in mid-20th century (2020-2059) and an increase frequency of dry winter and a decrease frequency of wet winter at the end of the 20th century. On the other hand, the WRF-MPI shows an increase frequency of dry winters and a decrease frequency of wet winter.

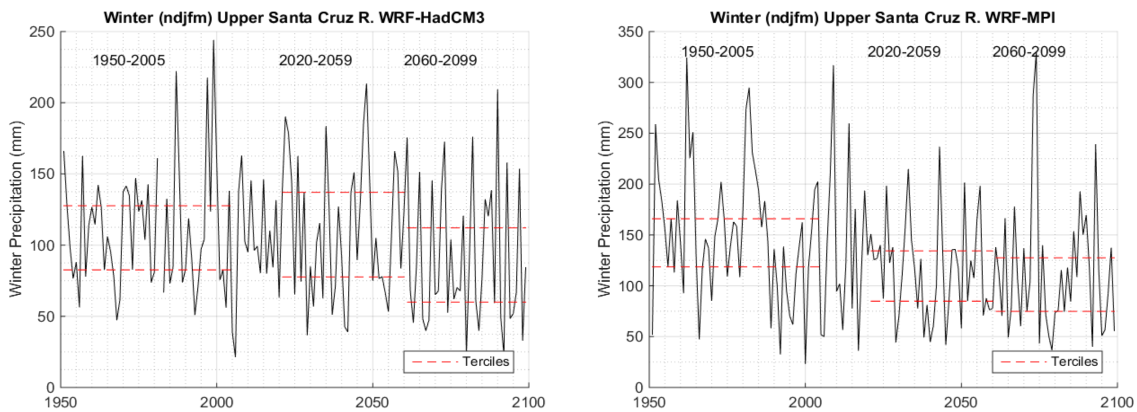

Figure 3: Total winter (November –March) precipitation over the study domain during 1950-2099 for the WRF-HadCM3 (left) and WRF-MPI (right). The dashed red lines mark the 33.3 and 67.7 quantiles during 1950-2005, 2020-2059, and 2060-2099.

An opposing trend between the two models is shown for the summer season. The WRF-HadCM3 points to an increase frequency of wet summer and a decrease frequency of dry summer, while on the other hand the WRF-MPI shows an increase frequency of dry summer and a decrease frequency of wet summer.

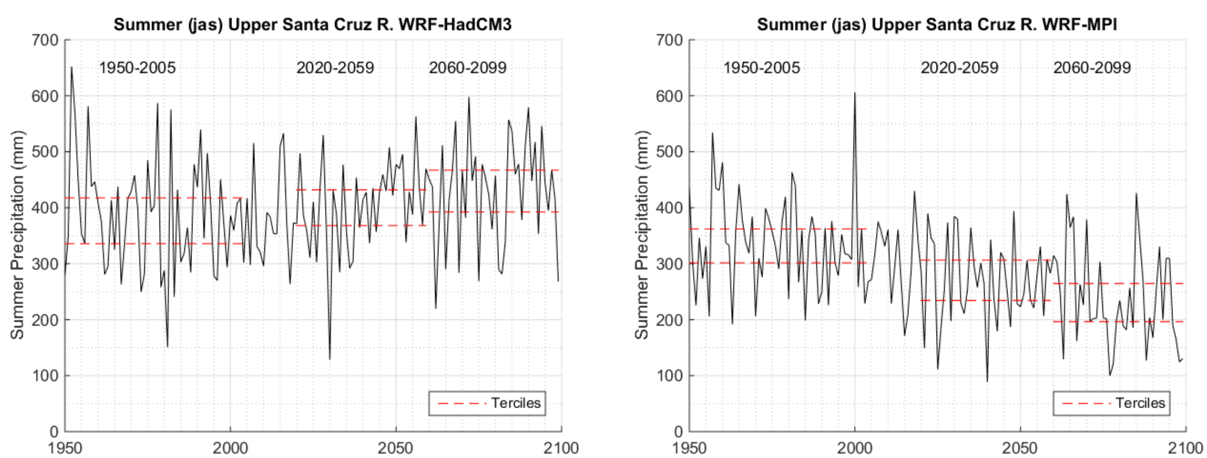

Figure 4: As of Figure 3 but for the summer (July-September).

The projected chance of the wetness categories to occur during in 2020-2059 as determined from the WRF-HAD and WRF-MPI simulations are in Table 2. This chances were derived by identifying the percentiles in the future projections of the terciles' values in the simulation of the historic period (1950-2005). Note that the changes are indicated for a given wetness category as the deviation from 33%.

Table 2. Projected 2020-2059 chances for the wetness categories to occur

	Winter		
	Dry	Normal	Wet
WRF-HAD	0.375	0.25	0.375
WRF-MPI	0.525	0.35	0.125
	Summer		
WRF-HAD	0.175	0.325	0.5
WRF-MPI	0.65	0.225	0.125

Further investigation for the precipitation properties in the USCRB that are projected to change is presented in the following. In Figures 5 the winter cumulative distributions of the historic period (1950-2005) and the projected mid-20th century (2020-2059) are shown in black and red, respectively for the WRF-MPI (left) and WRF-HAD (right). The four panels for each season include (a) the total seasonal precipitation, (b) the number of wet events, (c) the time of seasonal onset and, (d) the time of the seasonal offset. Figure 6 has a similar configuration but for the summer.

The conclusions that can be drawn from Figure 5 and 6 seem to hold for both summer and winter. The WRF-MPI projected drier seasons mainly because of less precipitation events. It is seen that the projected seasonal onset is similar to the historic period but the projected seasonal offset in the upper percentiles is longer, which implies shorter wet seasons. For the WRF-HAD on the other hands the CDFs of both historic and the future periods appear to have a better match.

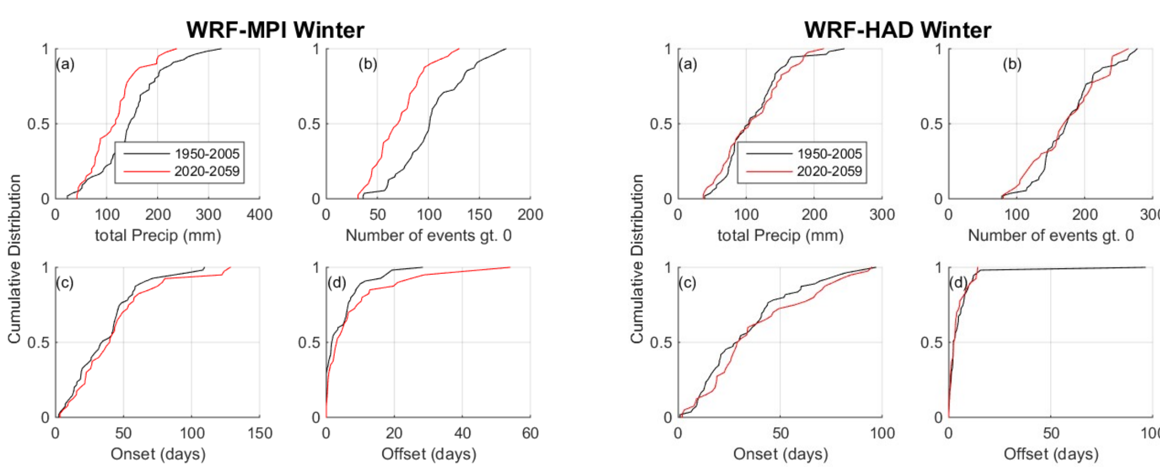

Figure 5: Cumulative distributions of the winter WRF-MPI (left) and WRF-HAD (right) simulations for the historic (1950-2005) and future (2020-2059) periods. The four panels represent a) the total seasonal precipitation, b) the number of precipitation events, c) the time of the seasonal onset and d) the time of seasonal offset.

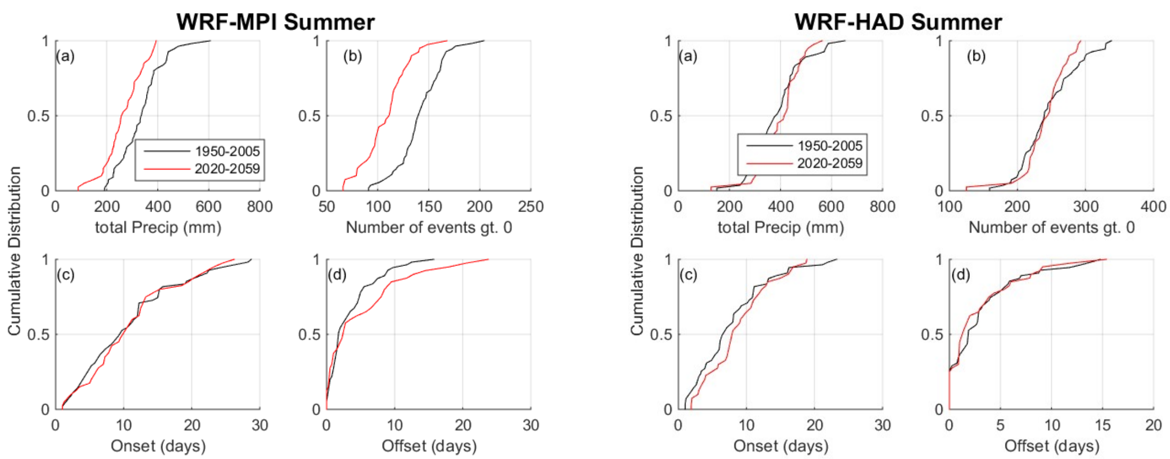

Figure 6: As of Figure 5 but for the summer

The distributions of the projected precipitation magnitude seem to be very similar to this of the historic period except from the summer simulation of the WRF-MPI. It seems that the WRF-MPI projected a substantial reduction in summer precipitation magnitude (Figure 7).

The distribution of time between the storms and the distribution of the duration of the storms are shown in Figures 8 and 9, respectively. In these plots the distribution of the future and historic periods have similar characteristics which means that no changes are projected in the inter-arrival time of storms and the duration of storms as defined in this study.

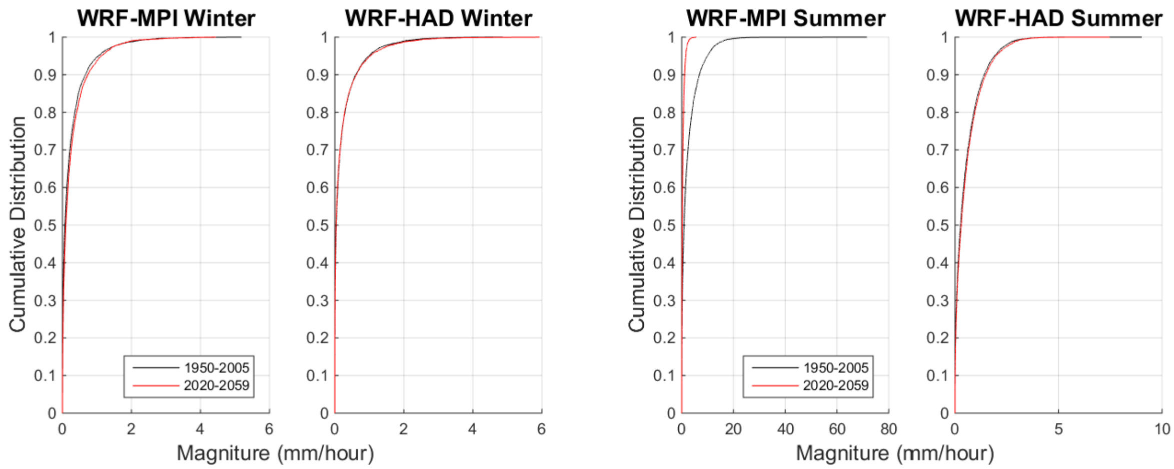

Figure 7: Cumulative distributions of the historic and projected hourly magnitude. From left to right winter WRF-MPI, winter WRF-HAD, summer WRF-MPI and summer WRF-HAD

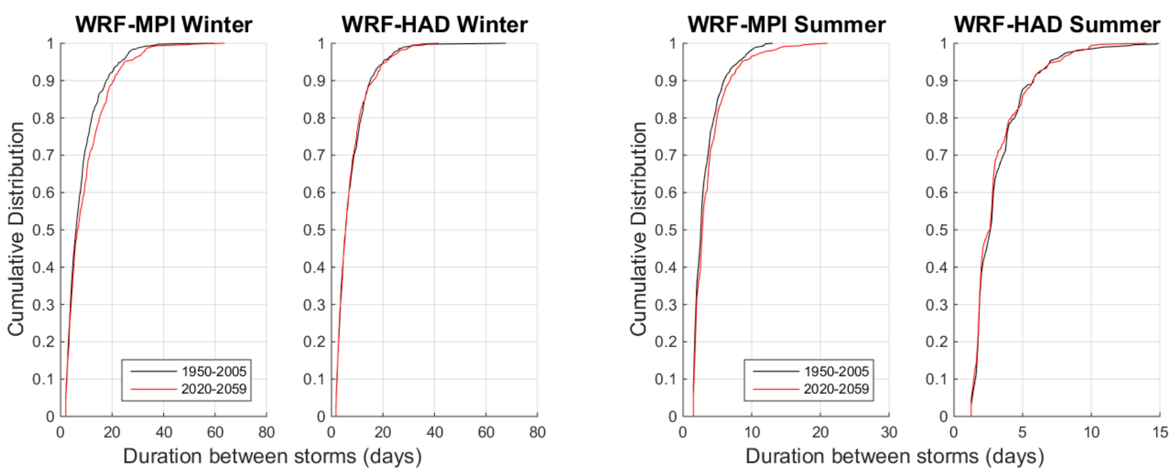

Figure 8: Same as Figure 7 for the distribution of duration between storms

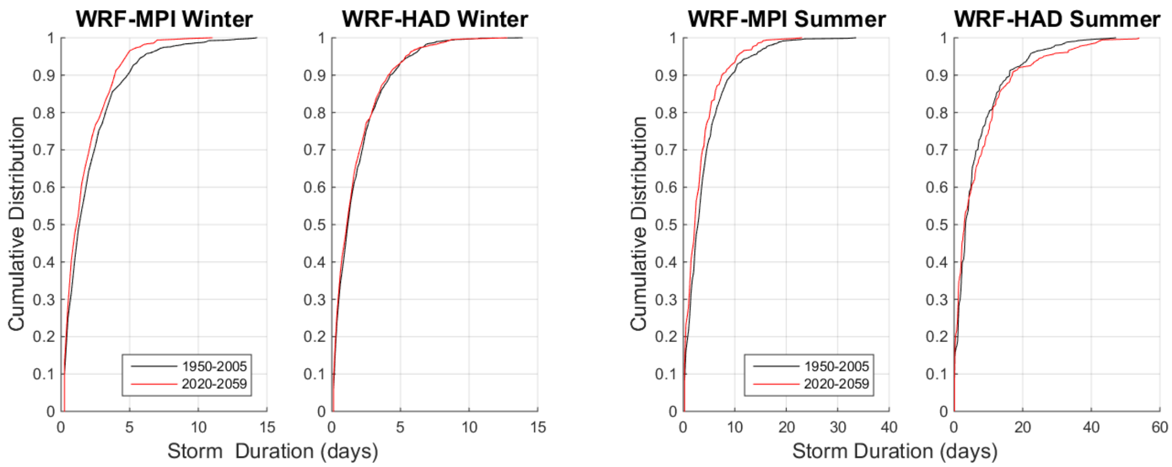

Figure 9: Same as Figure 7 for the distribution of storms duration

Task 4: Likely scenarios of the projected future precipitation using a Weather Generator

The (USCRB) hourly precipitation weather generator (WG) was initially developed and described in Shamir et al. (2005 and 2007), later was modified in Shamir et al., (2014 and 2015). The recent version of the WG, which is used in this study is described in Shamir (2017).

The WG produces likely hourly precipitation time series for a point and an ensemble of synthetic likely precipitation scenarios represents the regional rainfall characteristics, natural variability and the uncertainty that is associated with the observed record. The ability of the WG to produce likely to occur precipitation scenarios that represent the region in a probabilistic manner, makes it an appealing tool for water resources planning and management studies. In conjunction with hydrologic models that describe the natural water system of interest, it can be used to assess the impact of a range of scenarios such as, changes in water demand, construction of various structures and changes of projected climatic change. In addition, it can be used to identify best management practices that satisfy numerous objectives that often may compete.

For this study, three ensembles of hourly precipitation were generated. Each ensemble comprises 100 realizations of hourly precipitation for 69 years. We selected 69 years because this is the duration of the available historical precipitation record that was used to develop the WG. The first ensemble represents the historical period and the other two represents the projected precipitation of the WRG-MPI and WRF-HAD. To create these ensemble we modified the chance for getting a wetness category as analyzed in the DD for the 2020-2059 period (Table 2).

The leading assumption in that modification states that the internal characteristics of the future precipitation will remain similar to the seasonal precipitation that is described in the WG and the projected changes will be reflected as the frequency of arrival of the seasonal wetness categories.

Project Deliverables and status

Table 2. Description and status of the project's Deliverables

Deliverables	Status
The regional precipitation time-series from the DD climate models	An excel file was shared with WRRC scientists, June 13, 2017
Ensembles of hourly precipitation scenarios from the Weather Generator that represent the historic and future projections.	Three ensembles, each includes 100 realizations, 69 years each, of hourly precipitation was delivered on August 1st 2017. The three realizations represent the historic and the projected precipitation for 2020-2059 from the WRF-HAD and the WRF-MPI
A technical report that summarizes the analysis of the DD projections and describes the generation of the precipitation ensembles.	This document. It was first sent by email to Elia Tapia and Sharon Megdal on August 1, 2017. Relevant technical references are cited and will be made available upon request.

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