

**Final Project Memorandum**  
**SECSC Project 557-271:**  
**Developing multi-model ensemble projections of ecologically relevant climate variables for Puerto Rico and the US Caribbean**

**1. ADMINISTRATIVE**

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**Project title:** Developing multi-model ensemble projections of ecologically relevant climate variables for Puerto Rico and the US Caribbean

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**2. PUBLIC SUMMARY**

The global increases in surface air temperature are the most widespread and direct consequence of anthropogenic climate change. However, while 21st century temperatures are projected to increase in the Caribbean, the low variability and high average temperatures suggest that impacts on ecosystems and water resources are more likely through changes to the availability, timing, and pattern of moisture. The lack of local-scale climate model information that can resolve the complex topography and small scale climate features hinders the development of robust adaptation strategies. The goal of this project was to develop a suite of local-scale climate projections using dynamic downscaling to aid the development of adaptation strategies in Puerto Rico and the U.S. Virgin Islands (USVI). This project began by engaging the ecologists, hydrologists, and conservation biologists in the region to determine the most valuable types of information to aid research and decision making. The final product provides projections of future climate at a 2km horizontal resolution based on three global climate models and two regional climate models for a scenario with high greenhouse gas emissions. Results from the projections suggest that for Puerto Rico, annual temperature would increase between 1°C and 1.3°C by mid-century with larger temperature increases located in the interior portion of the island. Precipitation totals decrease for much of the island with island average decline between 12% and 19%, with some potentially large localized decreases exceeding 30%. The projected changes for the USVI are dominated by the surrounding ocean environment. The resulting projections will be provided to stakeholders in the region via the USGS and the CLCC.

### 3. TECHNICAL SUMMARY

The primary goal of this project was to develop dynamically downscaled climate change projections over Puerto Rico and the U.S. Virgin Islands, centered on mid-21<sup>st</sup> century global climate model (GCM) output under the aggressive (and close to historic trends) RCP8.5 emission pathway from the CMIP5 experiment. Dynamical downscaling is a physically-based modeling approach that employs regional climate models (RCMs) to simulate local scale atmospheric processes based on boundary inputs from spatially-coarse GCMs. For instance, 6-hour fields of 3-D temperature, moisture, and winds are required from the GCMs to perform dynamical downscaling. Overall, high-resolution climate change information (hourly model output at a 2-km horizontal resolution) is available from this project for Puerto Rico and the U.S. Virgin Islands.

This project began with testing various RCM configurations to help identify the model configuration (e.g. which micro-physics options to select) for a 2-km horizontal resolution. This horizontal resolution helps resolve gradients in terrain and land use across the island, which is one of the key benefits when applying RCMs. These RCM tests downscaled atmospheric reanalysis data with a comparable horizontal resolution to the GCMs. Downscaling atmospheric reanalysis data allowed us to simulate and evaluate changes in Puerto Rican and U.S. Virgin Island meteorology on daily to seasonal scales. These tests illustrated the potential uncertainty of the model configuration at atypical resolutions, and were considered a valuable contribution to the regional climate modeling community, as most regional climate models are configured on the order of 10-km. These results were published in the *Journal of Applied Meteorology and Climatology* (Wooten et al., 2016).

After defining the RCMs' configuration, they were used in production mode to generate the high-resolution regional climate change information from select GCMs. Two twenty-one year time-slices (1985-2005; 2040-2060) were dynamically downscaled using multiple RCMs: the Weather Research and Forecasting (WRF) model, and a combination of the Regional Spectral and Non-Hydrostatic Models (RSM-NHM). These RCMs downscaled two global climate models for each time-slice. Overall, there are 166 years of model output available between the two RCMs. Two years in the 20<sup>th</sup> century runs are not available for the GFDL-RSM-NHM configuration due to model integration issues (i.e. RCM failure). Thus, there are 19 years available for the GFDL-RSM-NHM configuration. The model output was post-processed to retain only the most relevant and actionable model output as identified by stakeholders, which was necessary to reduce the amount of required storage space. To complete the dynamical downscaling, millions of CPU processing hours were required and were generously provided by the Renaissance Computing Institute for WRF, and by Florida State High Performance Computing and the University of Texas High Performance Computing for RSM-NHM.

The final phase of this project began an evaluation of the high-resolution RCM output. Our initial evaluation includes an analysis of projected changes in mean statistics for temperature and precipitation, as well as an initial investigation of some of the most ecologically relevant

variables as defined by stakeholders. We also began an investigation into simulated changes in extreme precipitation.

#### **4. PURPOSE AND OBJECTIVES**

The primary objective of the project was to develop a suite of high-resolution dynamically downscaled climate projections for Puerto Rico to aid the development of adaptation strategies by the Puerto Rico Department of Natural and Environmental Resources and the U.S. Fish and Wildlife Service. These agencies seek to recover 11 species of terrestrial amphibians and reptiles with federal or state designations and prevent listing additional species that might become at risk. Persistence is threatened by the chance some species may not be able to cope with projected climatic changes (e.g. Gunderson and Leal, 2012), causing extinction risk to increase. Decisions by the Secretary of the Department of Natural and Environmental Resources entail selecting additional habitat, if needed to meet the objective of species persistence. These decisions should account for potential climatic changes by using dynamic downscaled projections that resolve the local scale conditions in Puerto Rico and the U.S. Caribbean.

Prior to this project, climate change projections for Puerto Rico have come from GCMs or dynamic downscaling efforts which are still too coarse to resolve small scale climate features that are most important to ecosystems and species of concern. The downscaled projections provided by this project are at a 2-km horizontal resolution and were created in consultation with key stakeholders in the region. This was designed to make certain the projections produced are relevant and add value to the decisions connected to the objective of the Puerto Rico Department of Natural and Environmental Resources and the U.S. Fish and Wildlife Service. As part of this project, we focused on:

- Engaging in ongoing dialogue with ecologists, hydrologists, and conservation biologists, eliciting expert knowledge to focus resources on the most valuable types of information that will aid decision making
- Simulate precipitation response to anthropogenic forcing at a scale that resolves key physical processes across Puerto Rico
- Characterize the uncertainty in the projections by nesting up to two RCMs with three GCMs that simulate the climate response to the anthropogenic forcing based on a 'business-as-usual' emission scenario (known as RCP 8.5)
- Develop projections of ecologically-relevant climate variables that will directly influence the distribution and persistence of wildlife species

#### **5. ORGANIZATION AND APPROACH**

##### **Engagement**

In order to make the resulting downscaled climate projections salient to decision making in Puerto Rico, the first step involved engaging ecologists, hydrologists, and conservation biologists studying species of concern in the region. This was done during a workshop held in San Juan, PR in November 2013. The two-day workshop brought together approximately 30 participants from across Puerto Rico and the U.S. Virgin Islands with the climate modelers involved in the project from North Carolina State University, the University of North Carolina Institute for the Environment, and the Florida State University Center for Ocean Atmosphere Prediction Studies. The workshop brought the two groups together to define variables of greatest need for adaptation decisions that would be available from the RCM output. A second workshop near the completion of the project was also organized to illustrate some preliminary findings, help stakeholders understand the strengths and limitations of the high resolution projections, and identify next steps for adaptation planning in the CLCC region. This final workshop also described how to access the high resolution downscaled projections product along with tips for visualizing and using the data.

### **Dynamical Downscaling**

The dynamical downscaling experiment used a combination of RCMs: WRF model v3.6.1 (Skamarock et al., 2008) and a combination of the RSM (Juang and Kanamitsu, 1994; Kanamitsu et al., 2010; DiNapoli and Misra, 2012) and NHM (Saito et al., 2006; Iizumi et al., 2011; Inatsu et al., 2015) models. Three GCMs were chosen to dynamically downscale: the Community Climate System Model version 4 (CCSM4; Gent et al., 2011), the Centre National de Recherches Meteorologiques Climate Model version 5 (CNRM-CM5; Voldoire et al., 2013), and the Geophysical Fluid Dynamics Laboratory Climate Model Version 3 (GFDL-CM3; Donner et al., 2011). These three GCMs were used as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) which was implemented for use in the IPCC Fifth Assessment Report. These specific GCMs were chosen based upon a performance evaluation of model simulation of bimodal precipitation distribution in the Caribbean, as shown by Ryu and Hayhoe (2013). To capture the uncertainty associated with RCMs and GCMs in the downscaled projections, each RCM is used to downscale two GCMs (Table 1).

**Table 1:** *Simulation Matrix for the RCM and GCM combinations*

	<b>WRF</b>	<b>NHM-RSM</b>
<b>CCSM4</b>	X	
<b>CNRM-CM5</b>	X	X
<b>GFDL-CM3</b>		X

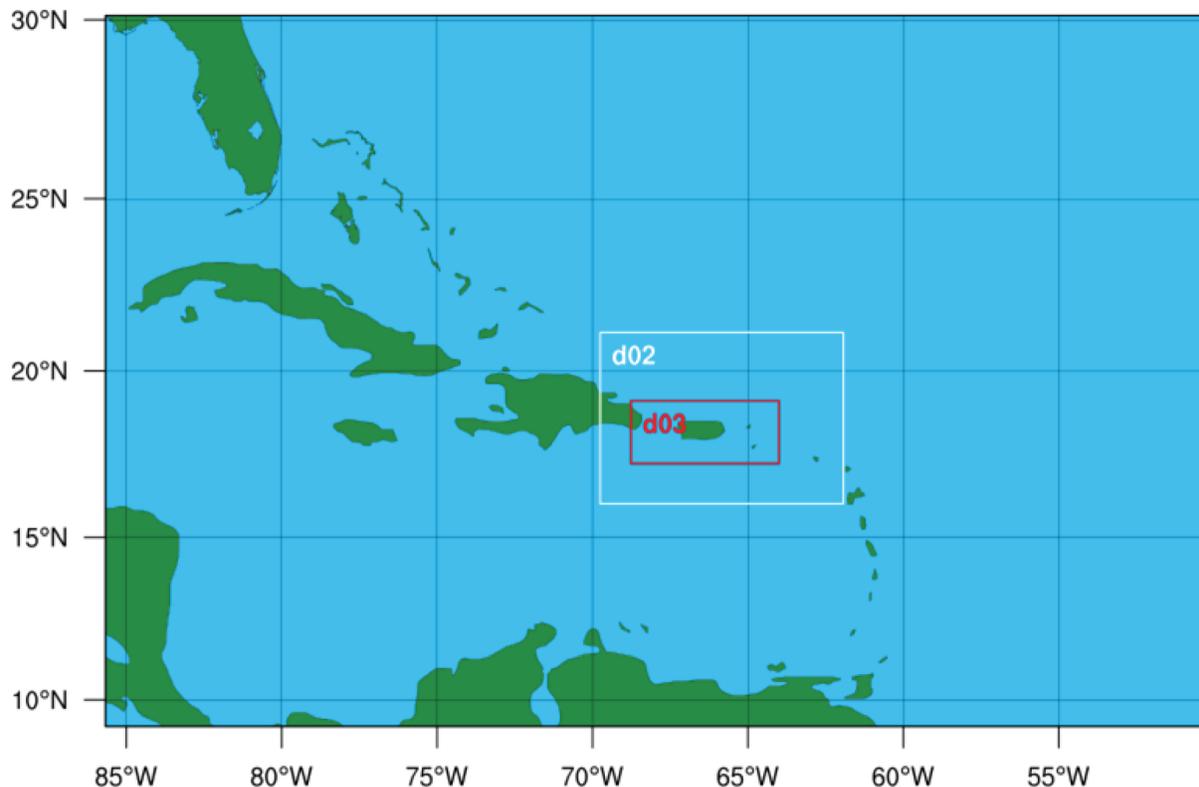
The WRF model was run using a triple nested domain centered over Puerto Rico and the USVI to nest down to 2 km as shown in Figure 1 (30-km; 10-km; 2-km). Various WRF configurations were tested to improve the regional climate model error and bias, especially for precipitation. These results were published in Wootten et al. (2016) and the best performing model

configuration was used to downscale the GCMs. The following micro-physics options were used for the WRF simulations:

- Radiation - RRTMG (Iacano et al., 2008)
- Microphysics - WSM6 (Hong and Lim, 2006)
- PBL (Planetary Boundary Layer) - YSU (Hong et al., 2006)
- Land Surface - Noah (Chen and Dudhia, 2001)
- Convection - Modified Kain Fritsch (Herwehe et al., 2014)

Analysis nudging is also applied to the 30-km and 10-km domains as discussed in Wootten et al. (2016).

## WRF Domain Configuration



**Figure 1:** Domain configuration for WRF simulations

The dual configuration of NHM and RSM is run to match the 10-km and 2-km domains of the WRF simulations (Figure 1). RSM is run with boundaries from the GCMs and produces output at 10 km, which is used to drive the boundaries of NHM to produce 2 km output centered over Puerto Rico. The parameterization schemes chosen for RSM include:

- PBL (Hong and Pan, 1996)
- Radiation (Chou and Suarez, 1994; Chou and Lee, 1996)
- Shallow Convection (Tiedtke, 1983)
- Deep Convection - Simplified Arakawa Schubert (Pan and Wu, 1995)

- Land Surface - Noah 4 soil layers (Ek et al., 2003)

The parameterization chosen for the NHM model include:

- PBL - Mellor Yamada Level 3 (Nakanishi and Niino, 2006)
- Microphysics - Three ice bulk microphysics (Ikawa and Saito, 1991)
- Land Surface - (Beljaars and Holstag, 1991)
- Cumulus parameterization turned off at 2 km

Note, two model years for the 20<sup>th</sup> century could not be completed for the GFDL-RSM-NHM configuration, resulting in 19 years for the historical simulation. Because the final results from this configuration are still being transferred to the USGS Data Portal, only the results from the CCSM-RSM-NHM are summarized in the results section, along with all WRF RCM output.

## 6. PROJECT RESULTS

This project delivers several realizations of high-resolution dynamically downscaled data can supplement other, existing climate change projections that are available for the U.S. Caribbean region. The results can be used by stakeholders to help inform decisions regarding adaptation and mitigation actions. Selected results for dynamically downscaled temperature and precipitation model output are summarized in this section. This abbreviated discussion focuses on results for Puerto Rico, as a full discussion of results for the entire U.S. Caribbean region will be presented in a subsequent USGS publication.

Table 2 provides a summary of the annual mean change by mid-century for daily maximum and minimum temperature for Puerto Rico. The annual maximum and minimum temperature change for Puerto Rico is shown to increase in a range between 1-1.3°C. However, local changes in maximum daily temperature may be twice as large (upwards of 2.5°C) for interior portions of the island compared to coastal areas (Figure 2). The differences between coastal and inland locations are likely related to the large thermal inertial of the ocean, which dampens the daytime response of temperature in the coastal environments. Conversely, there are much smaller spatial variations in minimum temperatures (Figure 3).

Table 2 also provides a summary of projected precipitation changes by mid-century for annual rainfall and the wet and dry seasons, respectively. The RSM-NHM-CCSM model configuration shows larger changes in precipitation compared to both WRF simulations. The RSM-NHM-CCSM configuration also indicates larger amounts of drying in the wet season compared to the dry season, while the WRF simulations have more consistent drying throughout the year. Figure 4 illustrates the complexity of the drying patterns and the large differences between GCMs and RCMs. Some of the largest projected drying exceeds 30% with large decreases in precipitation for both the western and southern half of Puerto Rico. Note however that the same GCM (CCSM) downscaled using two different RCMs, can result in very different precipitation changes, as for example in the western portion of the island where the WRF simulation shows much more drying over the western Mayaguez plain compared to the RSM-NHM model. Similarly, there is significant uncertainty in the projected precipitation changes for the El Yunque

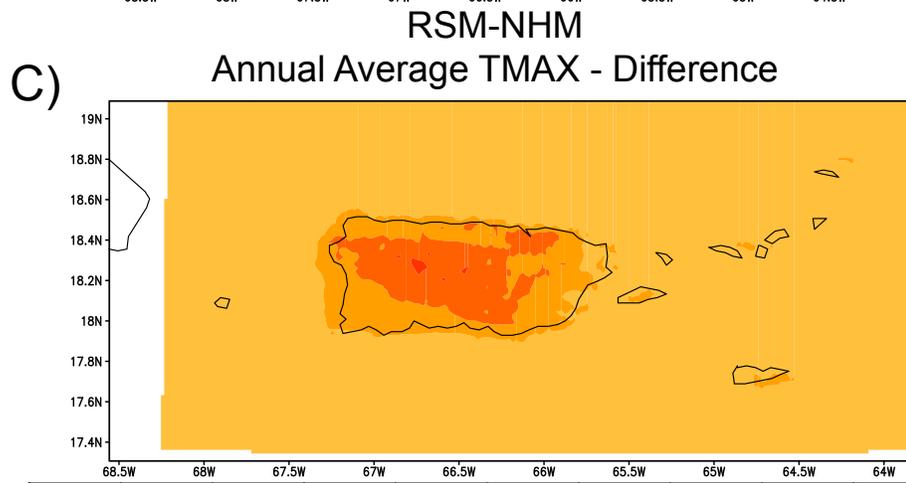
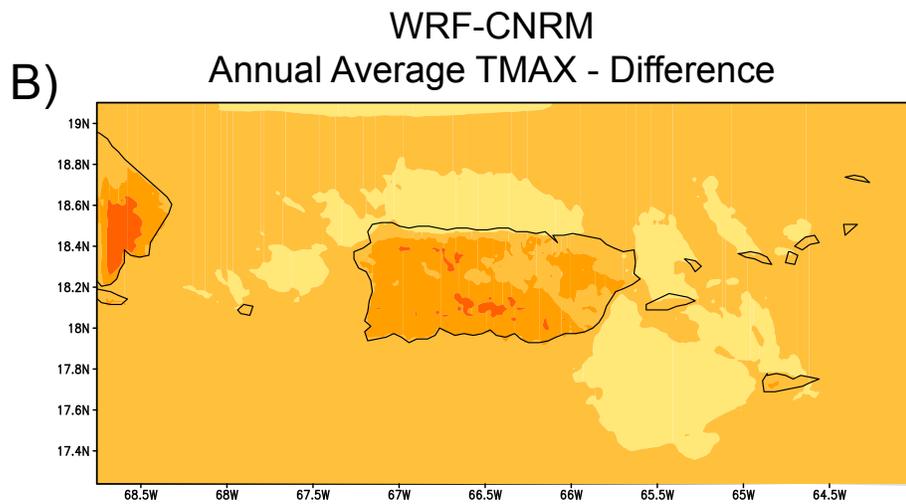
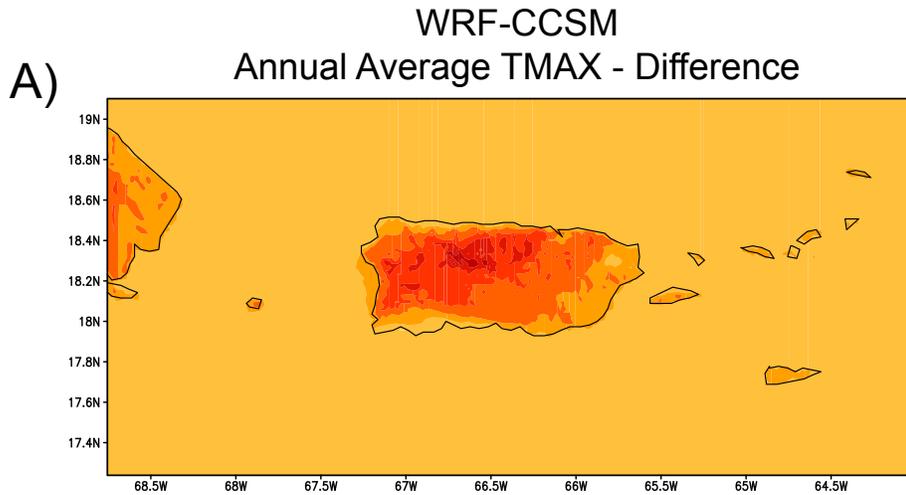
Rainforest, where some simulations produce a decrease and others an increase in precipitation relative to historical amounts (Figure 5). WRF-CCSM shows an increase in precipitation during the wet season in this area while NHM-RSM-CCSM shows a decrease.

Despite generally consistent model projections of precipitation decreases, there is some evidence for potential increases in extreme “short duration” hourly precipitation events. Taking advantage of hourly model output, we find some consistency between model simulations for extreme thresholds exceeding 20 mm/hour (0.79 inches/hour). Figure 6 shows the density of extreme precipitation events exceeding 20 mm/hour for all grid points within the subtropical dry forest. These events are rare, occurring less than 0.25% of the time (or for about 22 of the 8760 possible hours in a year); however, both WRF-CCSM and RSM-NHM-CCSM indicate some increases in extreme precipitation despite drying. Note that in the future time-slice, the simulations have short duration events not observed in the historical time-slice. Overall, more work is needed to understand these potential changes in extreme events from the dynamically downscaled model output.

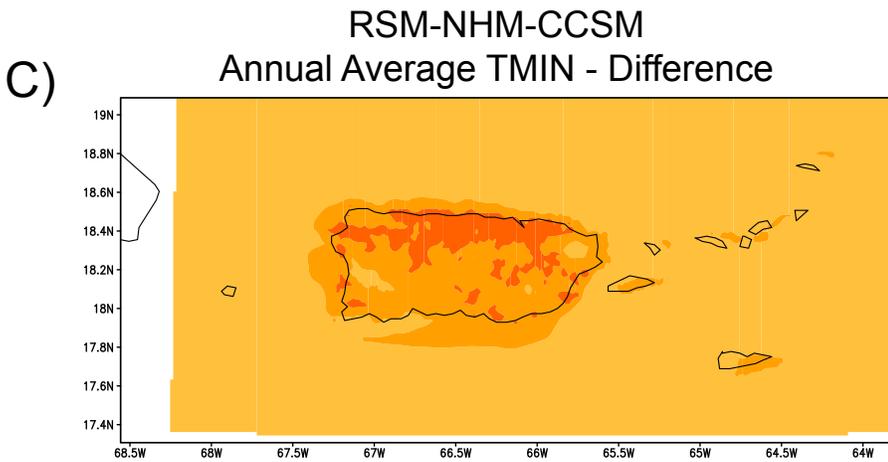
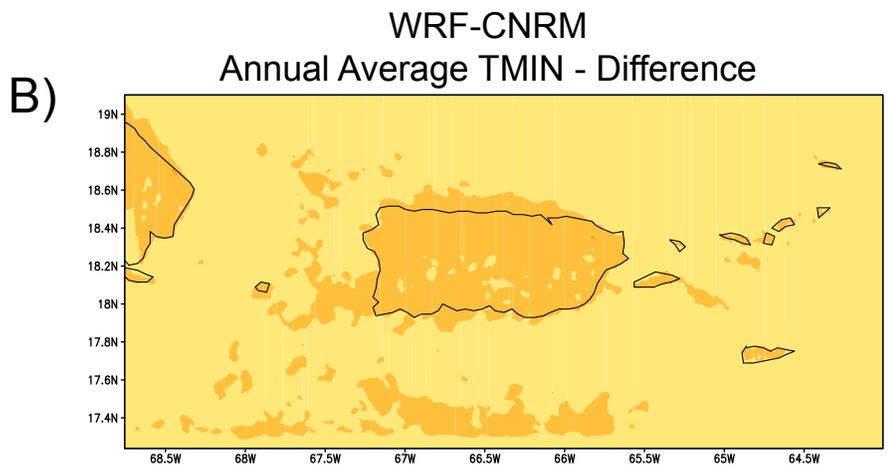
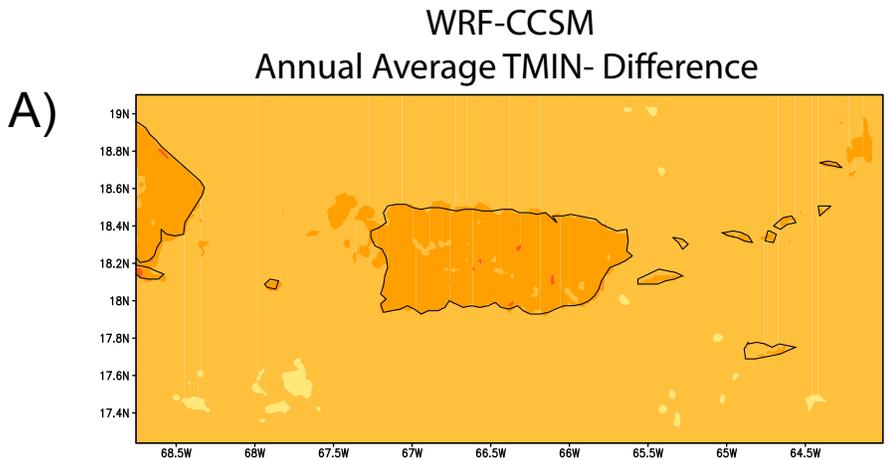
The dynamically downscaled climate change projections give scientists the ability to examine changes in variables other than temperature and precipitation that were identified as being important to key stakeholders. It also allows climate scientists the ability to more comprehensively understand the mechanisms in the climate system that are driving the locally experienced changes. At the initial stakeholder engagement meeting, one variable that was identified as important was cloud cover, particularly low-level clouds. Figure 7 shows the percent change in low-level cloud fraction, from the surface to approximately 3 km on average for the wet season. Despite the decrease in precipitation and increase in temperature, the models illustrate a general increase in low-level clouds. However, an important exception to this is a projected decrease in low-level clouds across higher elevations, such as in El Yunque region. These results could have a significant impact on the ecology and persistence of cloud forests. Future work is needed to investigate potential changes in climate variables as identified by stakeholders, including clouding cover.

**Table 2:** Puerto Rico island average change in annual average of daily maximum and minimum temperature and percent change in precipitation. For precipitation, wet season (April – October) and dry season (November – March) statistics are included.

<b>RCM-GCM</b>	<b>Temperature (°C)</b>		<b>Precipitation (%)</b>		
	<b>Max.</b>	<b>Min.</b>	<b>Annual</b>	<b>Wet</b>	<b>Dry</b>
WRF-CCSM	+ 1.22	+ 1.14	- 12%	- 11%	- 14%
WRF-CNRM	+ 1.06	+ 0.97	- 14%	- 14 %	- 13%
RSM-NHM-CCSM	+ 1.18	+ 1.21	-19 %	- 24 %	- 13%



**Figure 2:** Projected change in the daily maximum temperature for a) WRF-CCSM, b) WRF-CNRM, and c) RSM-NHM.



**Figure 3:** Projected change in the daily minimum temperature for a) WRF-CCSM, b) WRF-CNRM, and c) RSM-NHM.

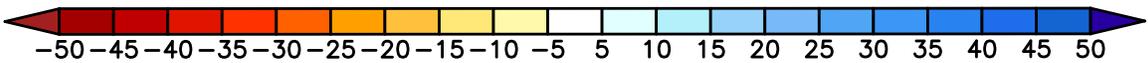
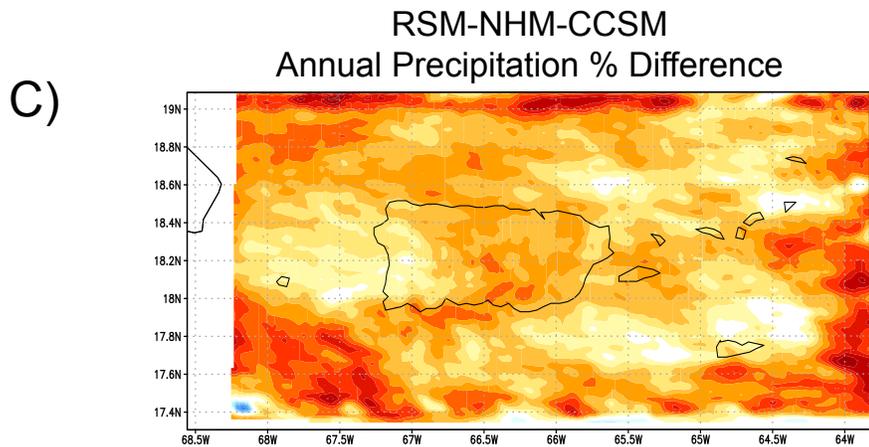
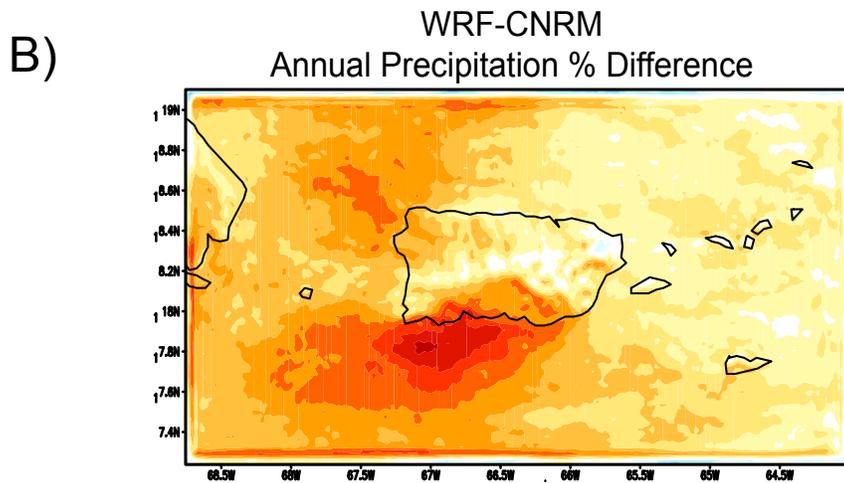
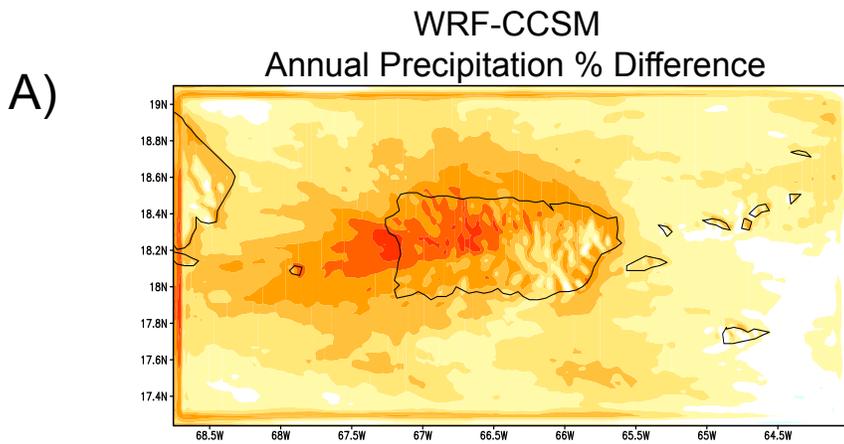
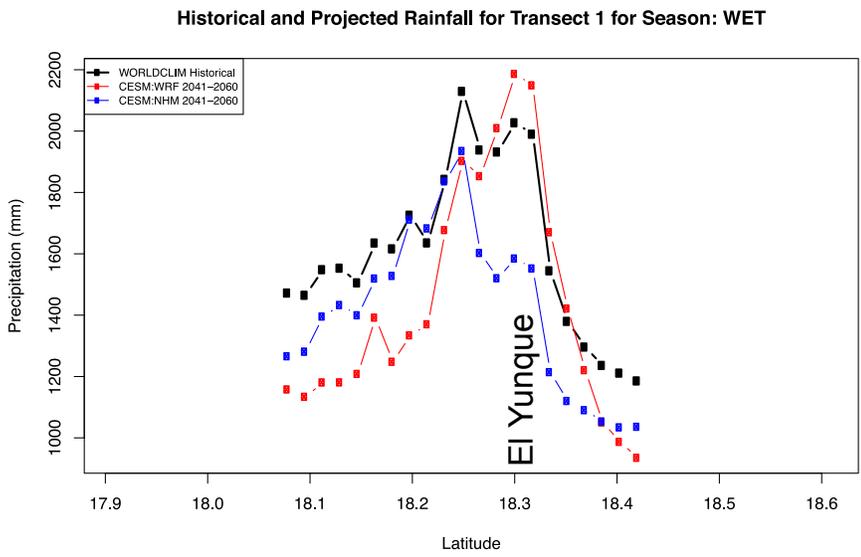
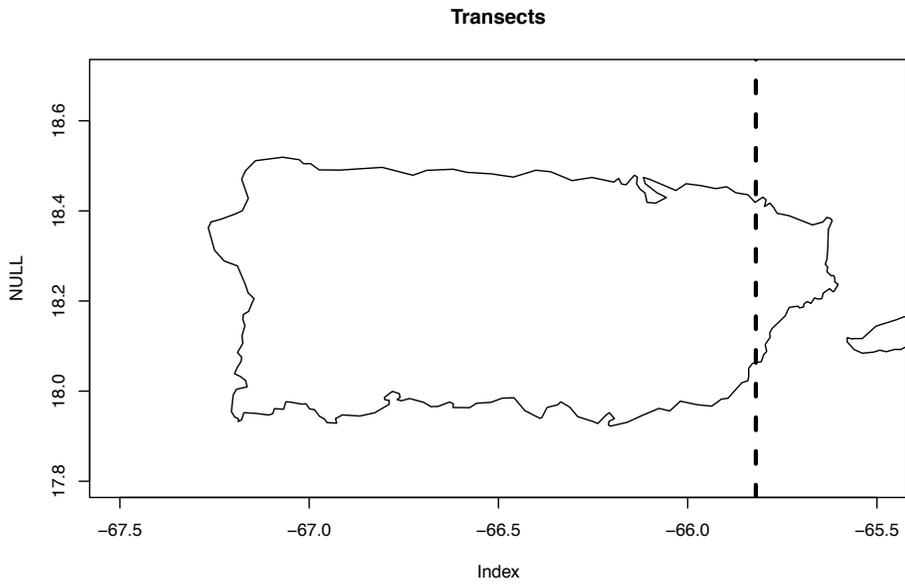
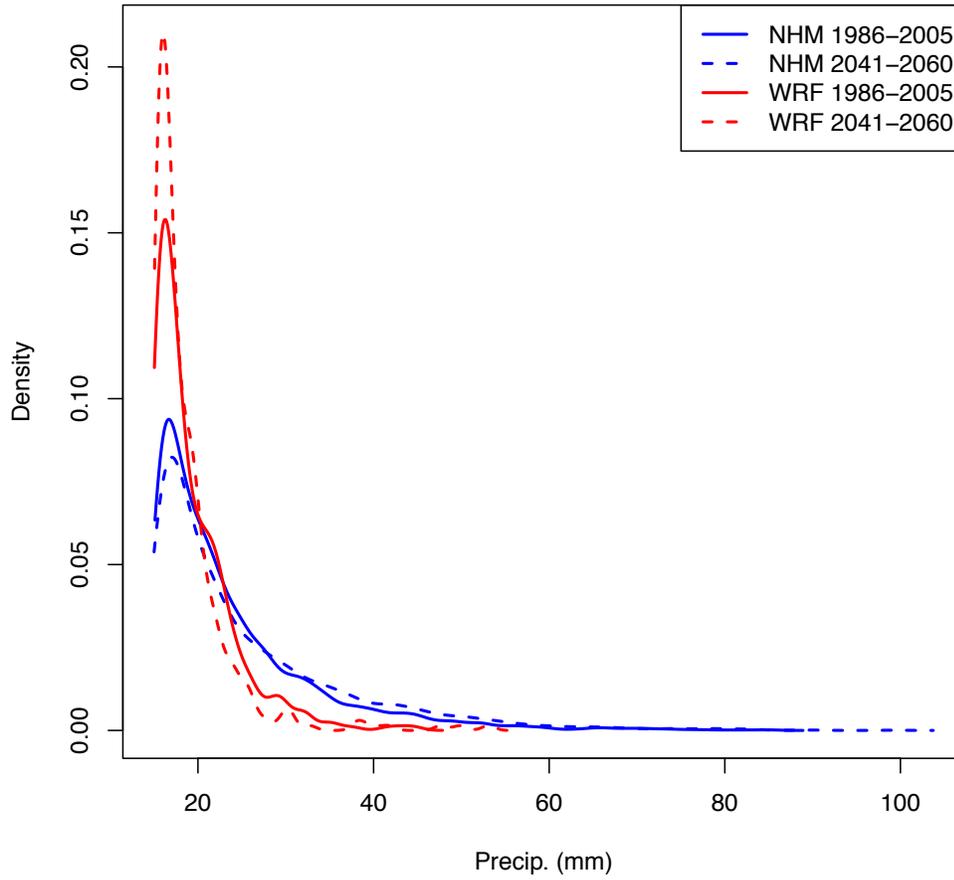


Figure 4: Percent change in annual precipitation for a) WRF-CCSM, b) WRF-CNRM, and c) RSM-NHM.

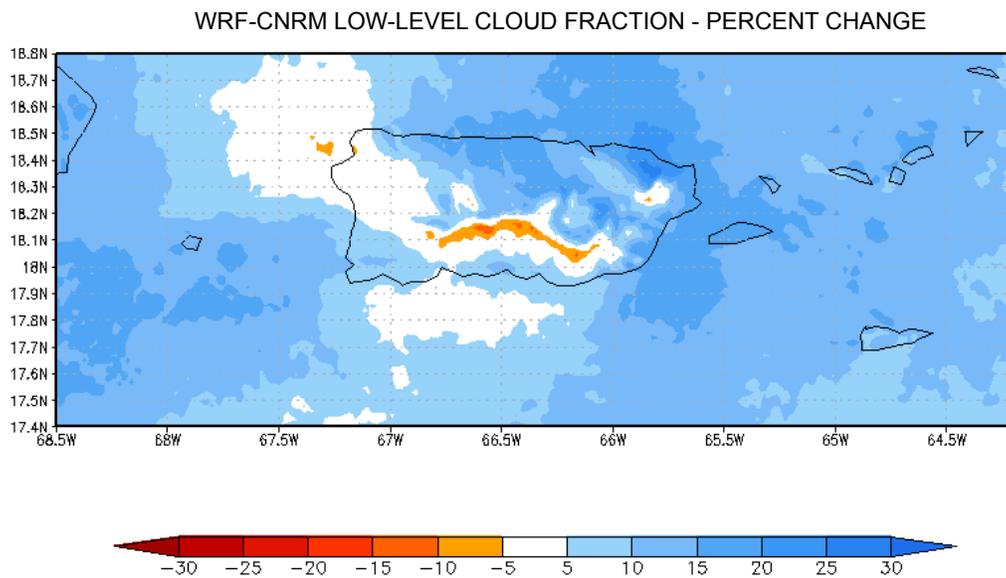
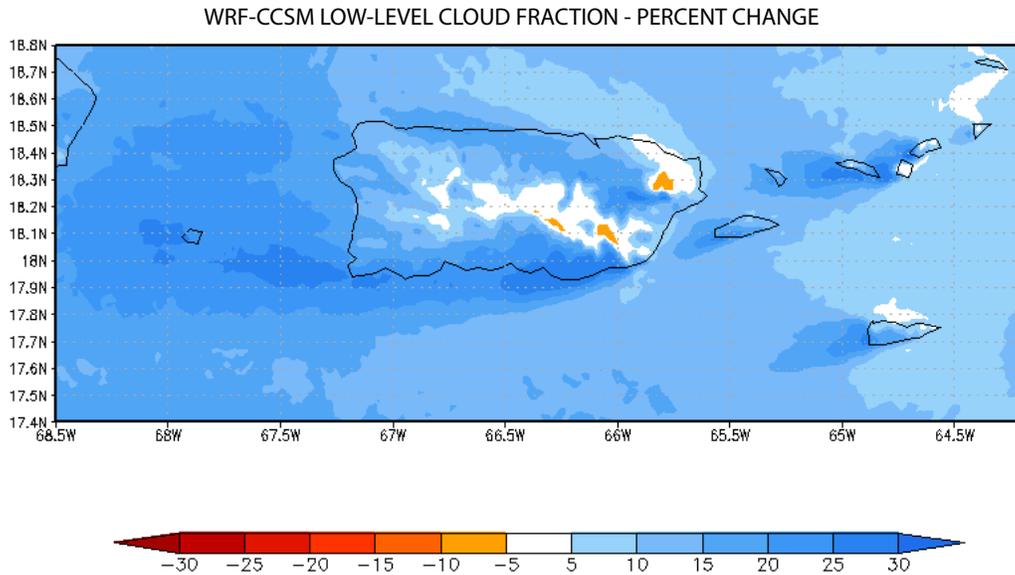


**Figure 5:** Model percent change applied to WORLDCLIM precipitation (black) for an N-S cross-section for rainfall totals during the WET season. WRF-CCSM is in red and NHM-RSM-CCSM is in blue. Cross-section is taken at a longitude that intersects El Yunque rainforest.

### Subtropical Dry Forest - Extreme Precipitation



**Figure 6:** PDF of precipitation extremes (mm/hour) for all grid points within the subtropical dry forest. The y-axis represents the percentage of the total number of events observed.



**Figure 7:** Percent change in low-level cloud fraction (surface to 700-hPa ~3km) for WRF-CCSM (top) and WRF-CNRM (bottom).

## 7. ANALYSIS AND FINDINGS

This project is unique, as it provides multi-decadal RCM simulations using different RCMs with input from multiple GCMs at convective permitting scales (<4-km). Other novel aspects of this project include an emphasis on stakeholder engagement *before* the experiment began to help modelers at UNC-Chapel Hill and FSU archive the most salient RCM output. Without stakeholder engagement, the dynamically downscaled climate change realizations would have required significantly larger data storage capacity and likely would have been impossible to comprehensively archive, meaning that the climate modelers would have relied on an ad hoc approach or climate science-centric criteria for deciding which model output to retain. The result of this project includes a list of archived data requested by stakeholders, provided in the supplementary information section.

The RCM-GCM realizations provided a unique perspective of some of the complexities that exist for local to regional climate change information for Puerto Rico and the U.S. Virgin Islands. Our dynamically downscaled model results indicate larger changes in the maximum temperature with concentrated changes in the interior portion of the islands, while minimum temperatures are fairly homogeneous across the island. The model analysis also revealed consistent drying projected by the GCMs; however, there is uncertainty about the pattern and magnitude of this drying. In particular, we find that some places could experience local drying as large as 30% for annual precipitation totals. The only region that the RCMs projected could experience potential increases in precipitation was El Yunque. We also found preliminary evidence that the frequency and intensity of extreme precipitation events could increase, despite drier conditions. Finally, our preliminary analysis revealed that local climatic responses will be complex and varied, even in small island geographies, as evidenced by the differing changes in low level clouds in the mountains versus coastal regions of Puerto Rico.

## 8. CONCLUSIONS AND RECOMMENDATIONS

Over 15 Tb of data are available as a result of this project, with high temporal (daily to hourly) and spatial (10km to 2km) output available for many climate variables. Such a rich dataset will allow for more detailed exploration of what global climate change means locally for the U.S. Caribbean. Additionally, several lessons learned can be applied to future downscaling efforts in this region, and likely across many similar island and sub-tropical environments. We briefly discuss a few of these points below.

Running RCMs at convective permitting scales required significant time to test various model configurations. The various model configurations were evaluated for precipitation and temperature to provide a vetted model configuration for each RCM. As a result, the two RCMs use slightly different modeling approaches to handle convection for the 2-km domain. WRF applied a cumulus parameterization scheme, while RSM-NHM configuration did not. The RSM-NHM configuration relies on the microphysics to produce precipitation. The final RCM

configurations have consistent dry biases. We hypothesize this issue is related to microphysics or other physics options that are not specifically developed for convective permitting scales.

This project has provided valuable insight into running RCMs at extremely high horizontal resolutions. Below is a list of recommendations that we feel are logical next steps given what has been completed thus far.

- This project created terabytes of model data. Further examination of the model output may be warranted to investigate changes in extreme events, changes to ecological climate variables of interest while engaging with island stakeholders, and research to understand the physical mechanisms responsible for changes for projected changes. This would include a more targeted investigation for the U.S. Virgin Islands.
- Dynamical downscaling is computationally expensive. We recommend comparing the dynamically downscaled model results to statistical downscaling products to help determine the added value of this method.
- Investigate methods to combine dynamical and statistical downscaling to take advantage of both approaches.
- Use the RCMs to provide additional simulations to further understand the driving mechanisms underlying the large differences between the projections that are of direct interest to stakeholders. Such scenario development could also take advantage of more recent developments in scale-aware physics within RCMs.

## **9. MANAGEMENT APPLICATIONS AND PRODUCTS**

The high-resolution downscaling products are currently being incorporated into the USGS Center for Integrated Data Analytics GeoData Portal (<https://cida.usgs.gov/gdp/>). Ultimately, the products will also be made available through the CLCC data portal. This will make the product easily accessible to stakeholders in the CLCC region. The engagement process that was part of this project between the PIs and the CLCC also allows for access to the expertise of the climate modelers producing the data for additional guidance to use the high resolution downscaling product.

The output from this work is being used to inform the Caribbean Chapter of the Fourth National Climate Assessment and the Puerto Rico Climate Change Council's State of the Climate Report. Finally, the results from this project are being used, as originally envisioned, to help inform adaptive management plans in the U.S. Caribbean, with initial work being conducted to assess the potential for establishing climate refugia on the island for threatened and endangered amphibians (Agreement Number: G14AC00349).

## **10. OUTREACH**

### **Peer-reviewed Publications**

Wootten, A., J. H. Bowden, R. Boyles, and A. Terando, 2016: The Sensitivity of WRF downscaled precipitation in Puerto Rico to Cumulus Parameterization and Interior Grid Nudging. *J. Applied Meteor. Climatol.*, **55**, 2263-2281, DOI: 10.1175/JAMC-D-16-0121.1.

Bhardwaj, A., V. Misra, A. Mishra, A. Wootten, R. P. Boyles, J.H. Bowden, and A. Terando, *in revision*: Downscaling Future Climate Change Projections over Puerto Rico using a Non-Hydrostatic Atmospheric Model. Submitted to *Climatic Change*.

Bowden J.H., A. Wootten, V. Misra, A. Mishra, R. Boyles, A.J. Terrando, B. Gould 2016: Comparing multi-decadal climate change projections at convective resolving scales for life zones within Puerto Rico. To be submitted to *Nature Climate Change*.

Wootten, A., J.H. Bowden, V. Misra, L. Stefanova, A. Mishra, R. Boyles, and A. Terando, *in preparation*. Structural Uncertainty in Regional Climate Models, are we only scratching the surface? To be submitted to *Geophysical Research Letters*.

## **Presentations**

Bowden, J.H., A. Wootten, R. Boyles, A. Terando, V. Misra, A. Bhardwaj, 2017: Comparing Mid-Century Climate Change Projections at Convective Resolving Scales (2-km) for Life Zones Within Puerto Rico, Annual American Meteorological Society Meeting, Seattle, WA.

Bowden, J.H., A. Wootten, R. Boyles, A. Terando, V. Misra, A. Bhardwaj: Comparing Mid-Century Climate Change Projections at Convective Resolving Scales (2-km) for Life Zones Within Puerto Rico, American Geophysical Union Fall Meeting.

Bowden, J.H., 2016: High resolution regional climate change projections for Puerto Rico and the U.S. Virgin Islands, Caribbean Landscape Cooperative, San Juan, PR – Invited Presentation.

Bowden, J.H., A. Wootten, R. Boyles, A. Terando, V. Misra, A. Bhardwaj: Comparing Mid-Century Climate Change Projections at Convective Resolving Scales (2-km) for Life Zones Within Puerto Rico, American Geophysical Union Fall Meeting.

Terando, A. 2015. Charting a course as a global change scientist: towards actionable science through cross-disciplinary research. *University of South Carolina Department of Geography Colloquium*.

Wootten, A, 2016: Climate Projections in the Caribbean: What they are, What they say. Caribbean Basin Ecosystem Based Management Tools Training Workshop, San Juan, PR - Invited Presentation.

- Wootten, A, A. Terando, J. Collazo, 2016: Ultra-high resolution ecologically-relevant climate projections for the US Caribbean: Results, discussion and uses for scientific study and decision making. NatureServe Biodiversity Without Boundaries 2016, San Juan, PR.
- Wootten, A., J.H. Bowden, V. Misra, L. Stefanova, R. Boyles, A. Terando, 2016: How well do high resolution limited area models simulate sub-tropical precipitation? A comparison of High Resolution Regional Climate Model Output for Puerto Rico. 30<sup>th</sup> Conference on Hydrology, New Orleans, LA.
- Wootten, A., J.H. Bowden, R.P. Boyles, A. Terando, 2016: The Sensitivity of WRF Downscaled Precipitation in Puerto Rico to Cumulus Parameterization and Interior Grid Nudging. 28<sup>th</sup> Conference on Climate Variability and Change, New Orleans, LA.
- Wootten, A., 2015: Creating High Resolution Projections For Puerto Rico: Downscaling with Ecosystems in Mind. NOAA Geophysical Fluid Dynamics Lab Seminar Series, Princeton, NJ – Invited Presentation.

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## Supplemental Information

Below is a summary of variable information to be retained by RCMs as requested by the stakeholders. Each modeling group worked to provide these relevant fields when archiving data.

	Variable
<b>Temperature</b>	
	Air temperature at pressure levels
	Air temperature at 2m
	Ground temperature
	Soil Temperature
<b>Moisture</b>	
	Relative humidity at pressure levels
	Specific humidity at 2m
	Dewpoint Temperature
	Canopy wetness
<b>Precipitation</b>	
	Convective precipitation
	Total precipitation
	Soil Moisture
<b>Winds</b>	
	Speed, direction at 10m
	Speed, direction at pressure levels
	Vertical velocity at pressure levels

	Variable
<b>Radiation</b>	
	Solar radiation down
	Solar radiation up
	Terrestrial radiation down
	Terrestrial radiation up
<b>Clouds</b>	
	Bottom height (for low, medium, high clouds)
	Top height (for low, medium, high clouds)
	Cloud cover % (low, medium, high, total)
<b>Pressure</b>	
	Surface pressure
	Pressure tendency (i.e., time-derivative of pressure, indicates pressure rising or falling)
	Geopotential height (i.e., height of pressure levels)
<b>Energy Fluxes</b>	
	Sensible
	Latent
	Ground
	Potential evapotranspiration