Global and Regional context for Puerto Rico’s changing climate

Puerto Rico’s Changing Climate

Oceans:
- Ocean Temperature
- Ocean Acidification
- Sea Level Change

Air:
- Composition
- Temperature
- Precipitation Variability
- Extreme Events
- Tropical Storms and Hurricanes

Coordinator: Ernesto Díaz
Dr. Adam Terando
Regional Climate Model Projections Update

Jared Bowden, University of North Carolina, Chapel Hill, Institute for the Environment


Adam Terando, US Geological Service, Southeast Climate Science Center
Existing Complementary Data Sets*

- Hayhoe’s statistically downscaled data sets
  - Point station resolution
  - CMIP 3: predicts drier future
  - CMIP 5: aerosols added predicting wetter future
  - More GCMs, full century predictions
  - Assumes linear and constant meteorological behavior from past to future time periods

- PRECIS-Caribbean
  - 50km and 25km resolution
  - CMIP 3

- SE Climate Science Center dynamically downscaled (focus of this presentation)

* Recommend using the suite of available data sources
GCM

Downscaled

WRF simulated 2-m average Temperature
January 4-8 2005
Experimental Design for Regional Climate Modeling

• **THREE GCMs**
  – CCSM4, CNRM5, GFDL-CM3

• **TWO RCMs**
  – WRF, NHM-RSM

• **TWO 20 year periods**
  – 1986-2005 (past)
  – 2040-2060 (future)
  – RCP 8.5 – high fossil fuel emissions scenario
# Downscaled Weather Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Temperature</th>
<th>Moisture</th>
<th>Precipitation</th>
<th>Winds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air temperature at pressure levels</td>
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First question to ask:

How well do we simulate the historical climate?

**Maximum 2-m Temperature** annual average over P.R.

- **WORLDCLIM Max. Temperature**
  - Annual (Deg. C)
  - -0.9°C

- **WRF-CNRM Max. Temperature**
  - Annual (Deg. C)
  - -0.5°C

- **RSM–NHM CCSM Max. Temperature**
  - Annual (Deg. C)
  - -2.7°C
Maximum 2-m Temperature Change
annual average

WRF–CCSM Max. Temperature Difference (Deg. C)

WRF–CNRM Max. Temperature Difference (Deg. C)

RSM–NHM CCSM Max. Temperature Difference (Deg. C)
Precipitation Change
percent change for the annual total
Precipitation Change during Wet Season (April-October)
South to North crossing El Yunque Rainforest

Historical and Projected Rainfall for Transect 1 for Season: WET
Example of Ongoing Analysis

ECOREGION ANALYSIS - Diurnal Cycle of Precipitation

Subtropical wet forest – Dark Green

Life zones of Puerto Rico (Ewel and Whitmore 1973):
- Lower montane rain forest
- Subtropical moist forest
- Lower montane wet forest
- Subtropical rain forest
- Subtropical dry forest
- Subtropical wet forest

Graph showing WRF-CCSM Historical and WRF-CCSM Future precipitation patterns.
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Sea Surface Temperature and Ocean Acidification trends in the Caribbean

Julio M. Morell, Melissa Melendez
Some impacts of increased ocean temperature & acidification:

- Coastal ecosystems: coral bleaching, hypoxia, decreased calcification
- Coastal barriers & reef framework (non-living): dissolution
- Fisheries: displacement of species, decreased diversity?
- Sea level rise: SW expansion, ice melting..
- Extreme climatic events: Tropical cyclones, precipitation, draught..
- Socio-economics: e.g. tourism
Atmospheric CO2 = increase in SST and ocean acidity

NOAA NCDC ERSST version4, In situ data
ICOADS2.5 before 2007, NCEP in situ data from 2008 to present

NE Caribbean SST Anomaly (°C)

polynomial fit: R²=0.31953, SD=0.34016, N=865, P<0.0001
Recent SST trends (3/1997 - 3/2017):

In < 100 years, coral reefs will be exposed to “bleaching” temperatures for months!
Recent pH trends (1992 to 2015) in the Caribbean:

Surface seawater pH from 1992 to 2015

Regional empirical model

Surface ocean pH has decreased by ~0.04 (-0.0018 yr\(^{-1}\)) units while acidity has increased by ca. 11%
Recent Omega trends (1992 to 2015) in the Caribbean & Puerto Rico:

Regional empirical model:
Ω_{arg} has decreased by -0.29 (-0.0121 yr^{-1}) units
This represent a decrease in Caribbean surface Ω_{arg} of ~ 7.4 %

La Parguera OA buoy located at the southwest of PR shows a Ω_{arg} decrease of ~1.2 % over the last 7 years

In < 100 years, coral reefs will be exposed to critical Ω_{arg}!
Sea Grant: Natural Coastal Barriers at Risk: A First Assessment of Biogeochemical & Physical Stressors

J. Salisbury, M. Melendez, J. Morell & S. Rodriguez

Organic carbon sources
Calcium carbonate structures and sediments
CO₂ buoy
La Parguera natural near-shore barriers
Natural Coastal Barriers at Risk?

spatial surveys

Seawater CO₂ concentrations

600 – 1000 ppm along the inner areas

> 4 = offshore mean

< 3 = difficult to calcify

< 1 = dissolution

sensitive to ocean acidification: carbonate sediments, calcareous algae and inner shelf coral reefs
Natural Coastal Barriers at Risk?
spatial surveys

Seawater CO₂ concentrations

1000 to 1350 ppm at Bioluminescent Bay

Ω aragonite

> 4 = offshore mean

<3 = difficult to calcify

<1 = dissolution

sensitive to ocean acidification: carbonate sediments, calcareous algae and coral reef zones outside the Bay

Carbonates exposed to organic load and freshwater are already exposed to low Ωarg consistent with dissolution
San Juan:
Red line slope: 2.04 mm/yr
Green curve: Locally Weighted Scatterplot Smoothing (Lowess)
Blue line slope: 10.8 mm/yr
Slope of green curve since 2010-2011: 9.3 mm/yr

Isla Magueyes:
Red line slope: 1.8 mm/yr
Green curve: Locally Weighted Scatterplot Smoothing (Lowess)
Blue line slope: 9.3 mm/yr
Slope of green curve since 2010-2011: 7.7 mm/yr

Most of the results to be shown can be found at http://coastalhazardspr.wordpress.com
SAN JUAN HISTORIC LINEAR SEA LEVEL RISE TREND RELATIVE TO 1962

[red line slope (acceleration in mm/year^2) = 0.033]

(data source NOAA; updated up to December 2016; Aurelio Mercado Irizarry/UPRM)

ISLA Magueyes Historic Linear Sea Level Rise Trend Relative to 1955

[red line slope (acceleration in mm/year^2) = 0.028]

(data source NOAA; updated up to December 2016; Aurelio Mercado Irizarry/UPRM)
San Juan: Annual Means of Sea Level

Black Curve with crosses: annual averages of sea surface elevation
Least Squares Fit of all annual data: red straight line (SLR rate 2.01 mm/year)
Least Squares Fit of annual data starting at 2010: green straight line (SLR rate 10.01 mm/year)
11 years span lowess low pass filter (blue curve)
Least Squares Fit of Lowess curve (SLR rate since 2010; magenta curve): 9.99 mm/year

(data source NOAA/updated up to 2016/Aurelio Mercado Irizarry/UPRM)

Magueyes: Annual Means of Sea Level

Black Curve with crosses: annual averages of sea surface elevation
Least Squares Fit of all annual data: red straight line (SLR rate 1.74 mm/year)
Least Squares Fit of annual data starting at 2010: green straight line (SLR rate 9.06 mm/year)
11 years lowess low pass filter (blue curve)
Least Squares Fit of Lowess curve (SLR rate since 2010; magenta curve): 8.51 mm/year
GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES

EXPIRATION DATE (30 March 2019)

Global Changes
PROCEDURES TO EVALUATE SEA LEVEL CHANGE: IMPACTS, RESPONSES, AND ADAPTATION

1. Purpose. This technical letter provides guidance for understanding the direct and indirect physical and ecological effects of projected future sea level change on USACE projects and systems of projects and considerations for adapting to these effects.

2. Applicability. This Engineer Technical Letter (ETL) applies to all USACE elements having responsibility for Civil Works.

3. Distribution Statement. Approved for public release; distribution is unlimited.

4. References. References are listed in Appendix A.

5. Discussion. USACE missions, operations, programs, and projects must be resilient to coastal climate change effects, beginning with sea level change (SLC). This ETL addresses adaptation to changing sea levels for every USACE coastal activity as far inland as the extent of estimated tidal influence. It includes a broadly applicable method encompassing four USACE mission areas and also provides insight into use for multipurpose projects. The information presented here is applicable to the full range of USACE projects and systems, from simple to complex, from small to very large, and over the full life cycle. This ETL integrates the recommended planning and engineering to understand and adapt to impacts of projected SLC through a hierarchy of decisions and review points that identify the level of analysis required as a function of project type, planning horizon, and potential consequences.

FOR THE COMMANDER:

JAMES C. DALTON, P.E., SES
Chief, Engineering and Construction Division
Directorate of Civil Works

7 Appendices
See Table of Contents
In order to bound the set of GMSL rise scenarios for year 2100, we assessed the most up-to-date scientific literature on scientifically supported upper-end GMSL projections, including recent observational and modeling literature related to the potential for rapid ice melt in Greenland and Antarctica. The projections and results presented in several peer-reviewed publications provide evidence to support a physically plausible GMSL rise in the range of 2.0 meters (m) to 2.7 m, and recent results regarding Antarctic ice-sheet instability indicate that such outcomes may be more likely than previously thought. To ensure consistency with these recent updates to the peer-reviewed scientific literature, we recommend a revised ‘extreme’ upper-bound scenario for GMSL rise of 2.5 m by the year 2100, which is 0.5 m higher than the upper bound scenario from Parris et al. (2012) employed by the Third NCA (NCA3).

Global and Regional Sea Level Rise Scenarios for the United States

PROJECTIONS (USGS/EPA/NOAA/Rutgers):

Based on six process-based (climate models) scenarios, and using results for Puerto Rico and the USVI:

- Low (0.3 m) Scenario: \( LRSL \) rise = 0.33 to 0.36 m.
- Intermediate-Low (0.5 m) Scenario: \( LRSL \) rise = 0.45 to 0.50 m.
- Intermediate (1.0 m) Scenario: \( LRSL \) rise = 1.0 to 1.1 m.
- Intermediate-High (1.5 m) Scenario: \( LRSL \) rise = 1.95 to 2.1 m.
- High (2.0 m) Scenario: \( LRSL \) rise = 2.8 to 3.0 m.
- Extreme (2.5 m) Scenario: \( LRSL \) rise = 3.5 to 3.75 m.

We should also have in mind the more dramatic projections by Hansen et al. (2016) and DeConto and Pollard (2016), which use very sophisticated modeling.

Based on the USACE Sea Level Rise calculator, 2100 projection of \( LRSL \):

- USACE and NOAA Low: \( LRSL \) rise = 0.36 m
- USACE Intermediate/NOAA Intermediate Low: \( LRSL \) rise = 0.67 m
- NOAA Intermediate High: \( LRSL \) rise = 1.37 m
- USACE High: \( LRSL \) rise = 1.67 m
- NOAA High: \( LRSL \) rise = 2.17 m

Sea Level Change (SLC) Rate (based on the satellite-derived Global Mean Sea Level Rise - San Juan: \( c = 3.3 \) – 0.02 = 3.28 mm/year):

Land rising in San Juan:
0.02 mm/yr
Zervas et al. (2013); NOAA Tech Rep NOS CO-OPS 065
NOAA Sea Level Rise Viewer - Blue: Permanent flooding; Green: Low-lying areas (NOAA High Scenario)
Before 2025 (0.6 m)  
Approx. 2060 (0.9 m)  
Approx. 2070 (1.2 m)  
Approx. 2080 (1.5 m)  
Approx. 2090 (1.8 m)

NOAA Sea Level Rise Viewer - Blue: Permanent flooding; Green: Low-lying áreas (NOAA High Scenario)