Working Group 1

- **Geophysical and Chemical Scientific knowledge**
  - Climate trends and projections for Puerto Rico and the Caribbean

Coordinator: Ernesto Díaz

Dr. Adam Terando

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

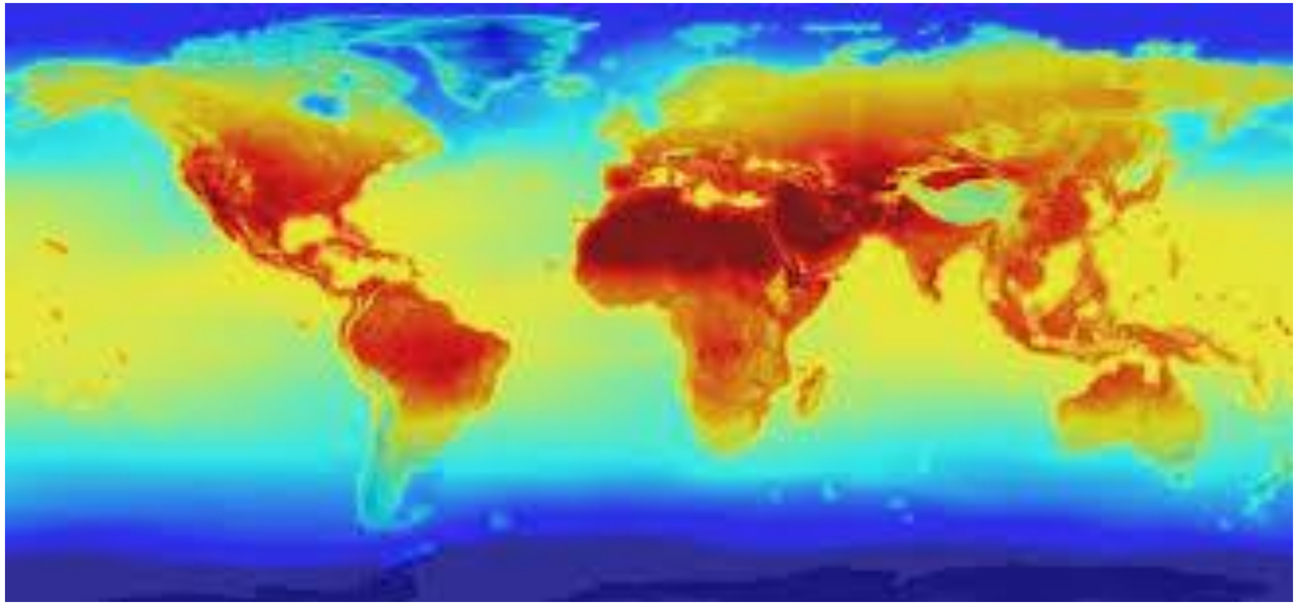
Temperature

Precipitation Variability

Extreme Events

Tropical Storms and Hurricanes

Regional Climate Model Projections Update



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

William Gould, US Forest Service, International Institute for Tropical Forestry

Adam Terando, US Geological Service, Southeast Climate Science Center

CONSEJO DE CAMBIOS CLIMÁTICOS
CLIMATE CHANGE COUNCIL
PUERTO RICO

UNC INSTITUTE FOR THE ENVIRONMENT

DEPARTMENT of the INTERIOR
SE CLIMATE SCIENCE CENTER

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
International Institute of Tropical Forestry
INTERNATIONAL INSTITUTE OF TROPICAL FORESTRY

CLCC Cooperativa para la Conservación del Paisaje en el Caribe
Creando puentes entre ciencia y acción, mar y tierra

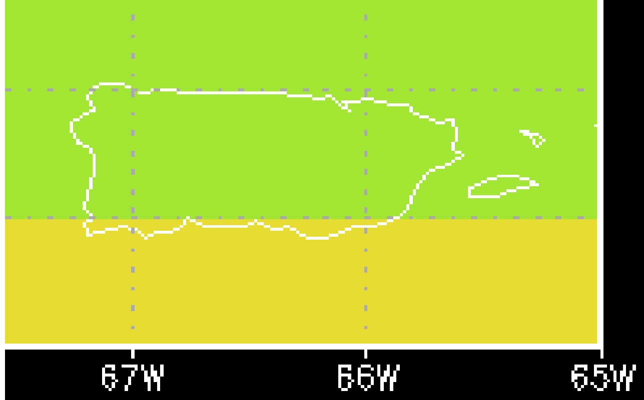
Existing Complementary Data Sets*

- 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 meterological 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)

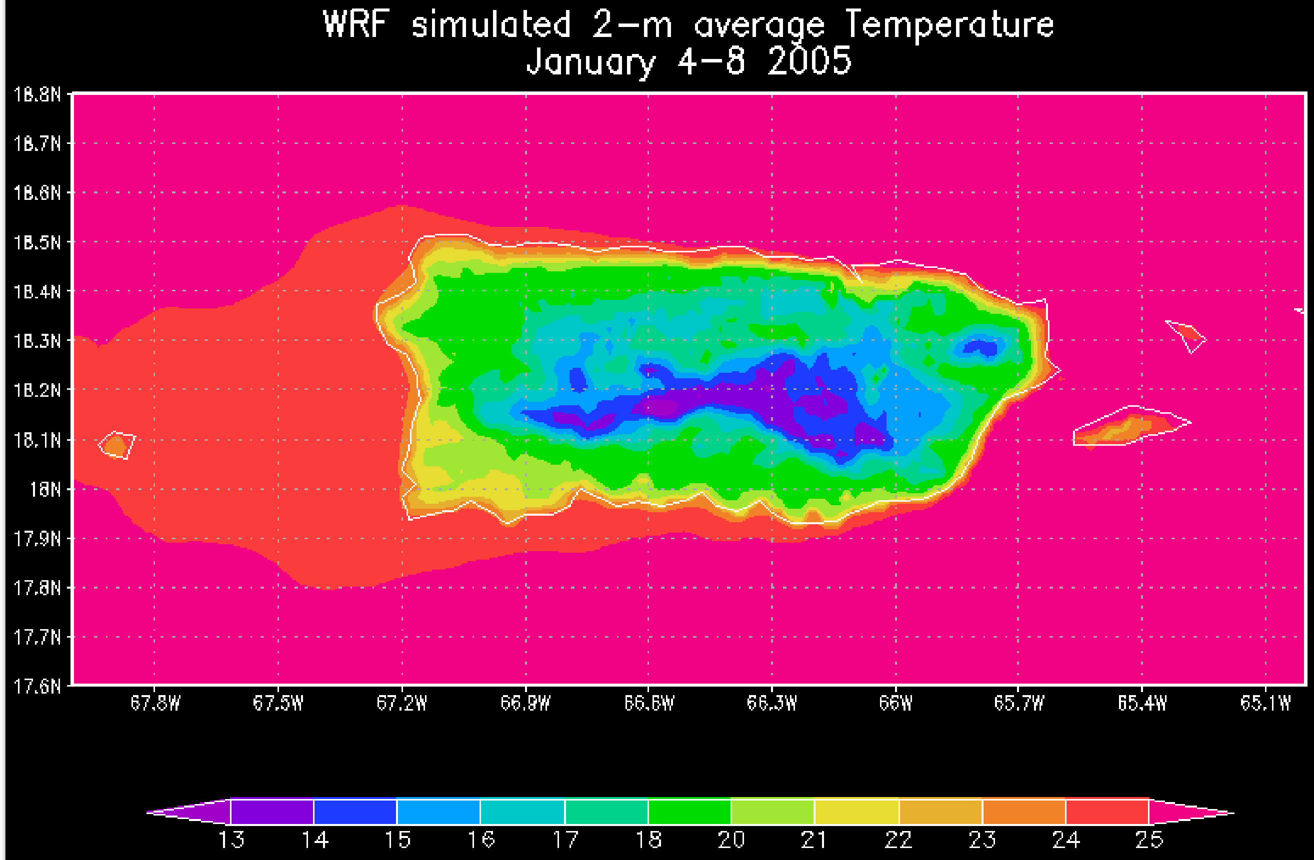
* Recommend using the suite of available data sources



DEPARTMENT of the INTERIOR
SE CLIMATE SCIENCE CENTER

GCM

Downscaled



Experimental Design for Regional Climate Modeling

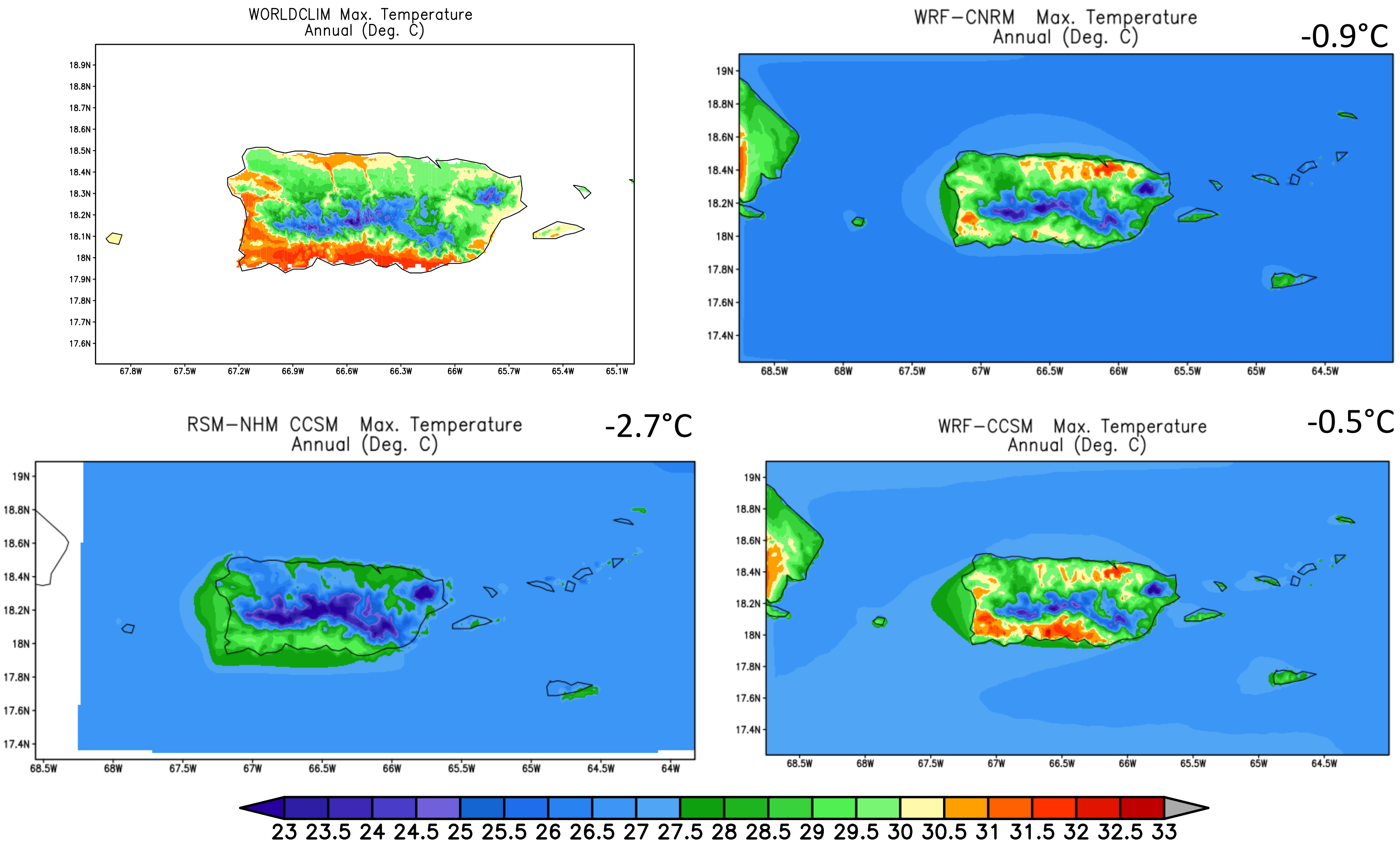
- ***THREE GCMs***
  - CCSM4, CNRM5, GFDL-CM3
- ***TWO RCMs***
  - WRF, NHM-RSM
- ***TWO 20 year periods***
  - 1986-2005 (past)
  - 2040-2060 (future)
  - RCP 8.5 – high fossil fuel emissions scenario

Downscaled Weather Variables

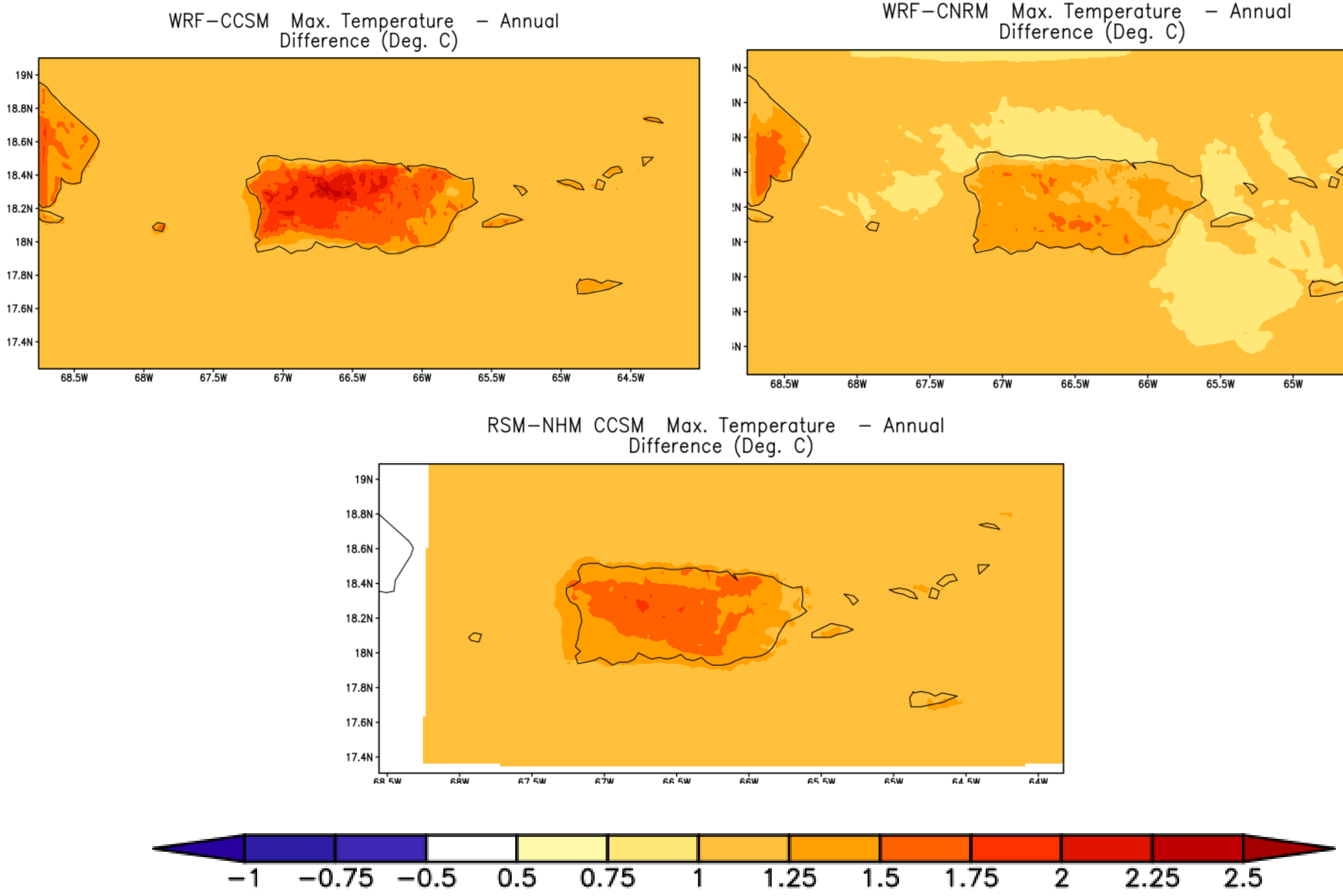
	Variable
Temperature	
	Air temperature at pressure levels
	Air temperature at 2m
	Ground temperature
	Soil Temperature
Moisture	
	Relative humidity at pressure levels
	Specific humidity at 2m
	Dewpoint Temperature
	Canopy wetness
Precipitation	
	Convective precipitation
	Total precipitation
	Soil Moisture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

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

First question to ask :
How well do we simulate the historical climate?
Maximum 2-m Temperature annual average over P.R.

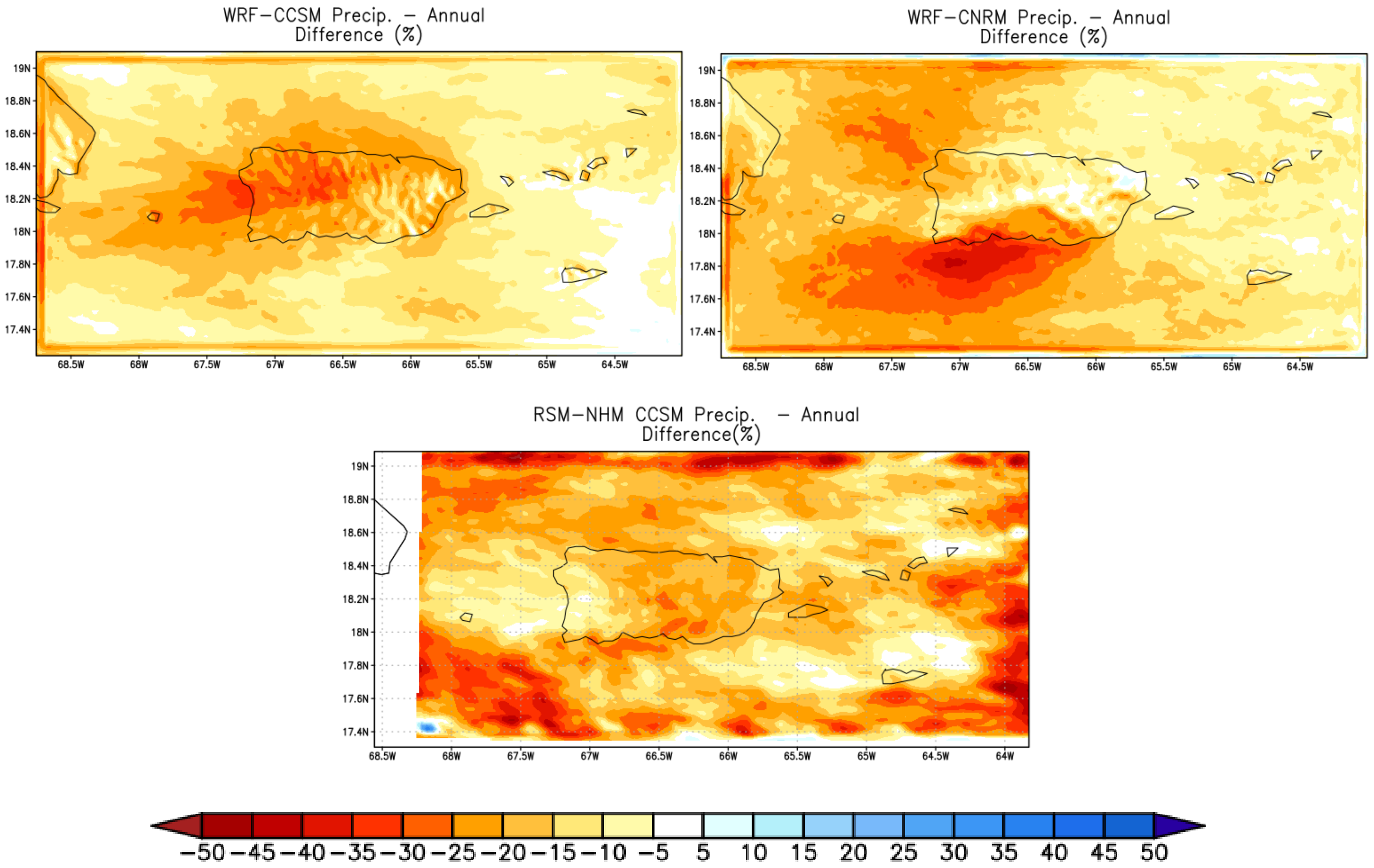


Maximum 2-m Temperature Change
annual average

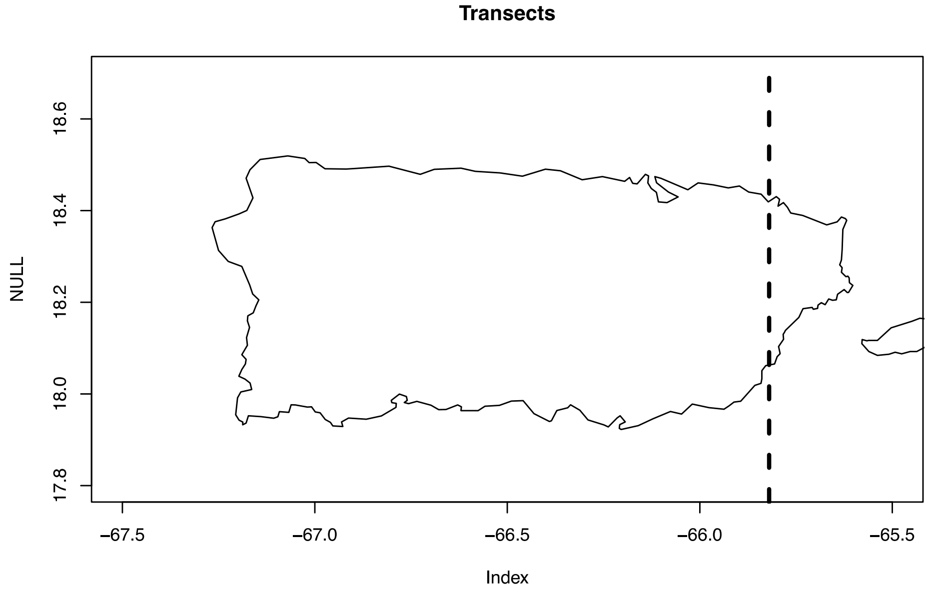


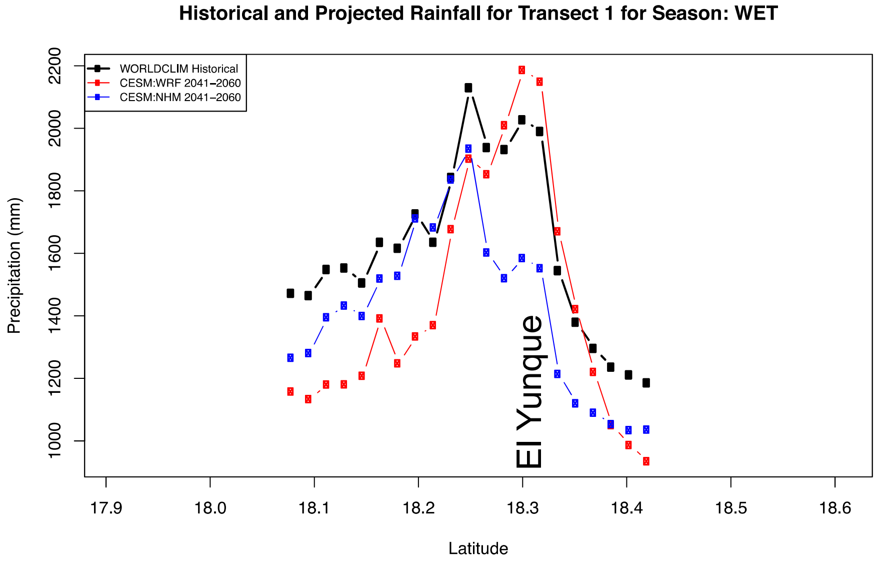
Precipitation Change

percent change for the annual total



Precipitation Change during Wet Season (April-October)
South to North crossing El Yunque Rainforest

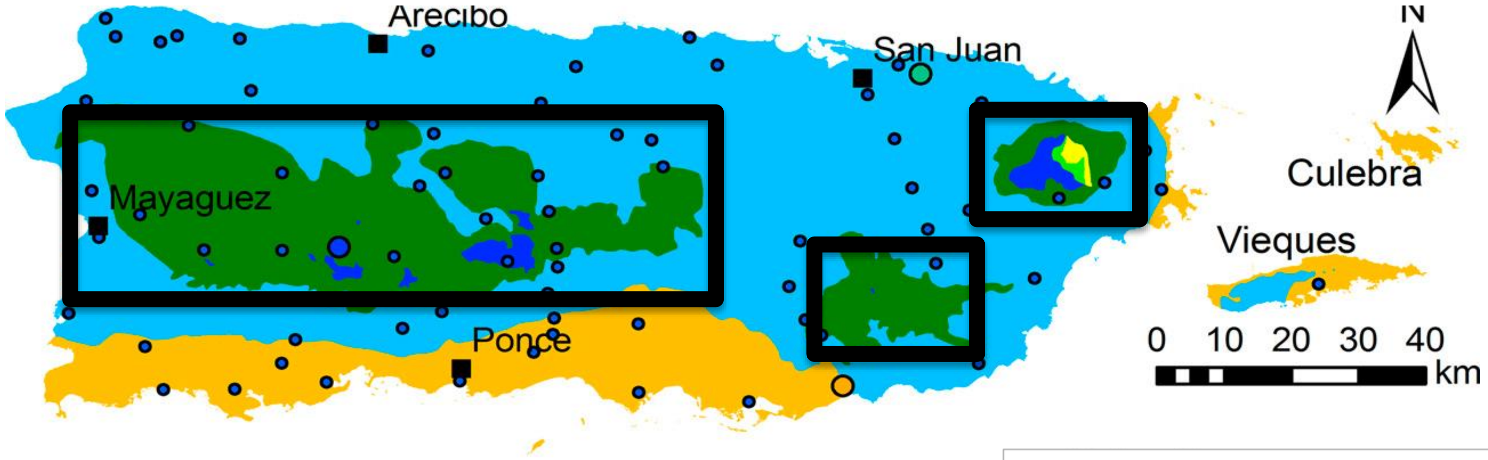


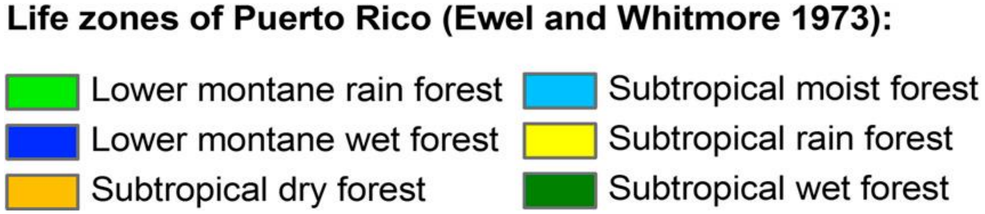


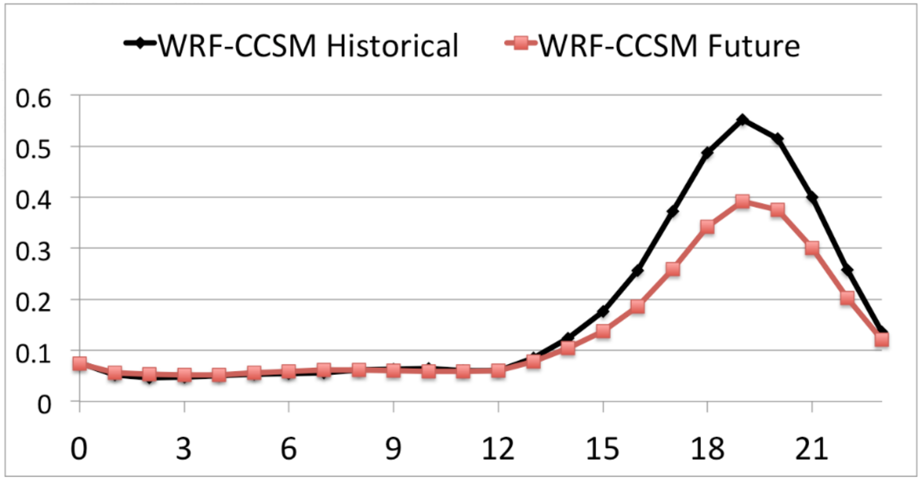
Example of Ongoing Analysis

ECOREGION ANALYSIS - Diurnal Cycle of Precipitation

Subtropical wet forest – Dark Green







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	Sensible
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	Ground
	Potential evapotransporation

8 va Reunión Cumbre del
Consejo de Cambio Climático de Puerto Rico

7 de abril de 2017
Hotel Intercontinental, San Juan

Sea Surface Temperature and Ocean Acidification trends in the Caribbean

Julio M. Morell, Melissa Melendez

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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

NATURE COMMUNICATIONS | ARTICLE OPEN

Caribbean-wide decline in carbonate production threatens coral reef growth

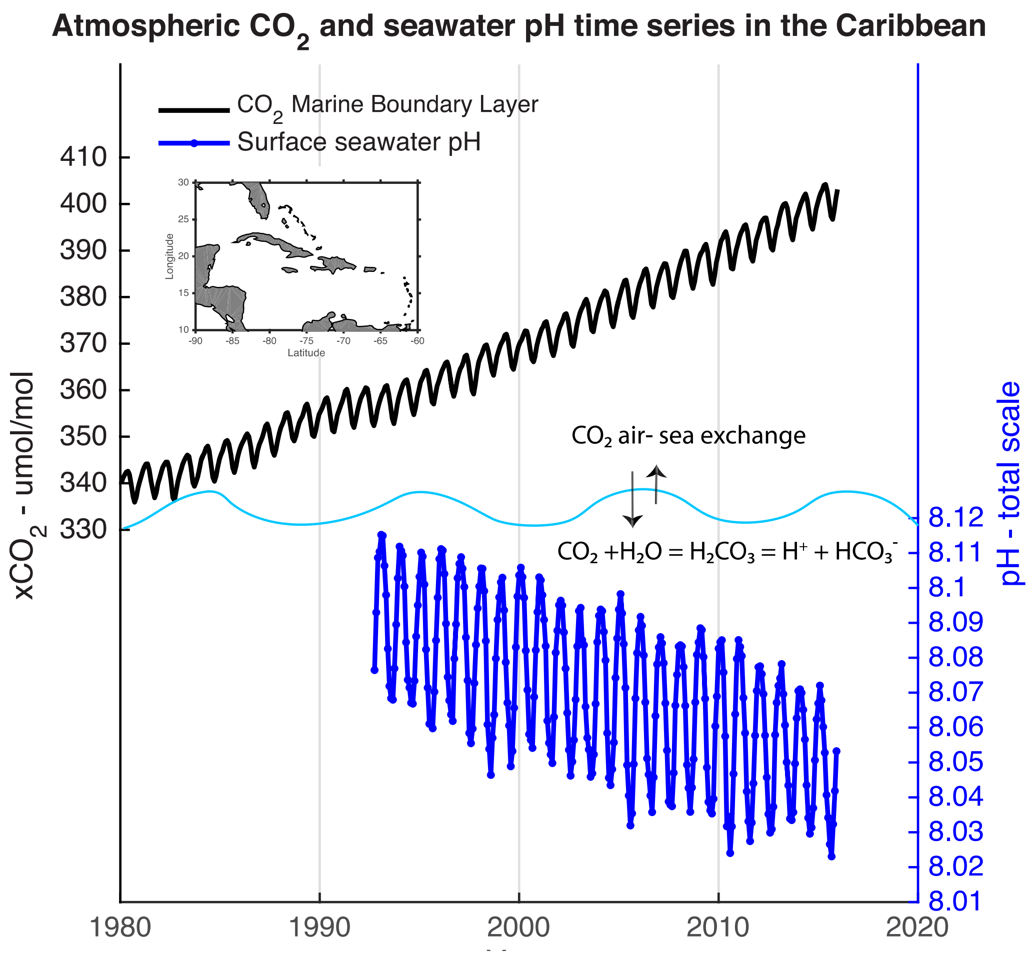
OCEANS

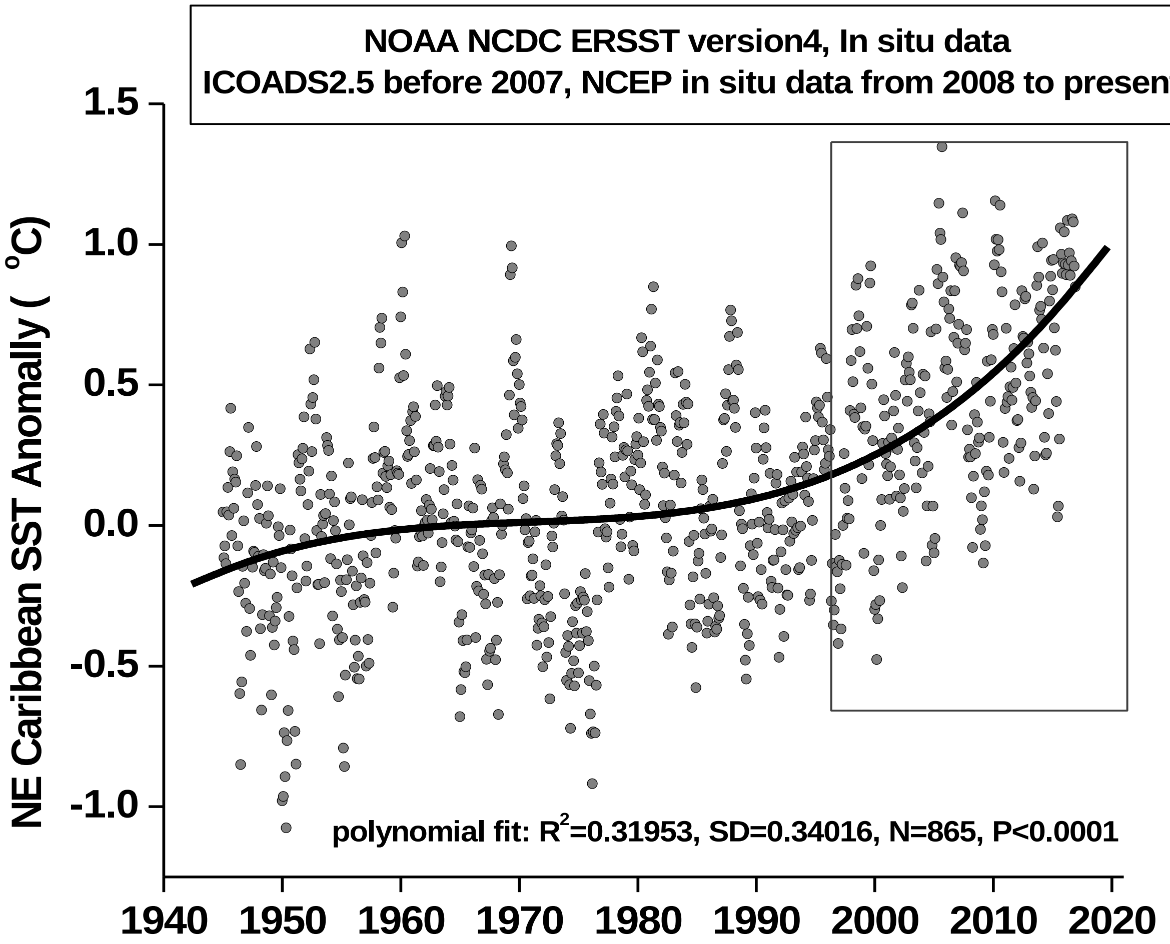
Fla. Keys Coral Reefs Dissolving Faster Than Thought

MAY 3, 2016 04:23 PM ET // BY PAUL HELTZEL

CARICOOS

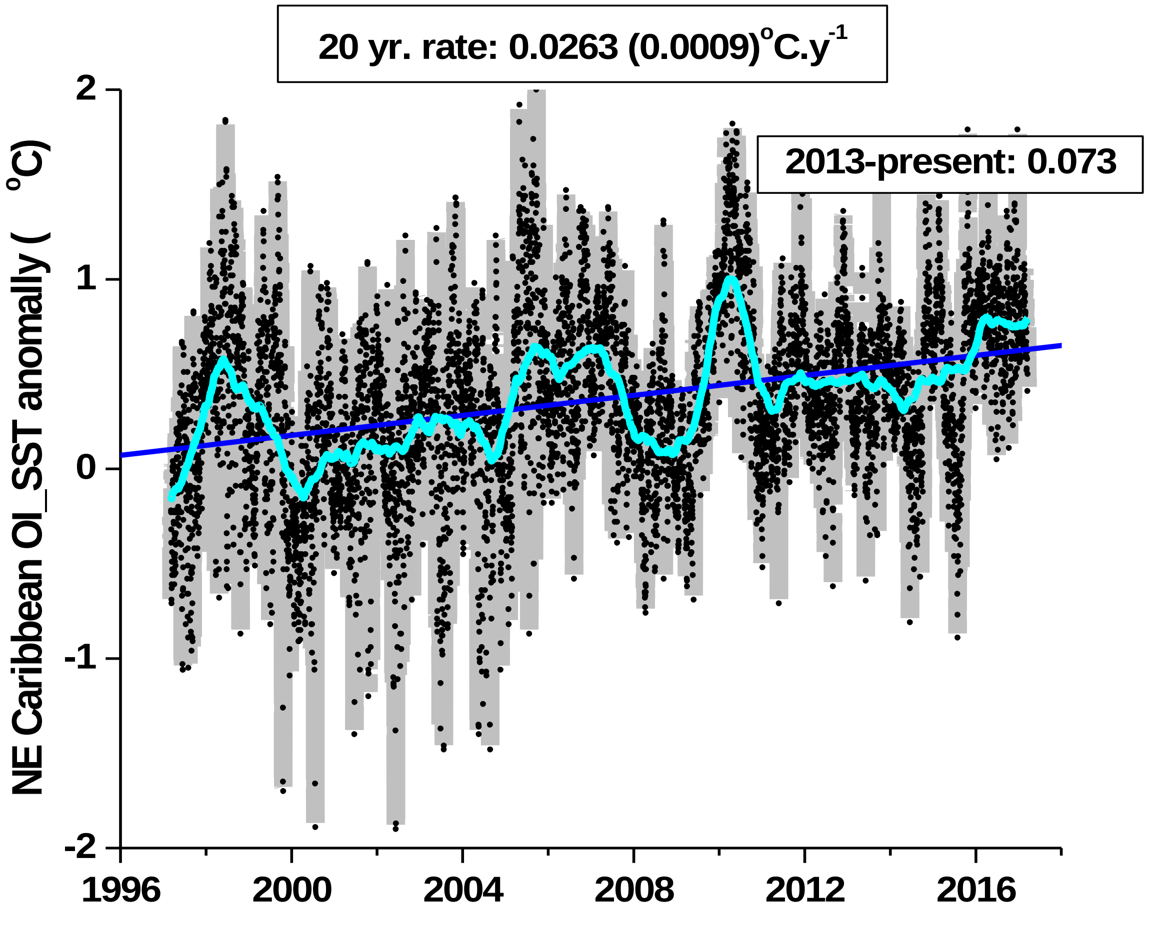
Atmospheric CO2 = increase in SST and ocean acidity

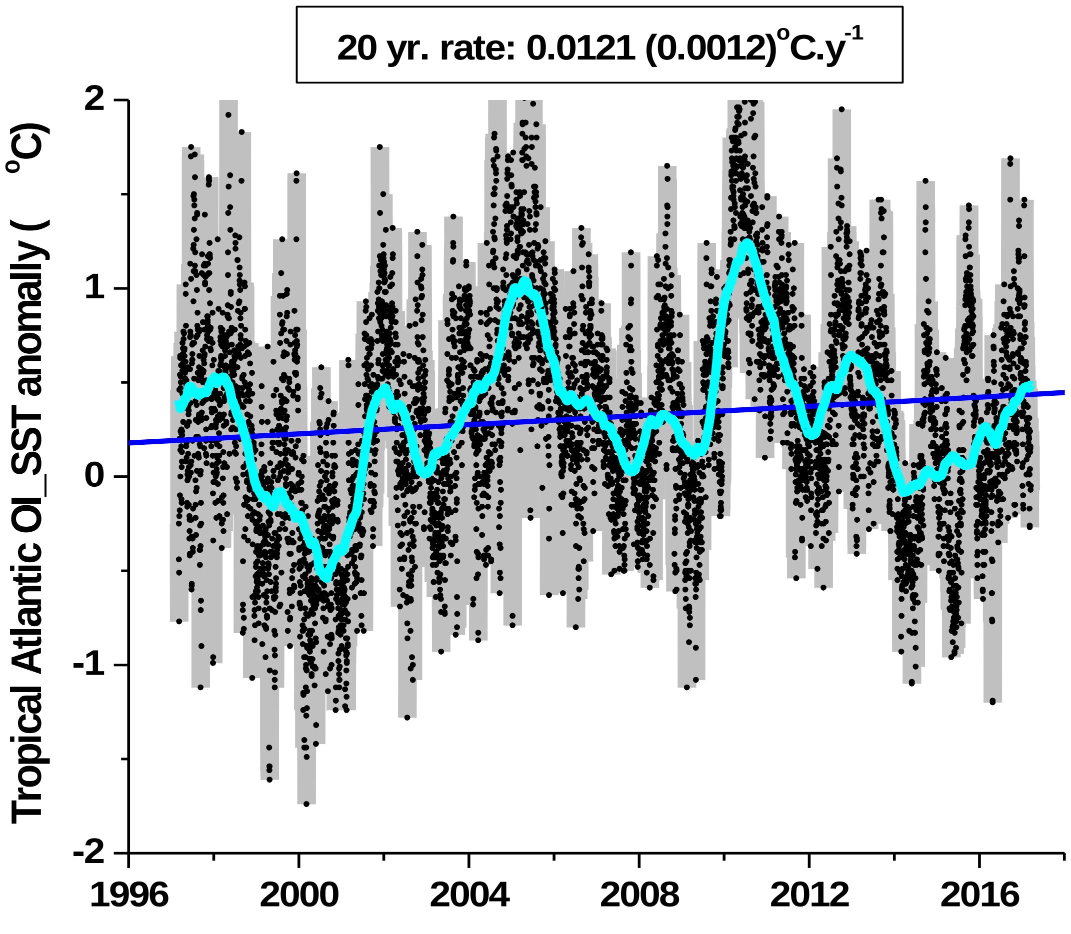




CARICOOS

Recent SST trends (3/1997 - 3/2017):

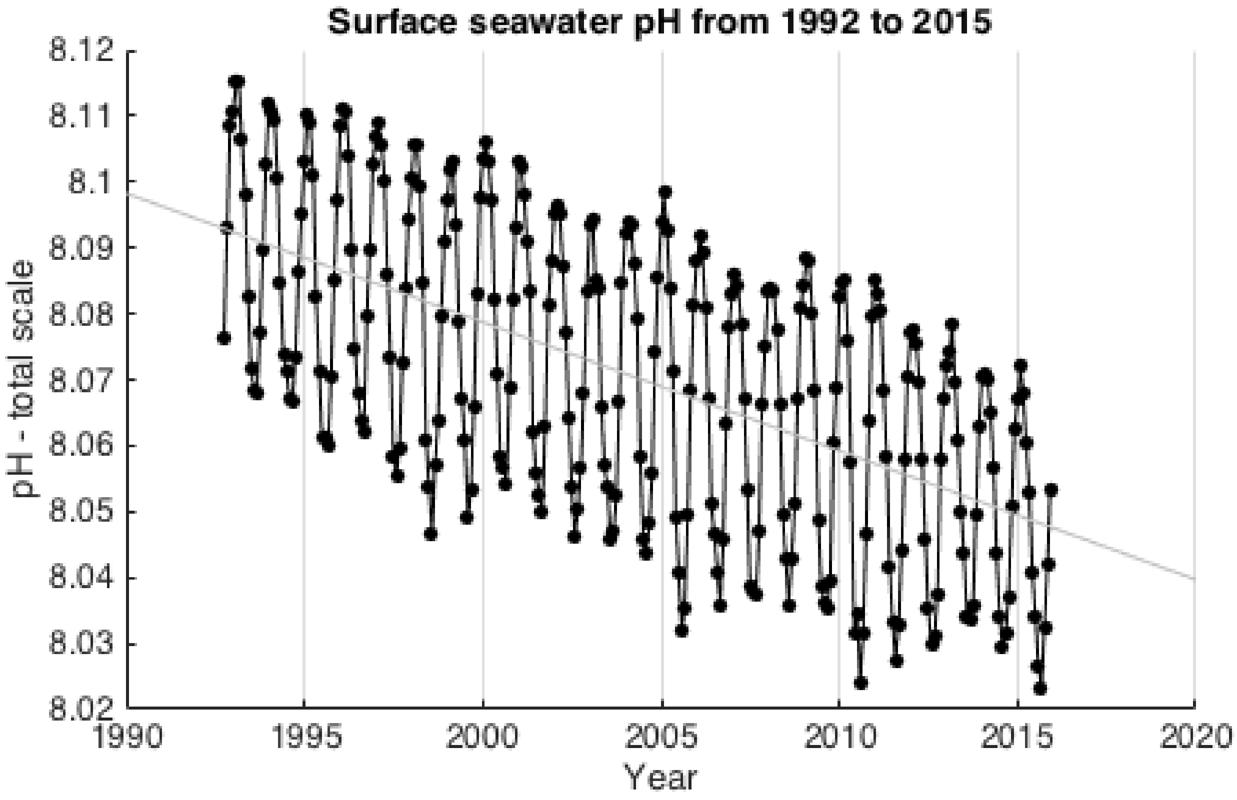


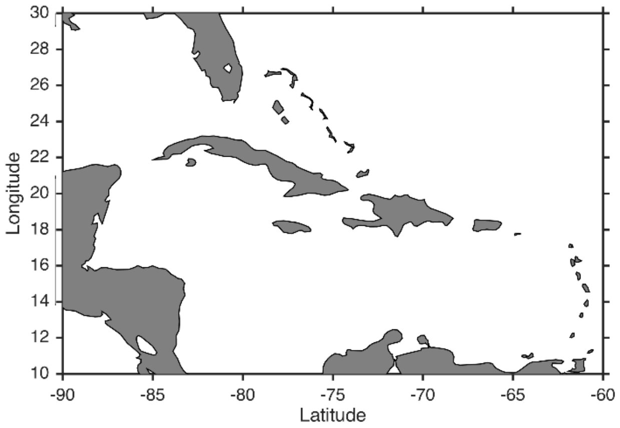


In < 100 years, coral reefs will be exposed to "bleaching" temperatures for months!

CARICOOS

Recent pH trends (1992 to 2015) in the Caribbean:



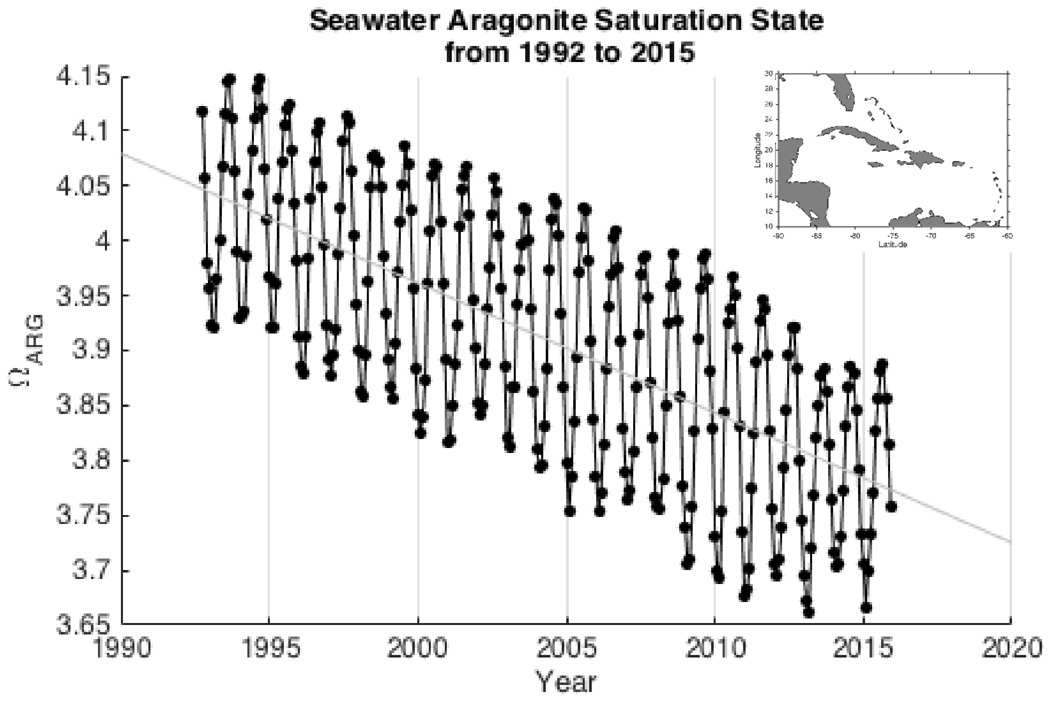


Regional empirical model

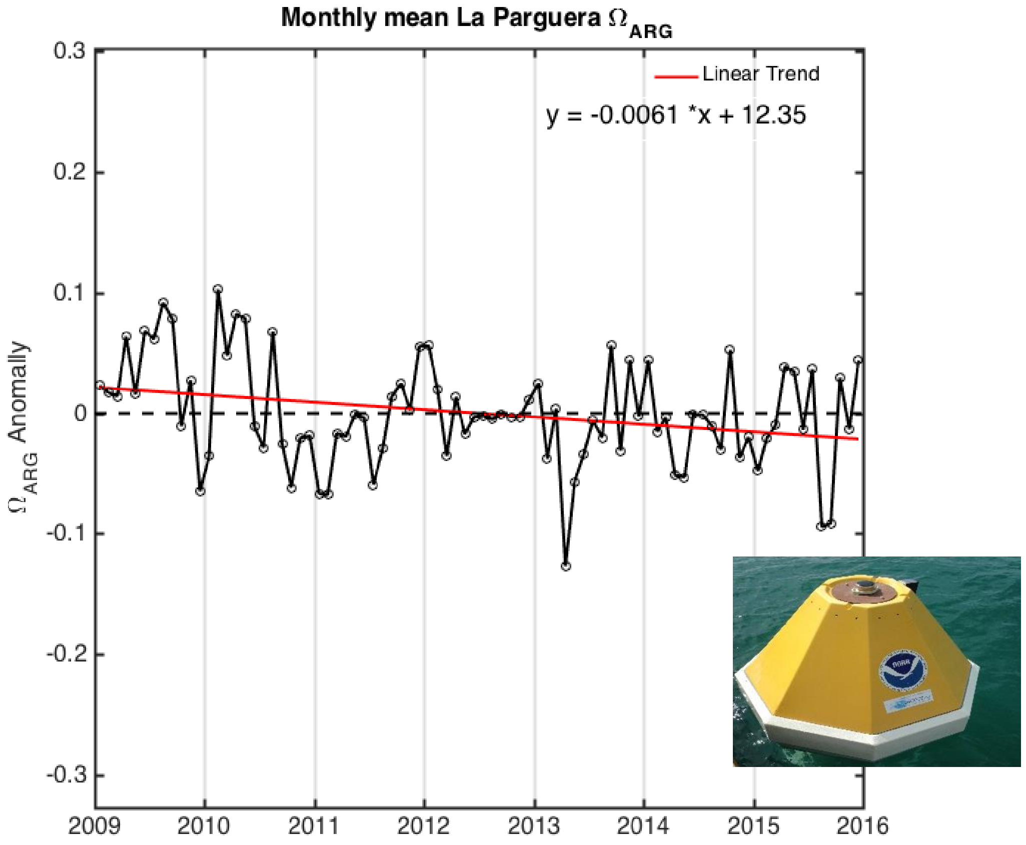
Surface ocean pH has decreased by ~0.04 (-0.0018 yr-1) units while acidity has increased by ca. 11%

CARICOOS

Recent Omega trends (1992 to 2015) in the Caribbean & Puerto Rico:



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



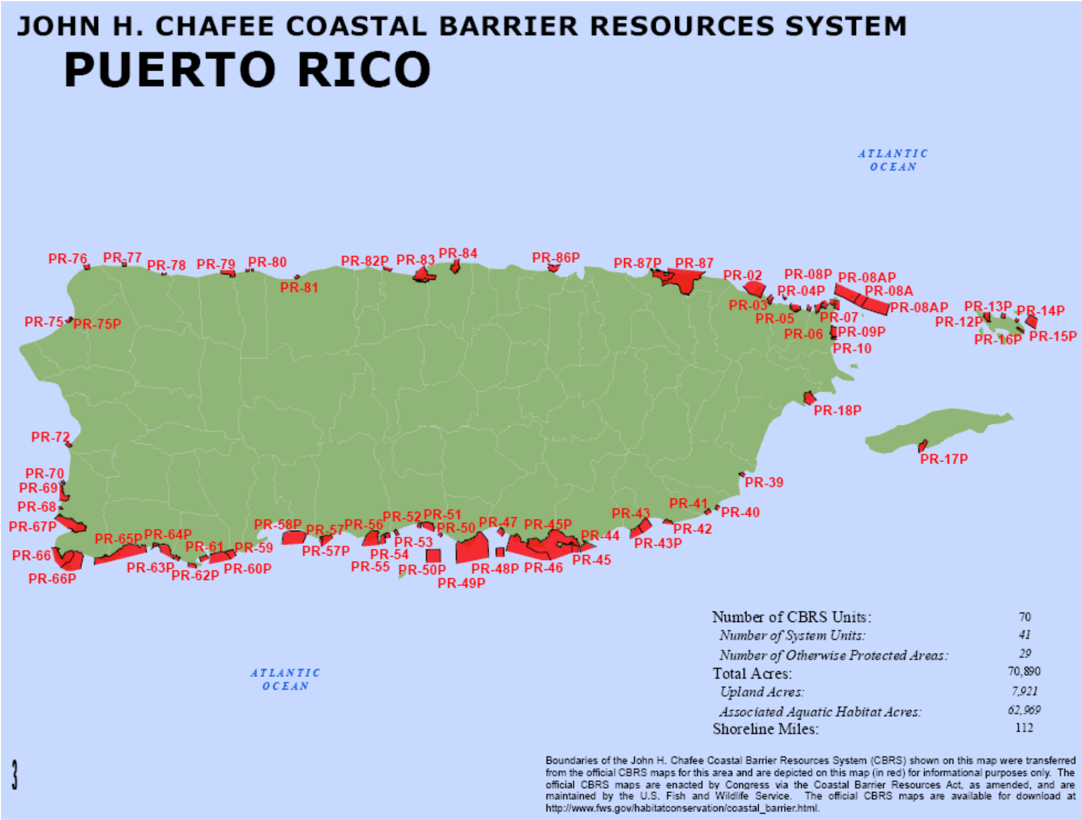
In < 100 years, coral reefs will be exposed to critical Ωarg !

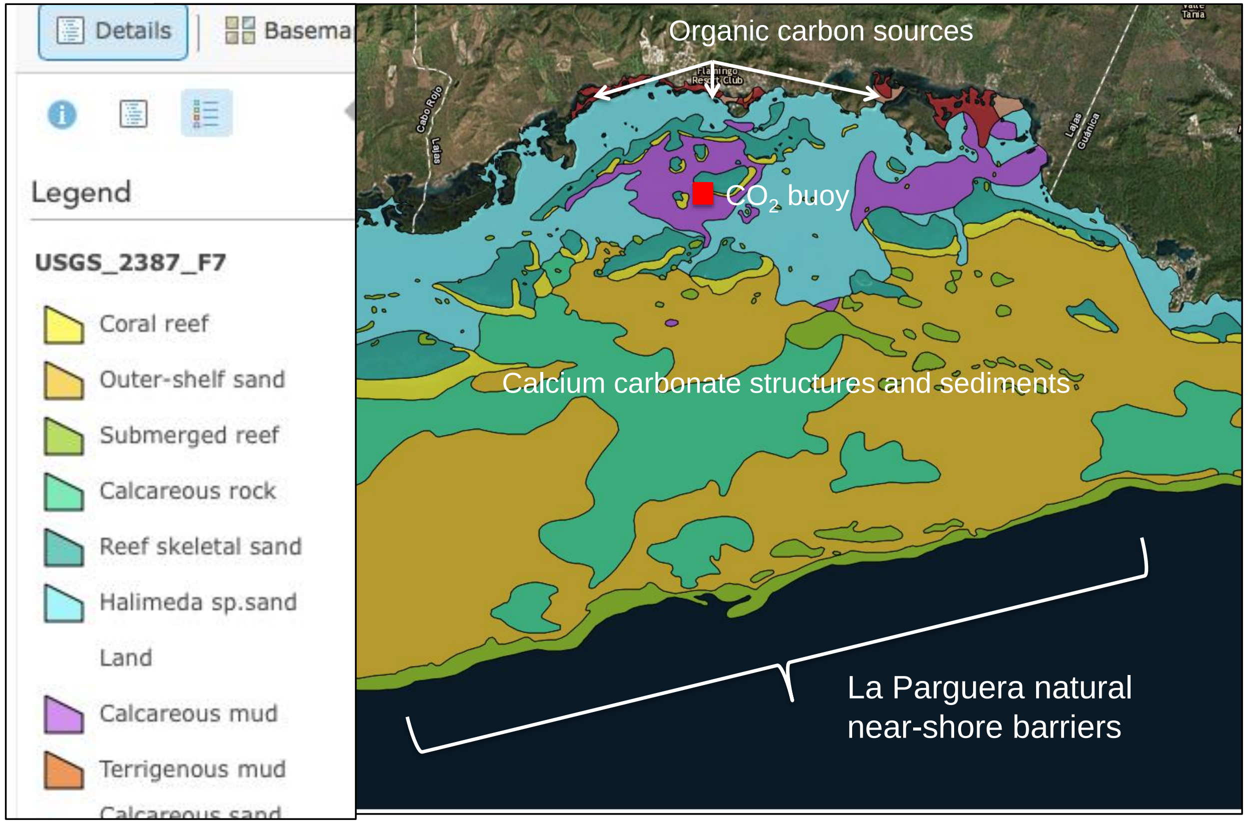
La Parguera OA buoy located at the southwest of PR shows a Ω_{arg} decrease of ~1.2 % over the last 7 years

CARICOOS

Sea Grant: Natural Coastal Barriers at Risk:
A First Assessment of Biogeochemical & Physical Stressors

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





CARICOOS

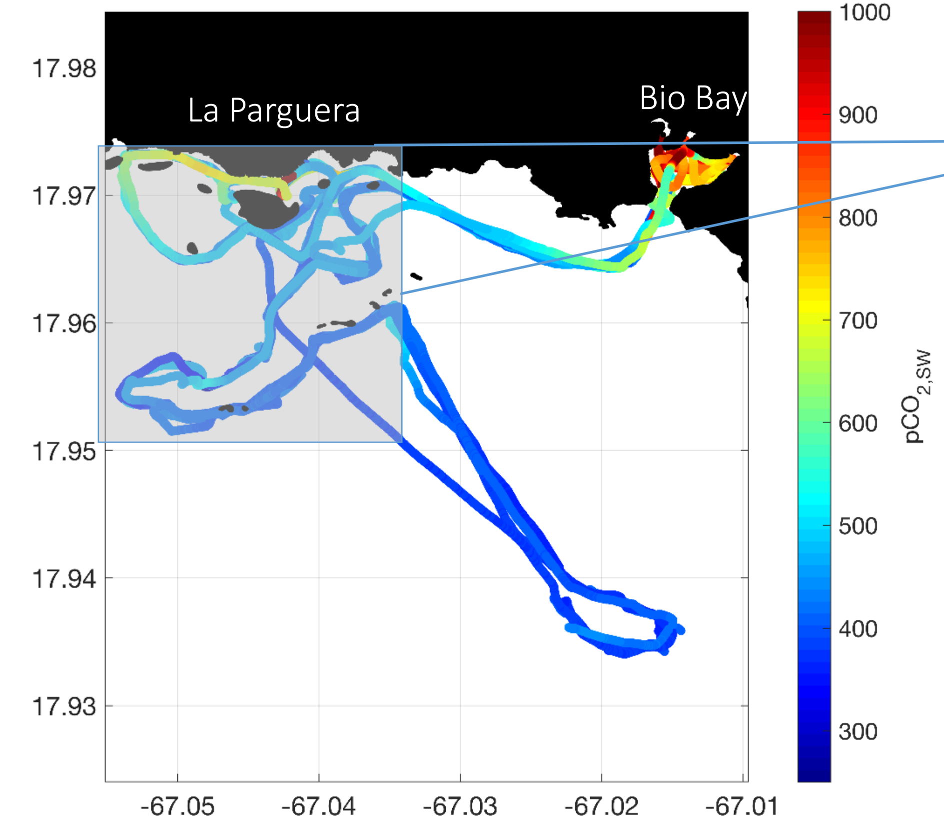
Sea Grant Puerto Rico

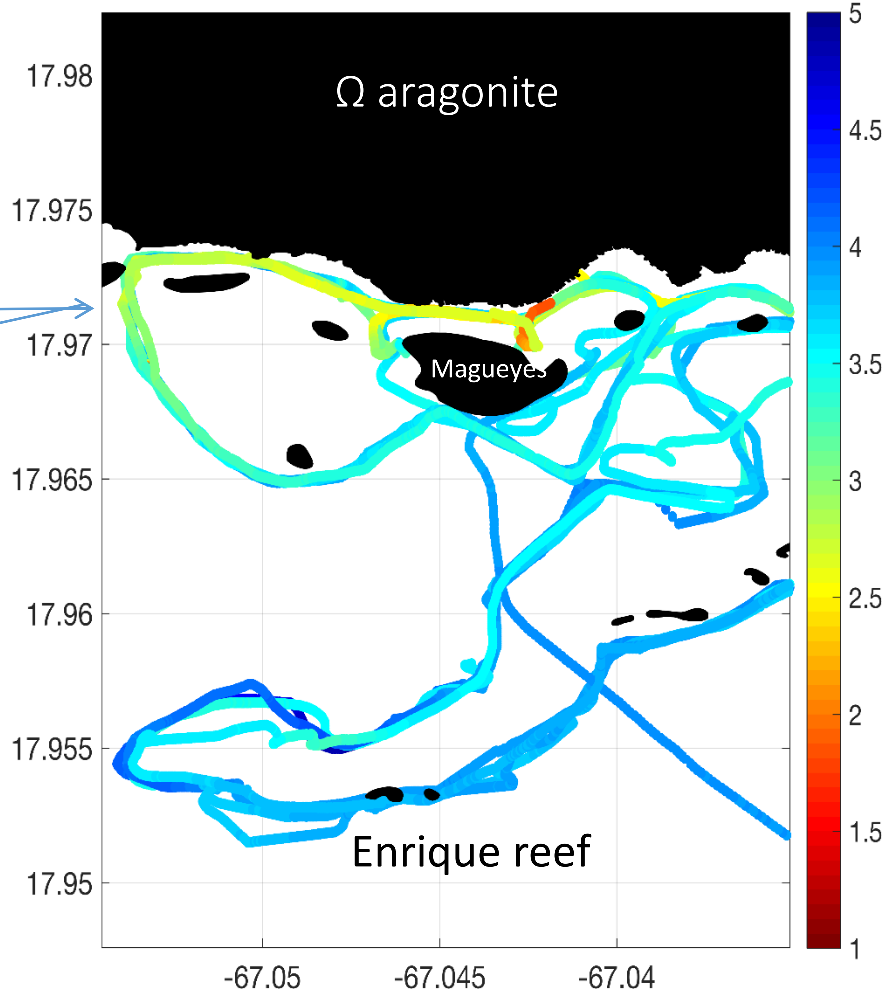
University of New Hampshire

Natural Coastal Barriers at Risk ?

spatial surveys

Seawater CO_2 concentrations





> 4 = offshore mean

<3 = difficult to calcify

<1 = dissolution

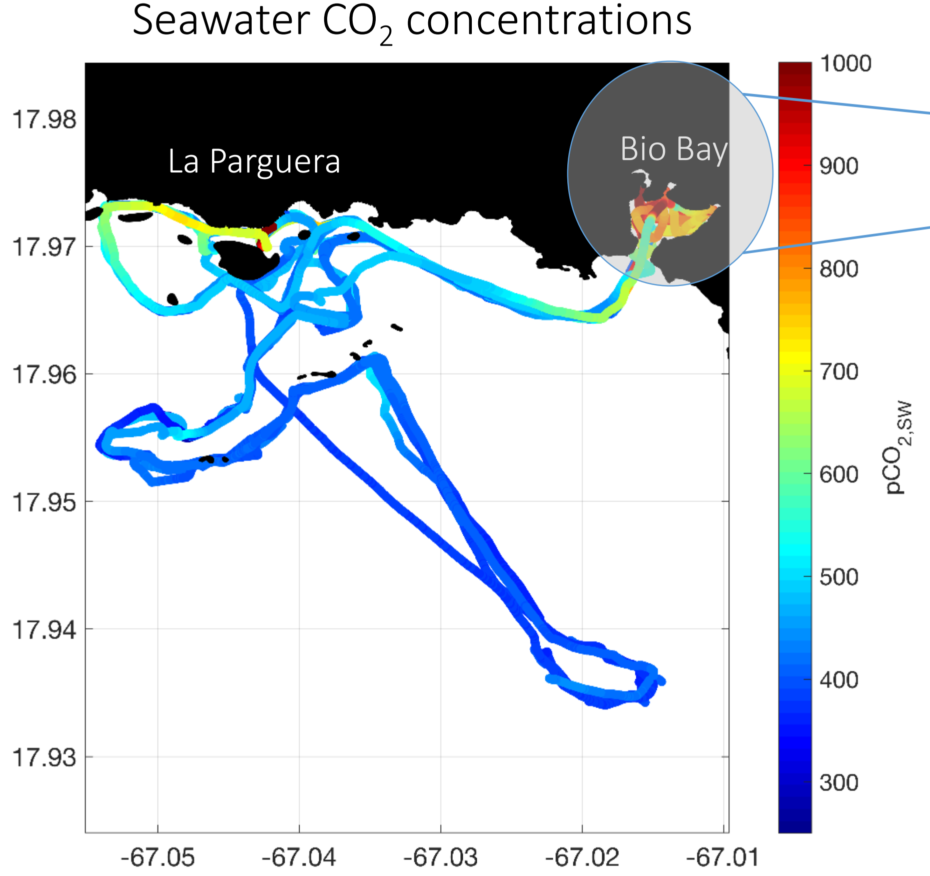
600 –1000 ppm along the inner areas

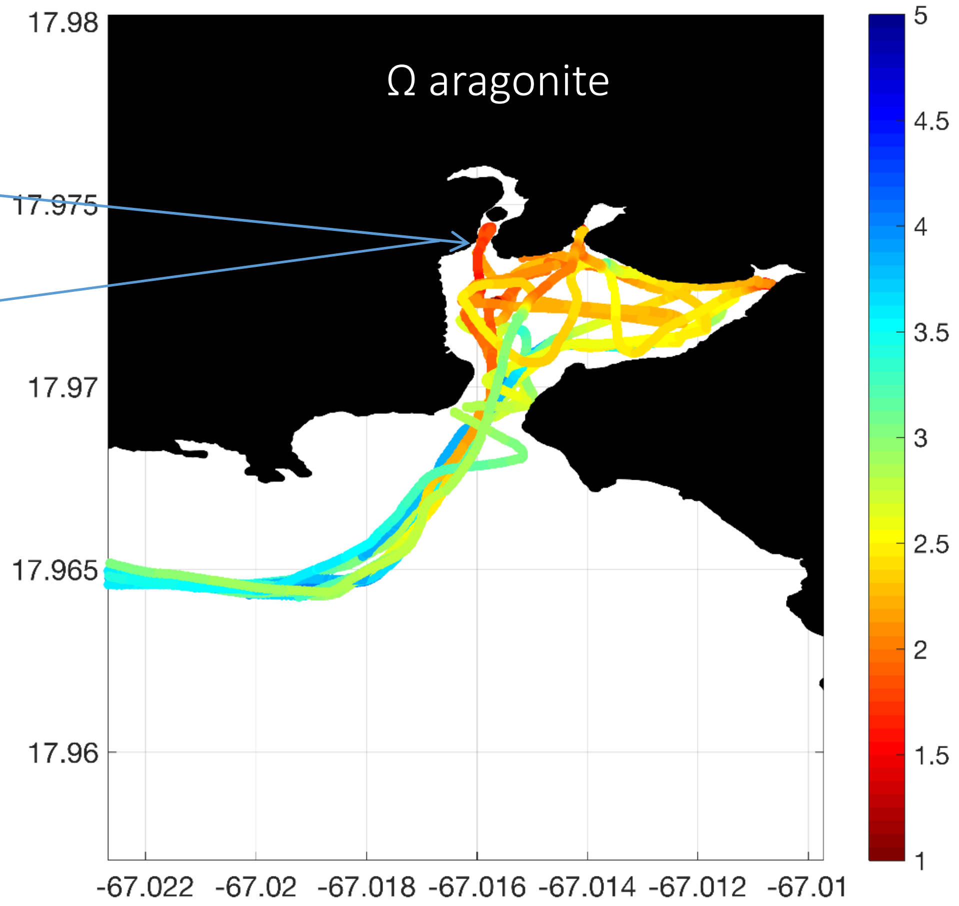
sensitive to ocean acidification:
carbonate sediments, calcareous algae and inner shelf coral reefs

CARICOOS

Natural Coastal Barriers at Risk ?

spatial surveys





> 4 = offshore mean

<3 = difficult to calcify

<1 = dissolution

1000 to 1350 ppm at Bioluminescent Bay

sensitive to ocean acidification:

carbonate sediments, calcareous algae and coral reef zones outside the Bay

CARICOOS

Carbonates exposed to organic load and freshwater are already exposed to low Ωarg consistent with dissolution

ASAMBLEA ANUAL CONCILIO CAMBIO CLIMATICO DE PUERTO RICO
7 DE ABRIL DE 2017

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

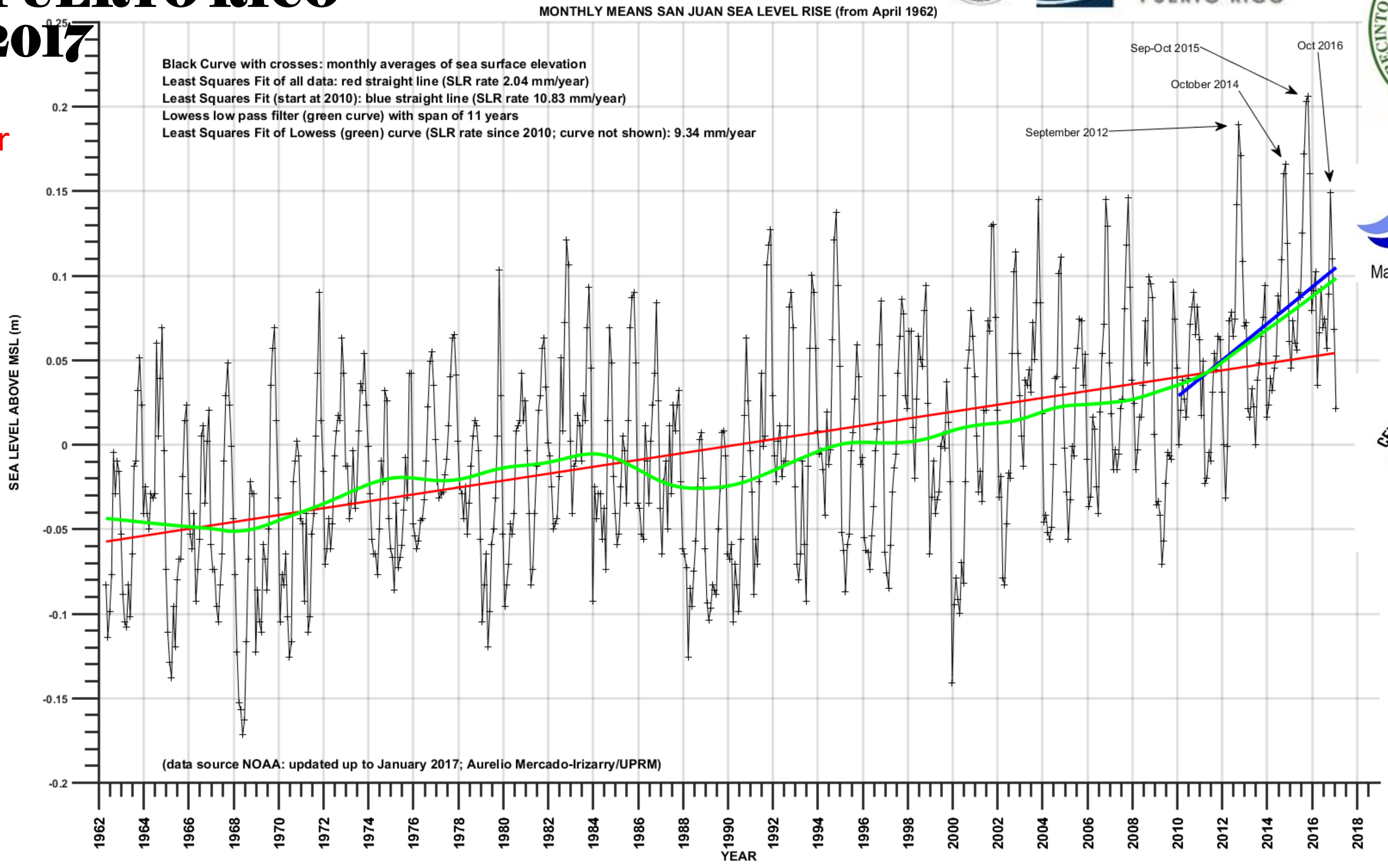
Isla Magueyes:

Red line slope: 1.8 mm/yr

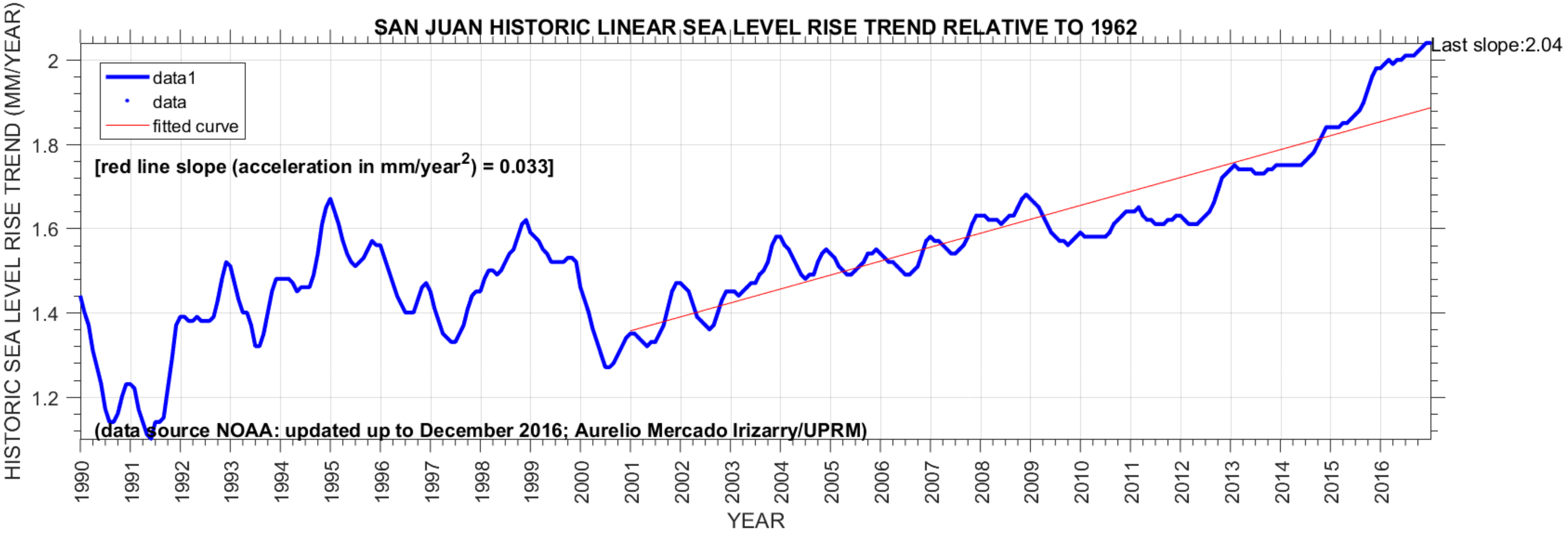
Green curve: Locally Weighted Scatterplot Smoothing (Lowess)

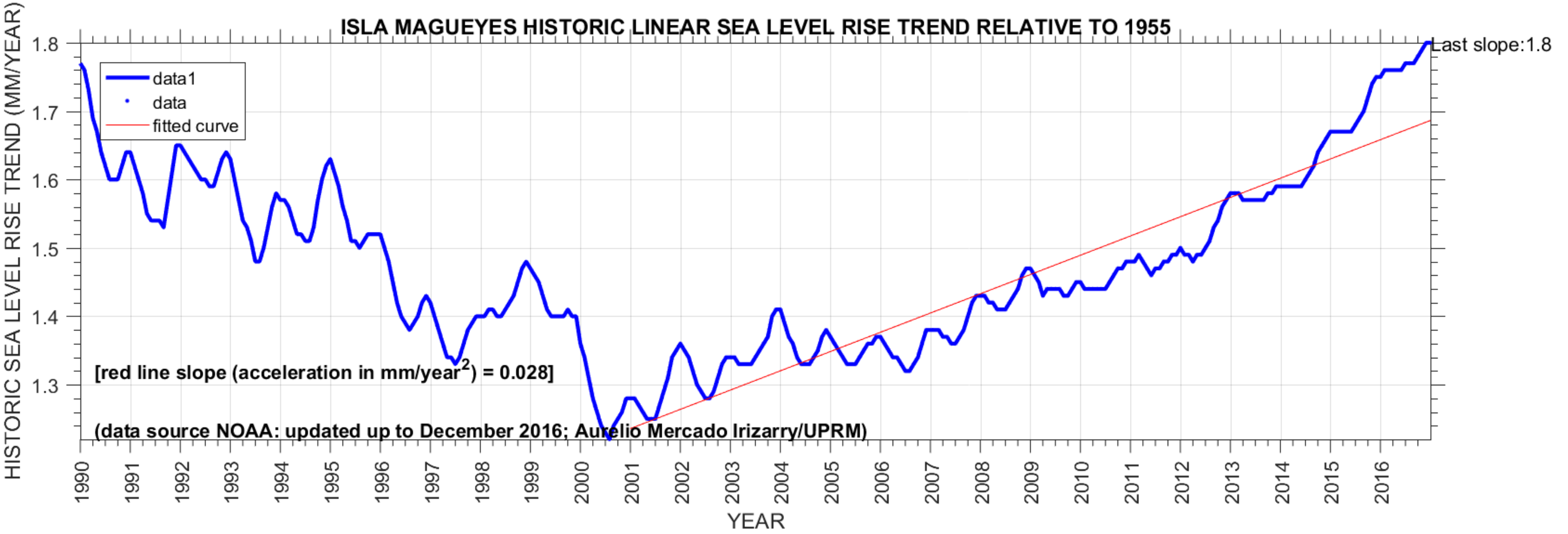
Blue line slope: 9.3 mm/yr

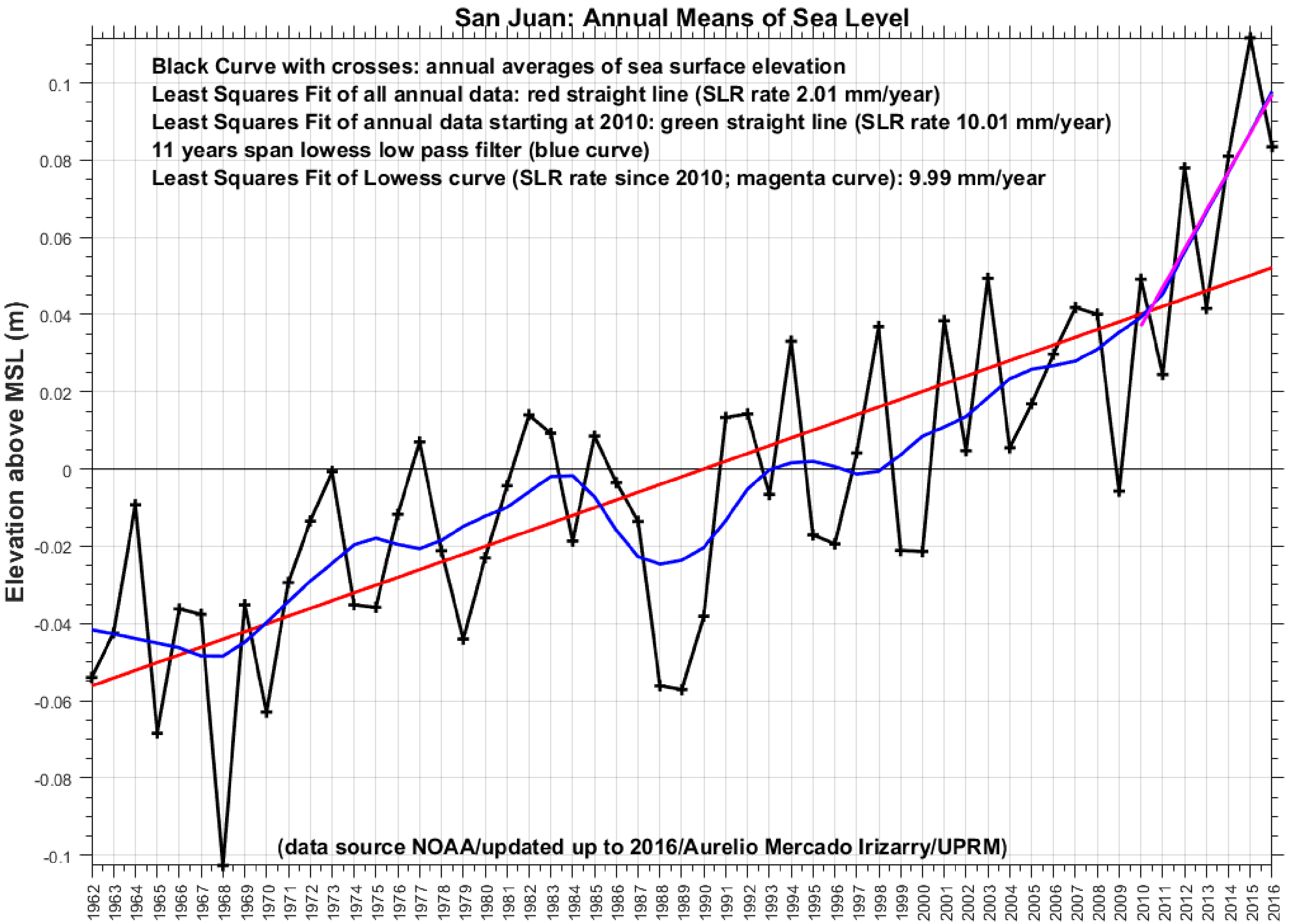
Slope of green curve since 2010-2011: 7.7 mm/yr



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
HISTORIC SEA LEVEL RISE TREND (MM/YEAR)
YEAR
data1
data
fitted curve
[red line slope (acceleration in mm/year^2) = 0.033]
(data source NOAA: updated up to December 2016; Aurelio Mercado Irizarry/UPRM)
Last slope:2.04


ISLA MAGUEYES HISTORIC LINEAR SEA LEVEL RISE TREND RELATIVE TO 1955
HISTORIC SEA LEVEL RISE TREND (MM/YEAR)
YEAR
data1
data
fitted curve
[red line slope (acceleration in mm/year^2) = 0.028]
(data source NOAA: updated up to December 2016; Aurelio Mercado Irizarry/UPRM)
Last slope:1.8



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)
Elevation above MSL (m)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
1962
1963
1964
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1966
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1969
1970
1971
1972
1973
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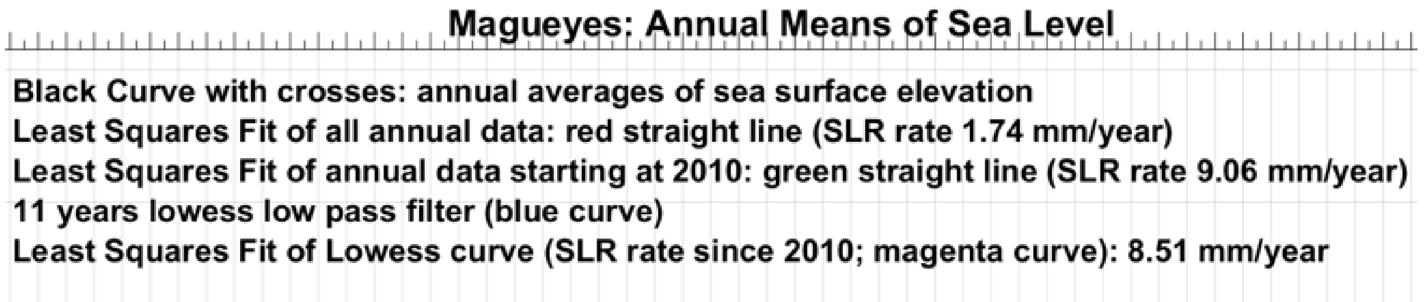

Magueyes: Annual Means of Sea Level
Black Curve with crosses: annual averages of sea surface elevation
Least Squares Fit of all annual data: red straight line (SLR rate 1.74 mm/year)
Least Squares Fit of annual data starting at 2010: green straight line (SLR rate 9.06 mm/year)
11 years lowess low pass filter (blue curve)
Least Squares Fit of Lowess curve (SLR rate since 2010; magenta curve): 8.51 mm/year

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

ETL 1100-2-1

CECW-CE
CECW-P

Technical Letter
No. 1100-2-1

30 June 2014

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 those 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:

7 Appendices
See Table of Contents

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

NOAA Technical Report NOS CO-OPS 083

GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES

Photo: Ocean City, Maryland

Silver Spring, Maryland
January 2017

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Marine Sciences, UPRM

Sea Grant
Universidad de Puerto Rico

SEA LEVEL RISE AROUND PUERTO RICO: A PROJECTION

Aurelio Mercado-Irizarry
Professor of Physical Oceanography
Department of Marine Sciences/University of Puerto Rico/Mayaguez

Requested report submitted to the Puerto Rico Climate Change Council (PRCCC)
Date: March 2017
For additional discussions related with sea level rise, please visit
https://coastalhazardspr.wordpress.com/

Based on the USACE Sea Level Rise calculator, and using the satellite-derived Global Mean Sea Level Rise of 3.3 mm/year (Leuliette and Scharroo, 2010; Nerem et al., 2010; Cazenave et al., 2014; Leuliette and Nerem, 2016), the 2100 projection of Local Sea Level (LSL) rise:

- ***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***

Based on six process-based (climate models) scenarios presented in Sweet et al., 2017, and using results for Puerto Rico and the USVI (values within parenthesis are Global Mean Sea Level Rise projections for 2100 for the respective scenario):

- ***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.

EXECUTIVE SUMMARY (part of – Sweet et al. 2017)

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

NOAA Technical Report NOS CO-OPS 083 (January 2017)

PROJECTIONS (USGS/EPA/NOAA/Rutgers):
Global and Regional Sea Level Rise Scenarios for the United States (January 2017; NOAA Technical Report NOS CO-OPS 083) – Sweet et al.

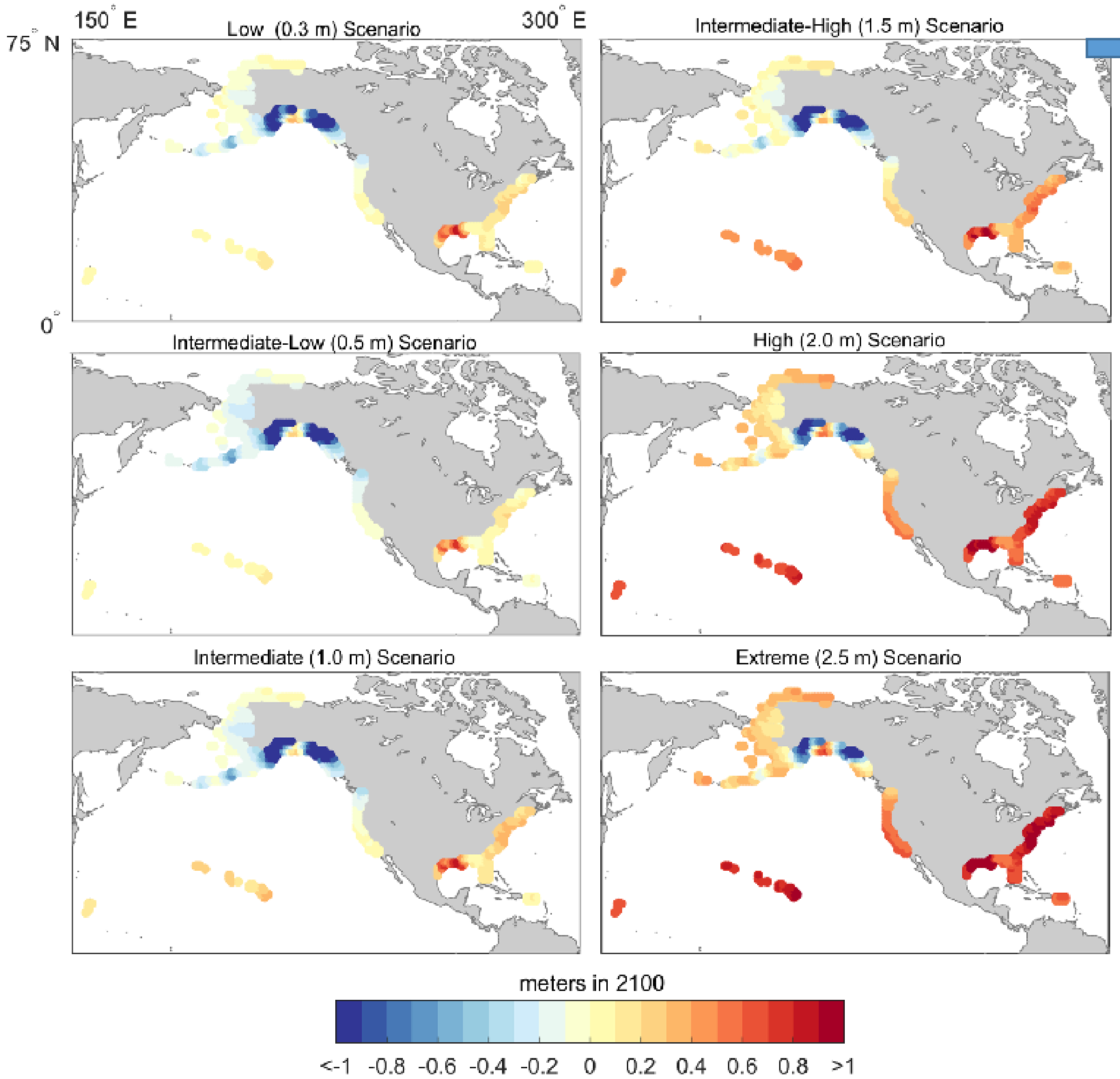

Figure 13. Total RSL change at 1-degree resolution for 2100 (in meters) relative to the corresponding (median-value) GMSL rise amount for that scenario. To determine the total RSL change, add the GMSL scenario amount to the value shown.

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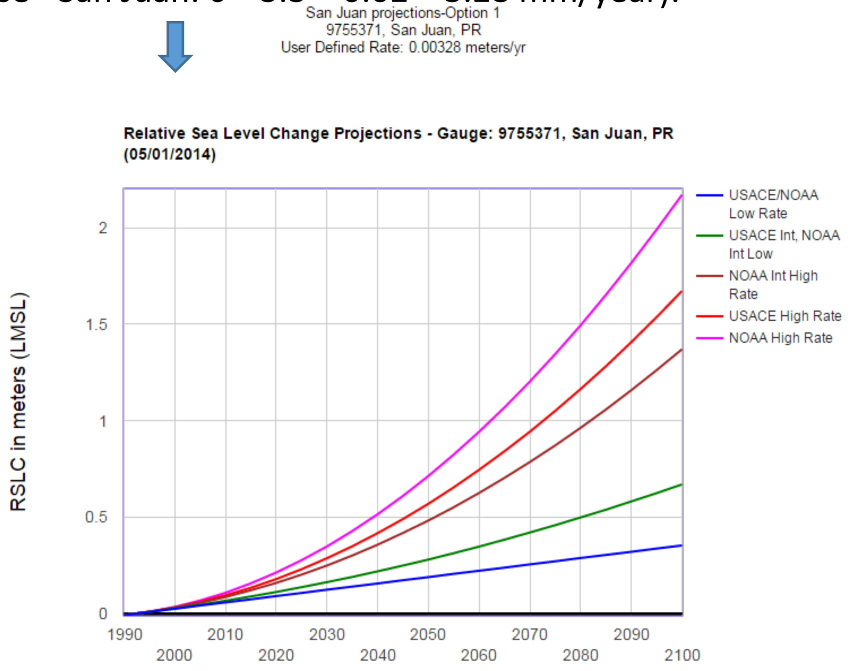
We should also have in mind the more dramatic projections by Hansen et al. (2016) and DeConto and Pollard (2016), which use very sophisticated modeling.

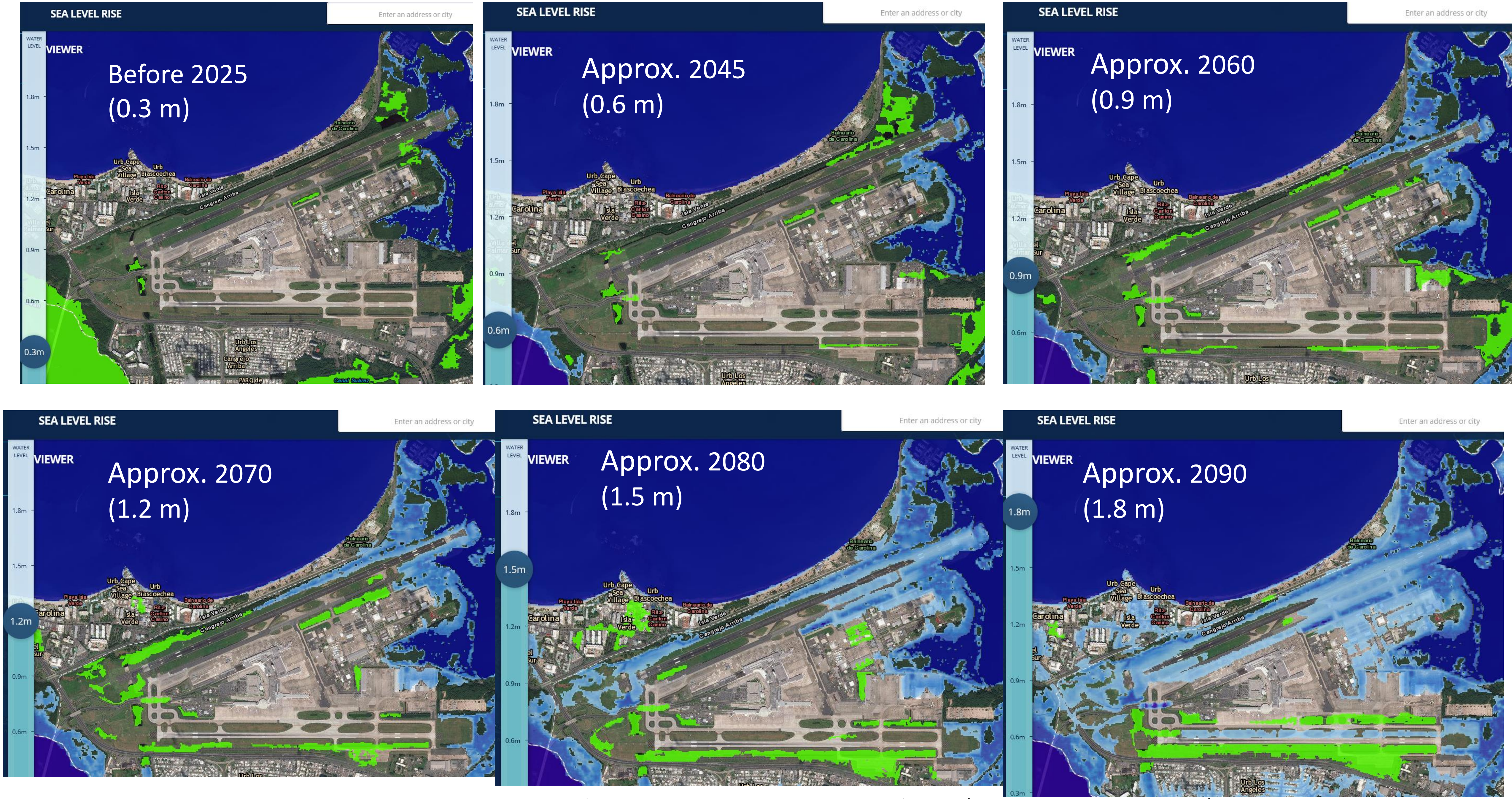
Based on the USACE Sea Level Rise calculator, 2100 projection of LSLR:

- ***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***

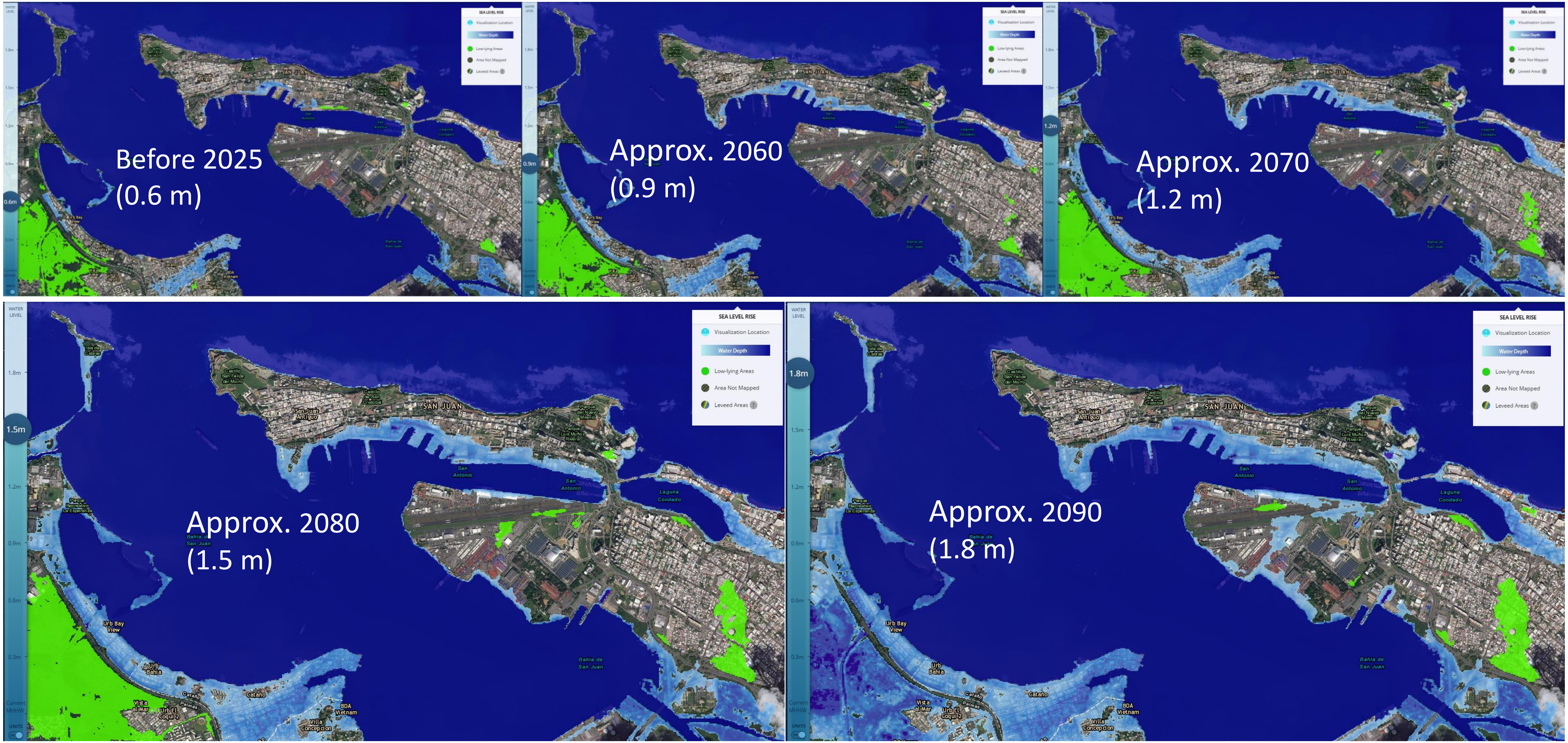
Sea Level Change (SLC) Rate (based on the satellite-derived Global Mean Sea Level Rise - San Juan: c = 3.3 – 0.02 = 3.28 mm/year):

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 áreas (NOAA High Scenario)



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