Spatiotemporal Structure and Trends of Puerto Rico's Wave Climate:

Implications for Coastal Erosion and Flooding

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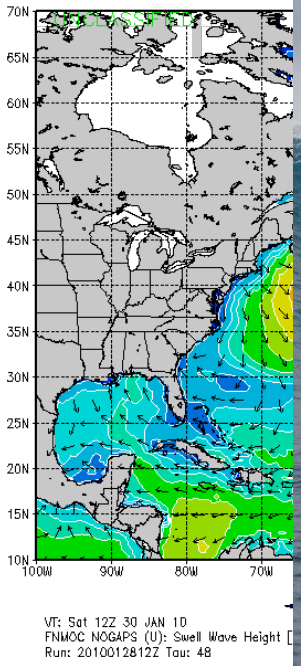
March 17, 2022

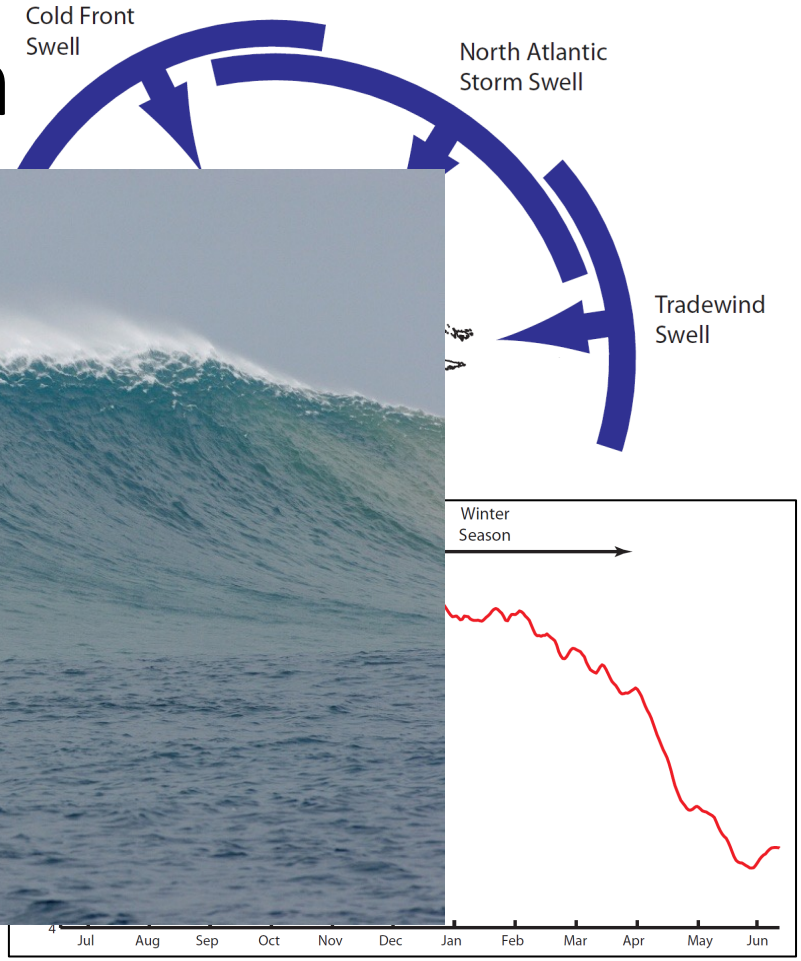
What is coastal erosion?

- **Erosion = Sediment deficit somewhere at some time scale**
  - Could be due to natural process of shoreline regression
  - Could simply be seasonal response of shoreline
  - Poorly designed coastal structures, interruption of sediment supply, and human intervention
  - Changing hydrodynamics:
    - Sea level rise
    - Changes / variability in wave climate

***In PR beaches and public and the extent of the public domain is determined by the wave climate (Ley de Puertos 19886)**

Puerto Rico's wave clim





TOWARDS A HYDRODYNAMIC ATLAS OF PUERTO RICO / USVI

DRNA

CARICOOS

Puerto Rico Science, Technology & Research Trust

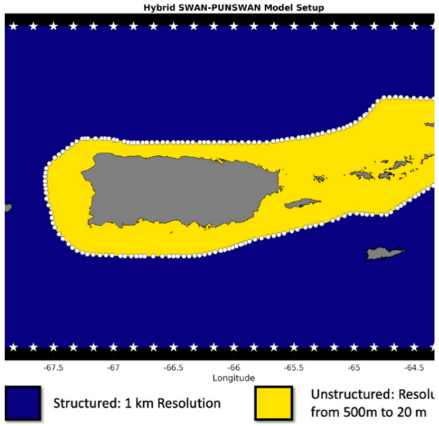
Sea Grant Puerto Rico

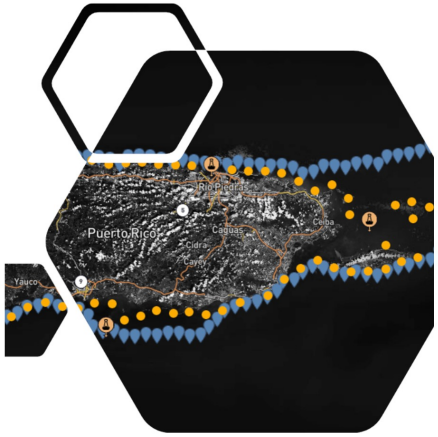
PROGRAMA DE MANEJO ZONA COSTANERA

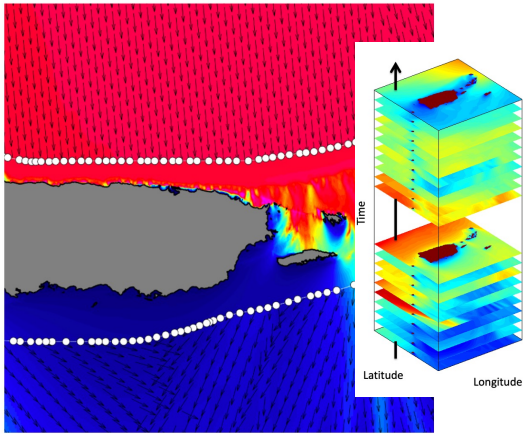
The Puerto Rico High-Resolution Wave Climate Atlas

(Website: http://www.canalsresearch.com/wave-climate-atlas)

The Puerto Rico Wave Climate Atlas was funded by the Puerto Rico Department of Natural Resources (through the Puerto Rico Coastal Zone Management Program) and with funds from The Puerto Rico Science, Technology and Research Trust. Administrative, financial and technical support was also provided by UPR Sea Grant and CARICOOS. The Puerto Rico Wave Climate Atlas is a tool to analyze seasonal, interannual and long-term changes in Puerto Rico's wave climate over the 40-year period from 1979-2019 using very high-resolution numerical simulations. These simulations have been validated with CARICOOS buoy data to ensure the atlas accurately captures PR's wave climate. This atlas is meant to serve as a tool for scientists, planners, engineers and other professionals working in Puerto Rico's coastal zone. For technical or data access questions please contact the Principal Investigator Miguel F Canals Silander via email: miguelf.canals@upr.edu.







TECHNICAL OVERVIEW

This page includes a brief technical description of the model setup, mesh, resolution, and wave and wind boundary conditions.

EXPLORE TECHNICAL ASPECTS

MODEL POINT OUTPUT

In this web interface, time series data and graphical products are provided at buoy locations and points along the 20-meter and 100-meter depth contours.

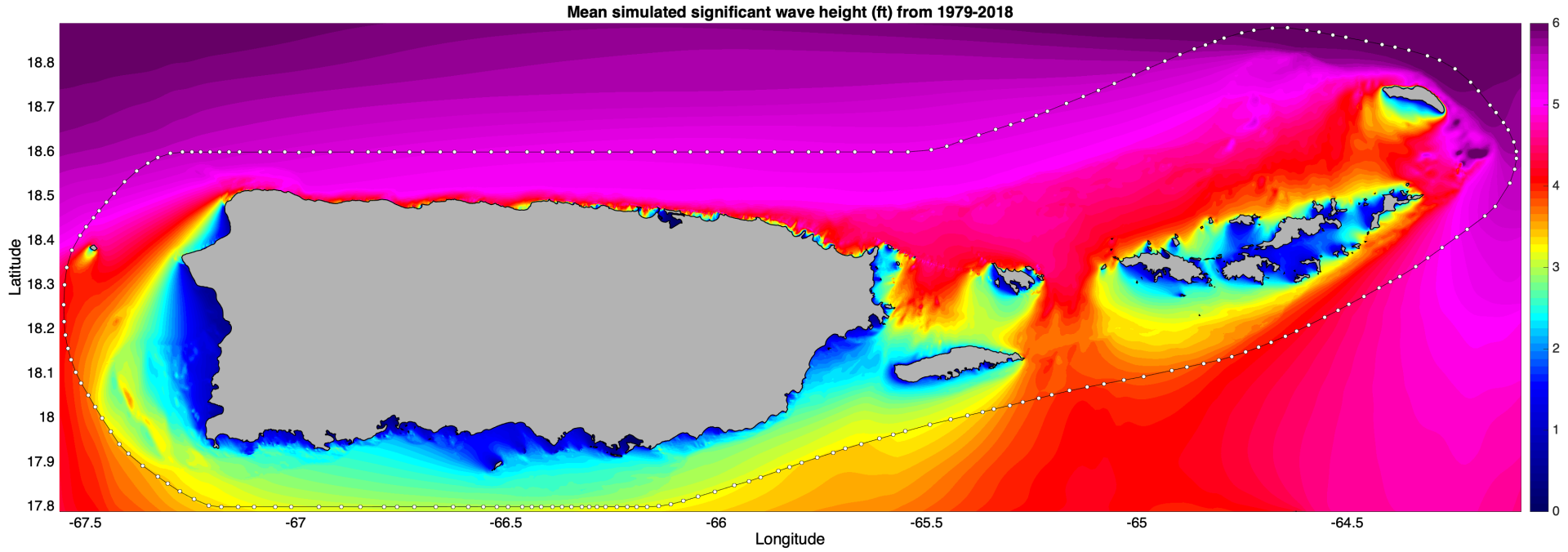
ACCESS POINT OUTPUT

MAP PRODUCTS

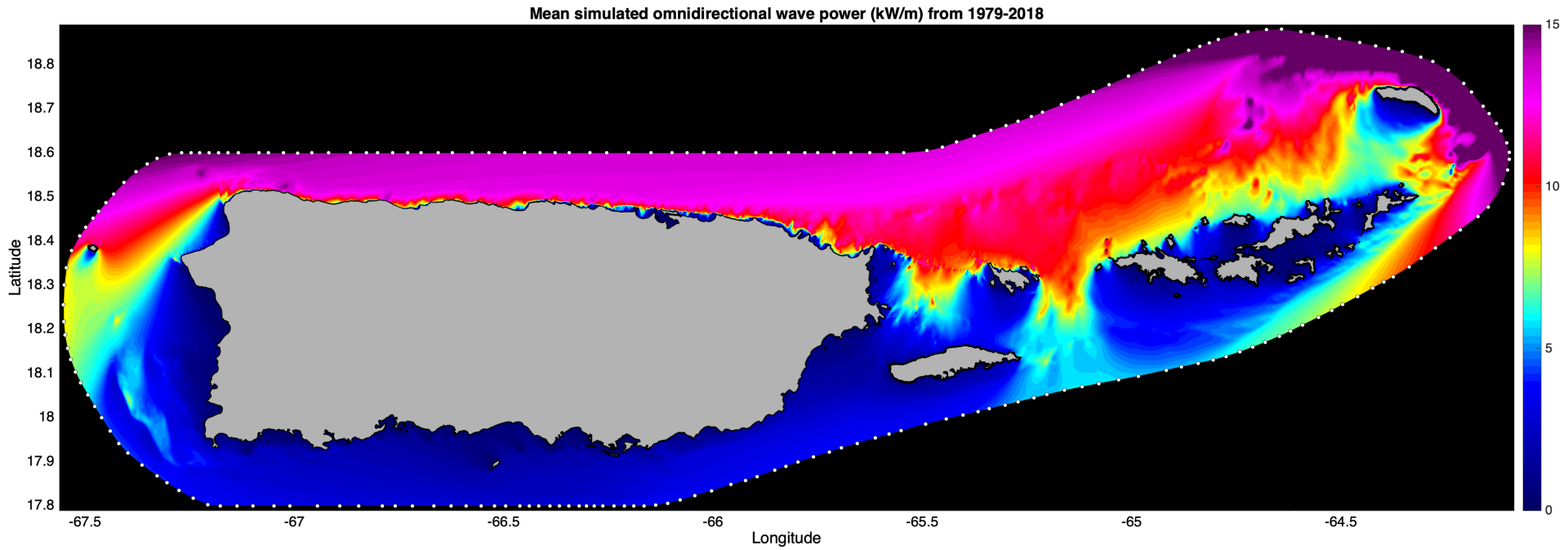
This page includes maps of average and extreme parameters such as wave height, wave power, and other spatially-variable quantities.

ACCESS MAP PRODUCTS

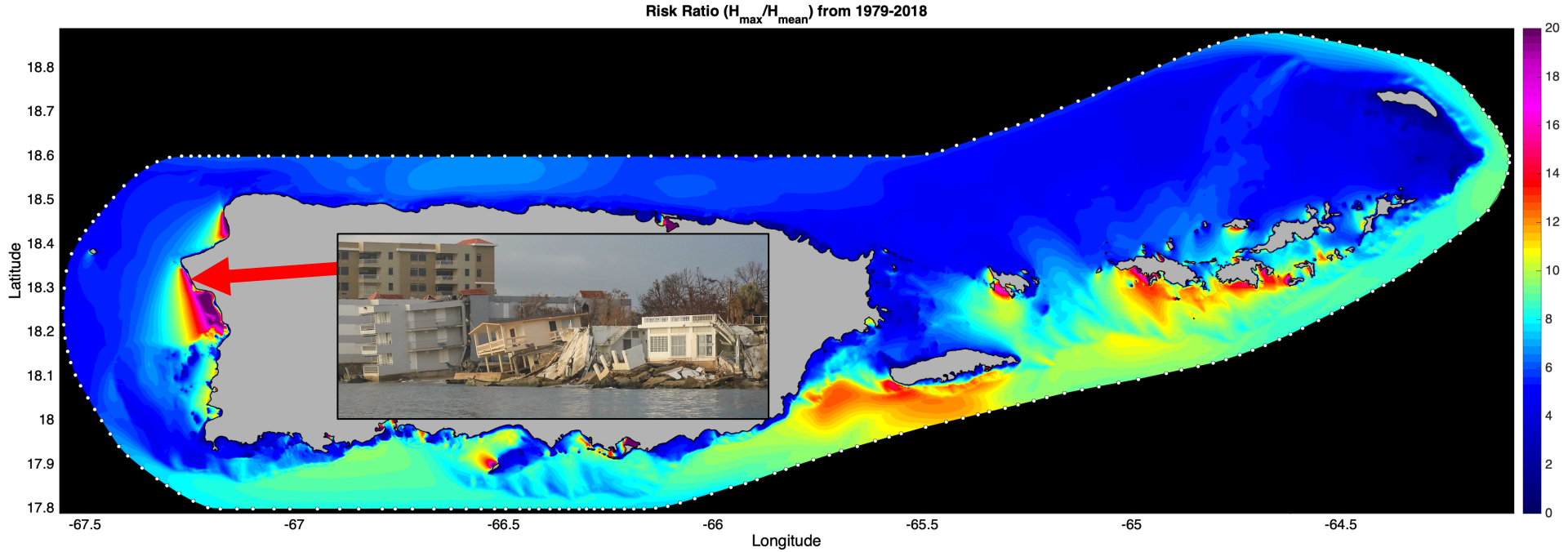
MEAN WAVE HEIGHTS



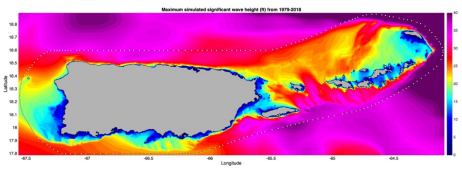
MEAN WAVE POWER



WAVE EXPOSURE RISK RATIO



$$RR = \frac{Hs_{max}\ (40yr)}{Hs\ (mean)} =$$



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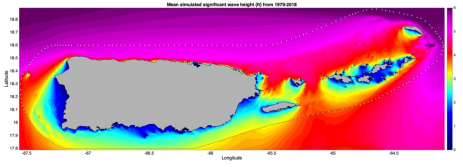
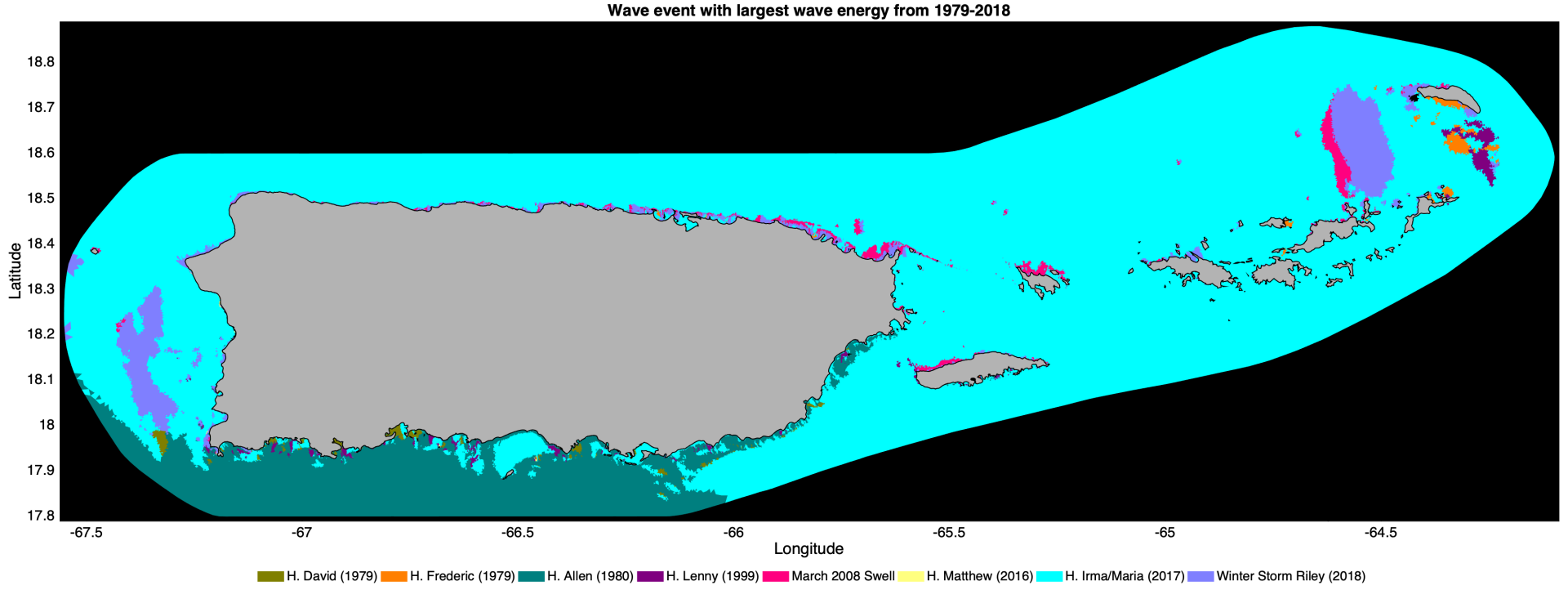
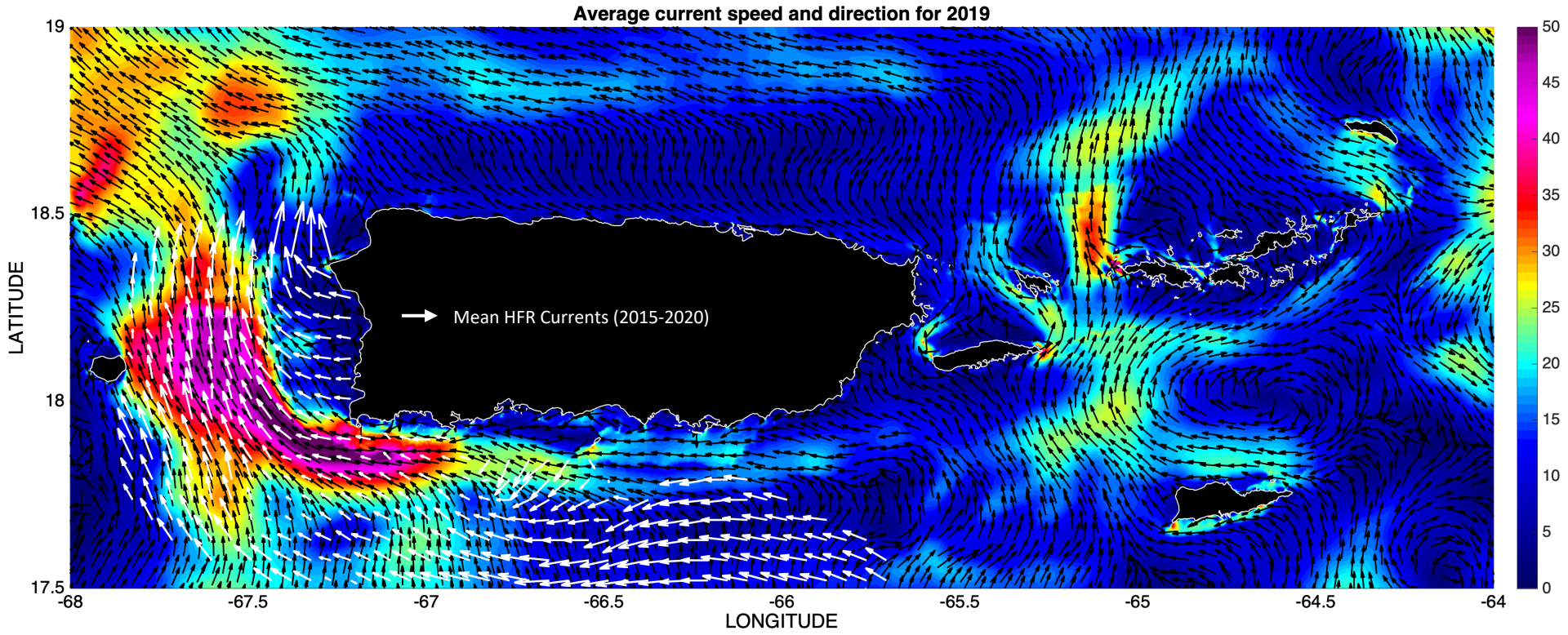


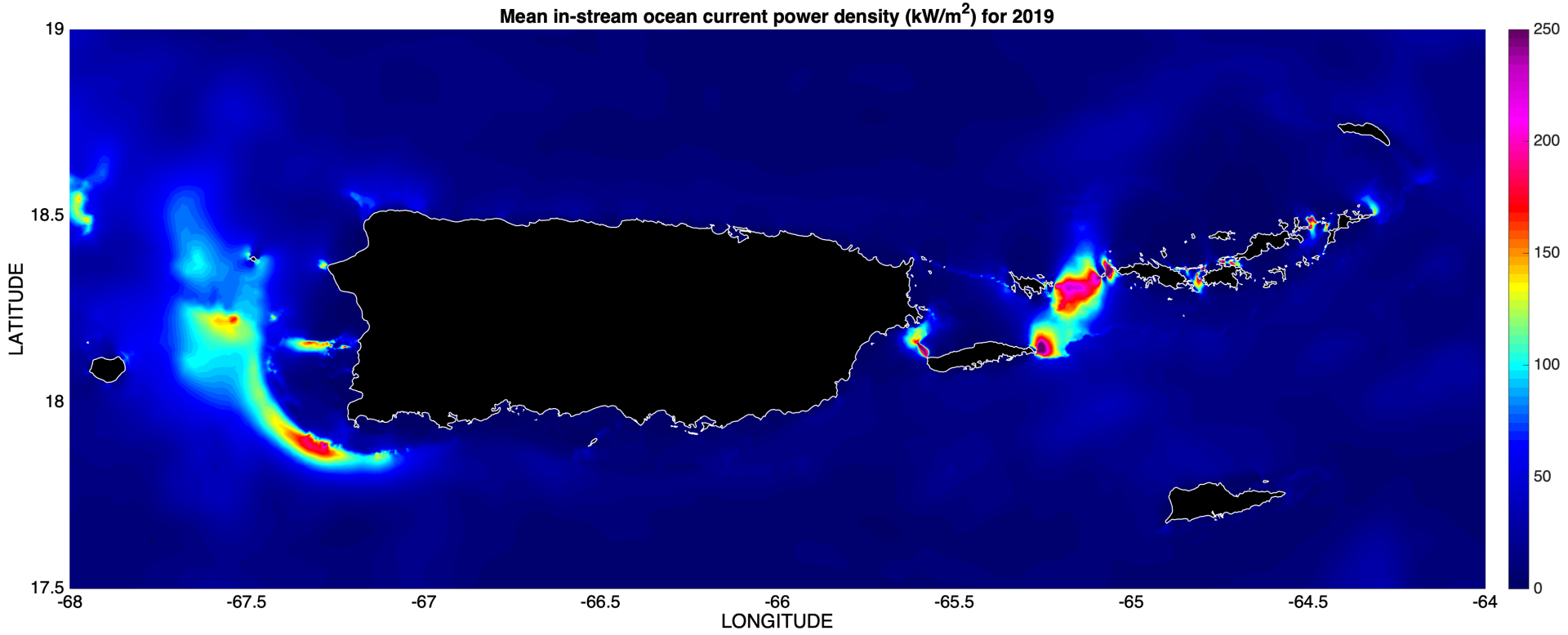
EVENT-DRIVEN EXPOSURE



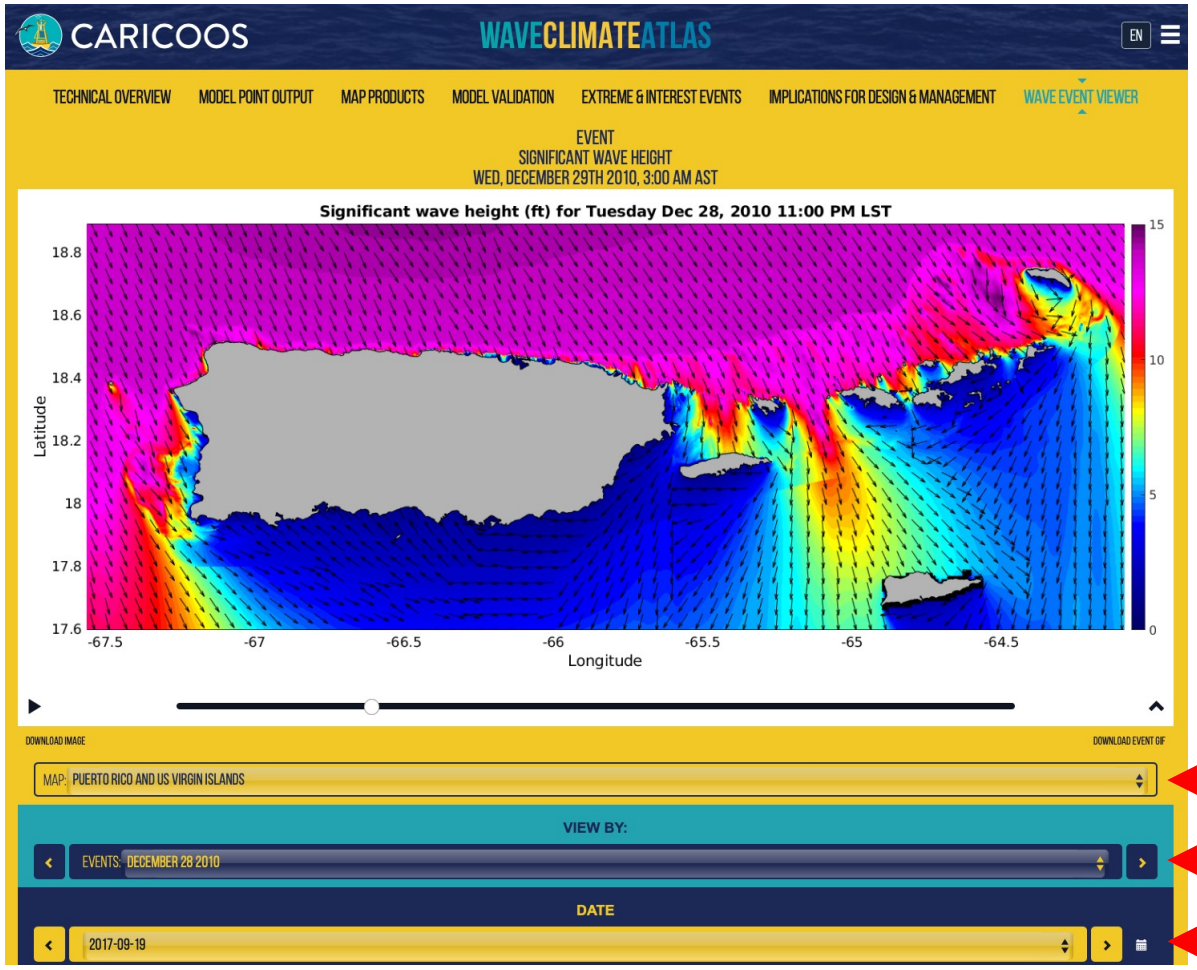
MEAN CURRENTS



MEAN IN-STREAM OCEAN CURRENT POWER DENSITY



The Puerto Rico Wave Event Viewer: http://www.caricoos.org/waveclimateatlas/calendar



Provides access to all wave events and time steps with wave heights > 6’ for the time period 2008-2018

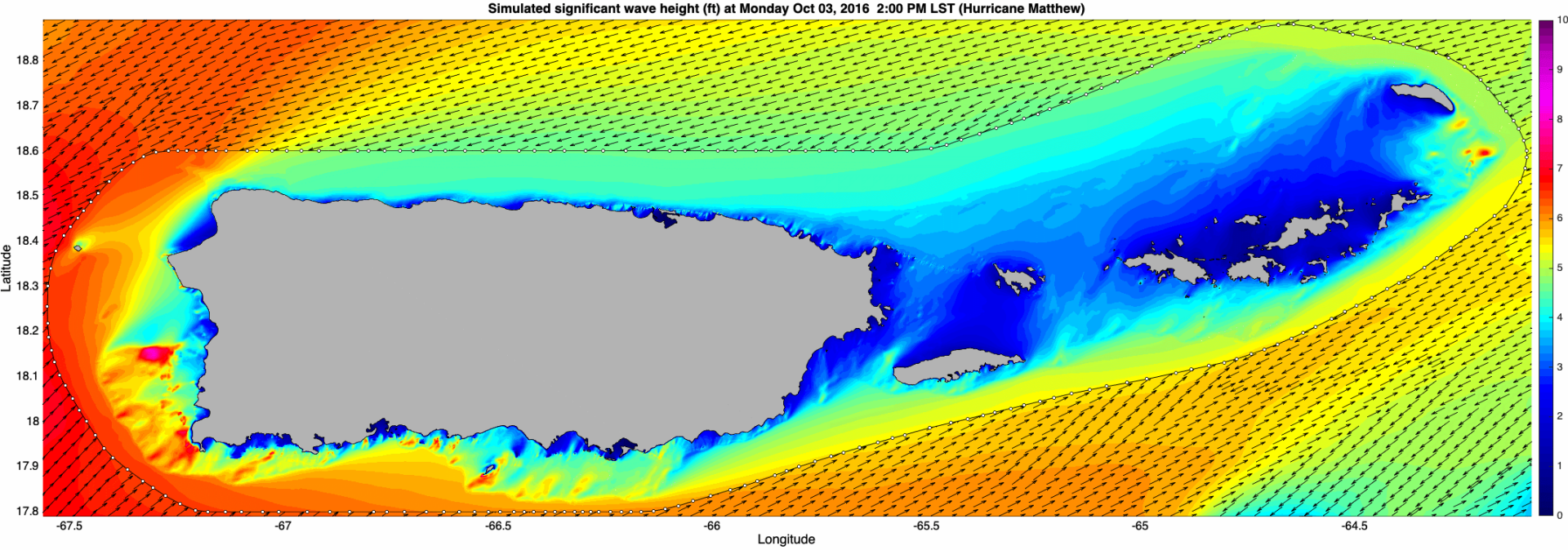
Select geographic area

Select event

Or… Select time step

Hurricane Matthew west-southwest swell

Tuesday Oct 4 2016



What is happening to the wave climate at a global scale?

NATURE COMMUNICATIONS | https://doi.org/10.1038/s41467-018-08066-0 ARTICLE

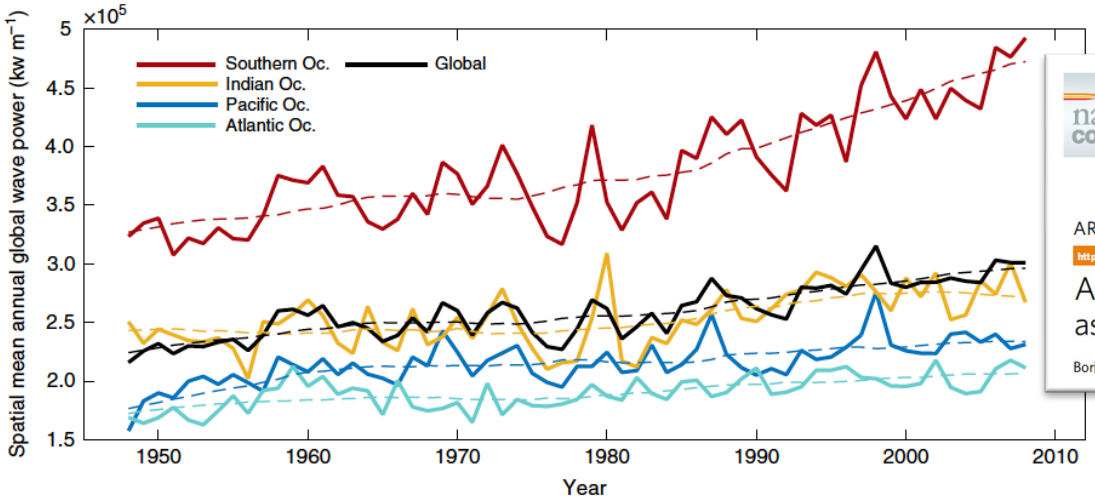


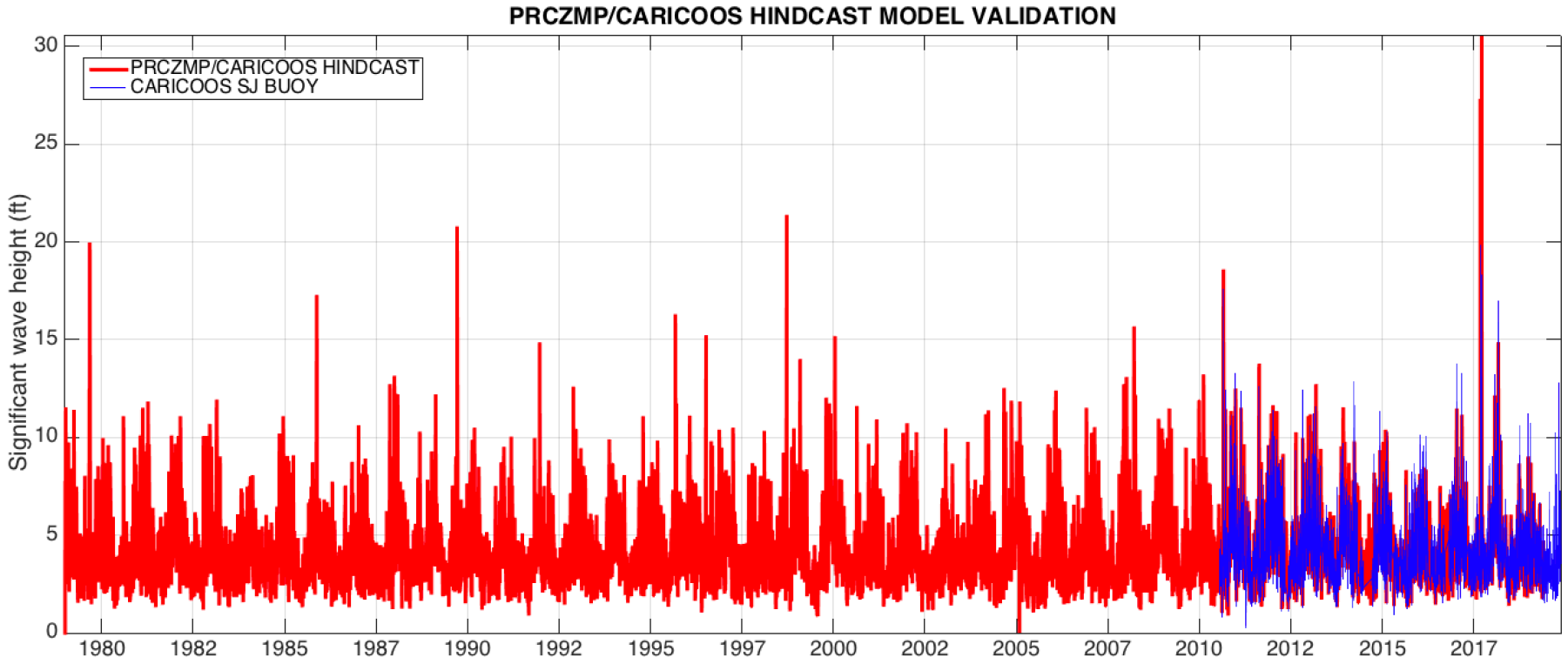
Fig. 1 Spatial mean annual Wave Power calculated globally and by ocean basin. The dashed lines represent the 10-year moving averages. The Southern Ocean is defined between latitudes of 40°S and 80°S. The mean regional Wave Power is calculated as the spatial average of each historical wave power time series (see Methods). The solid lines indicate each time series. The dashed lines correspond to the 10-year moving average. The time series calculated by latitudinal bands can be found in Supplementary Figure 1

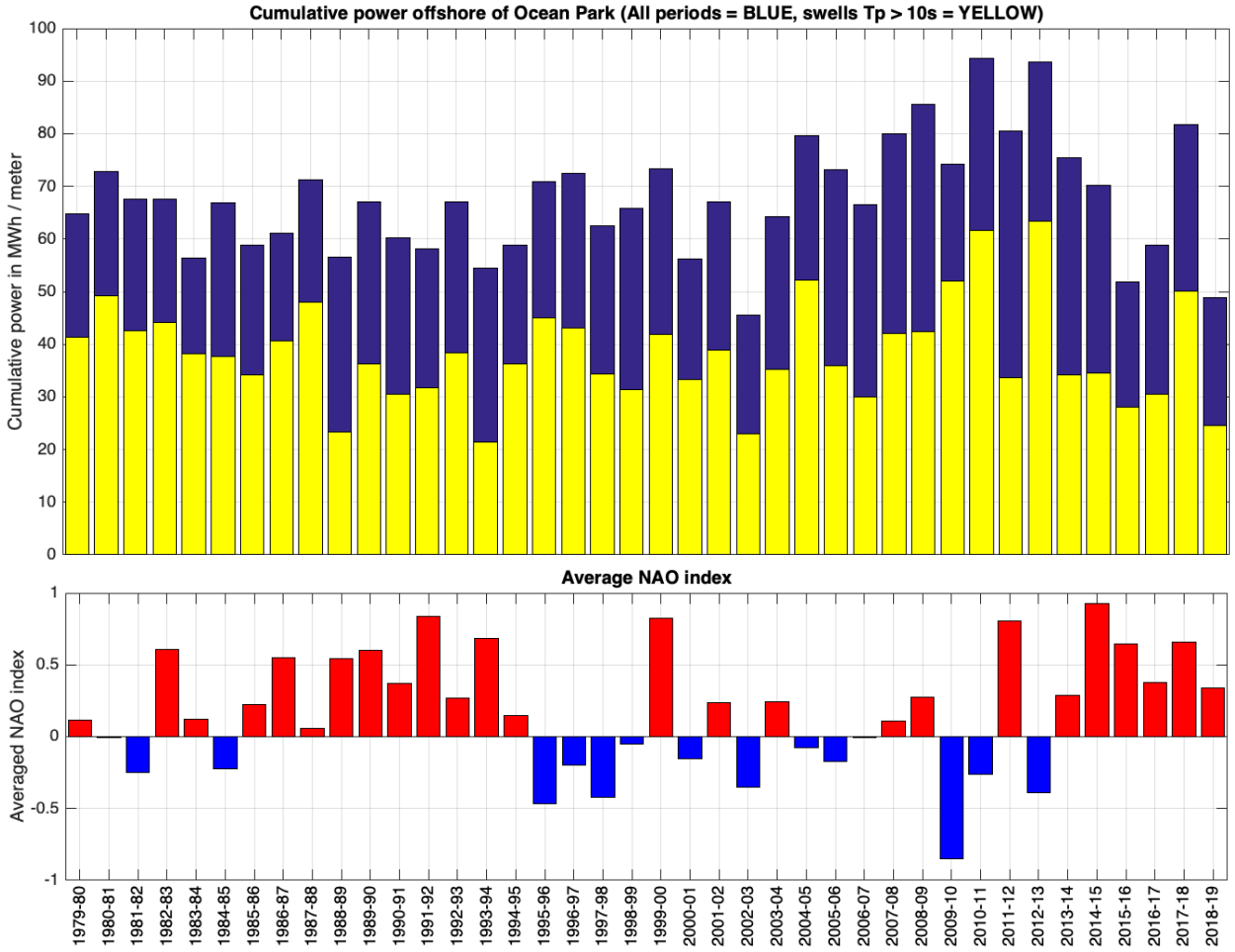
Question:

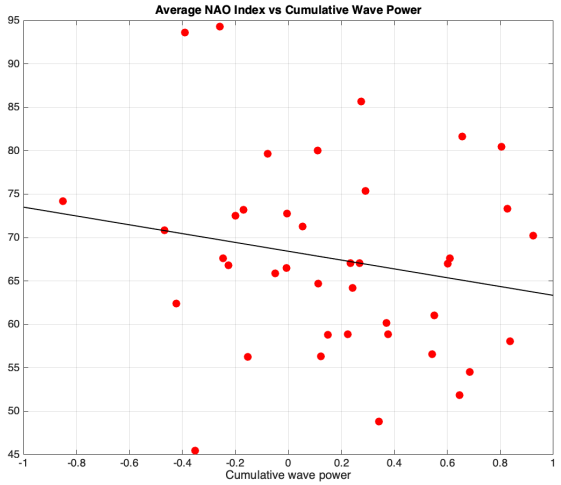
Is there a **detectable signal** in Puerto Rico's wave climate as a result of climate change?


CARICOOS
WAVECLIMATEATLAS
EN
TECHNICAL OVERVIEW
MODEL POINT OUTPUT
MAP PRODUCTS
MODEL VALIDATION
EXTREME & INTEREST EVENTS
IMPLICATIONS FOR DESIGN & MANAGEMENT
WAVE EVENT VIEWER
20-M DEPTH CONTOUR:
[-66.0347,18.4676]
40-year time series plot (PNG file)
40-year wave rose plot (PNG file)
40-year time series data (MATLAB file)
Isabela
Arecibo
Vega Baja
San Juan
Bayamón
Carolina
Fajardo
Utuado
Caguas
Mayagüez
Cabo Rojo
Yauco
Coamo
Juana Díaz
Cayey
Charlotte Amalie
British Virgin Islands
Spanish Town
US Virgin Islands

40 YEAR WAVE HISTORY OFF OCEAN PARK, OUTSIDE OF OUTER REEFS




Cumulative power offshore of Ocean Park (All periods = BLUE, swells Tp > 10s = YELLOW)
Cumulative power in MWh / meter
Average NAO index
Averaged NAO index
1979-80
1980-81
1981-82
1982-83
1983-84
1984-85
1985-86
1986-87
1987-88
1988-89
1989-90
1990-91
1991-92
1992-93
1993-94
1994-95
1995-96
1996-97
1997-98
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19


Average NAO Index vs Cumulative Wave Power
Cumulative wave power

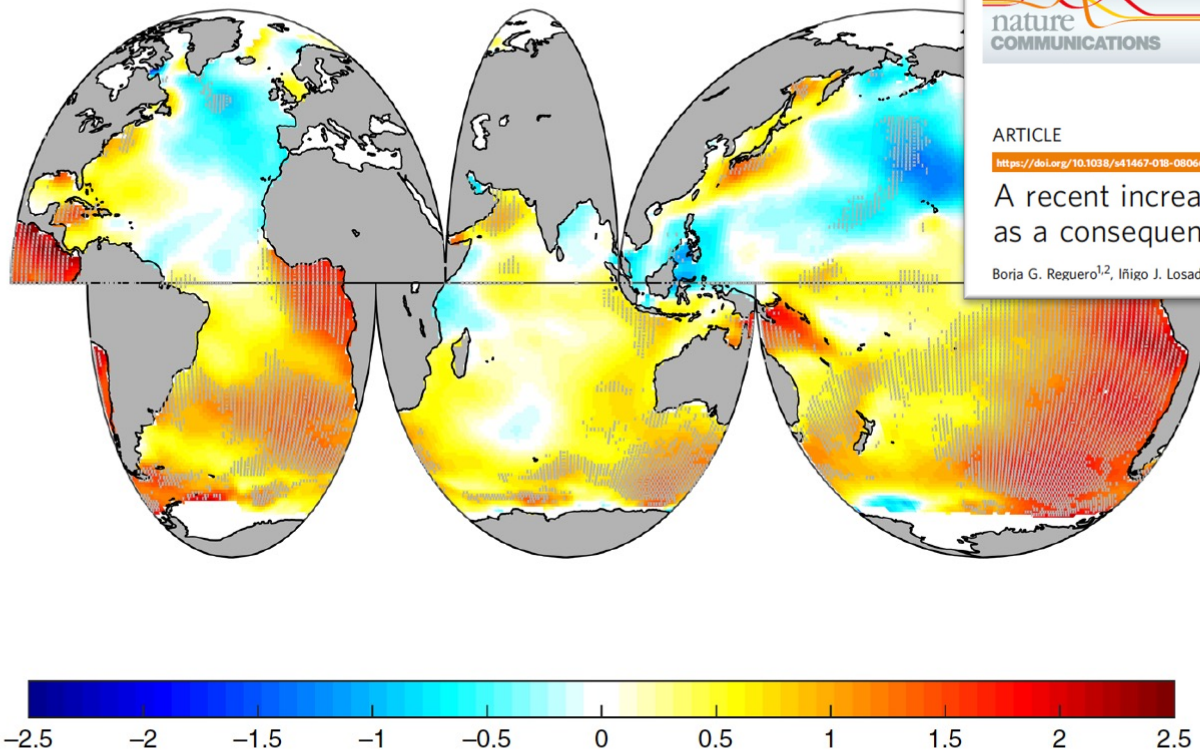
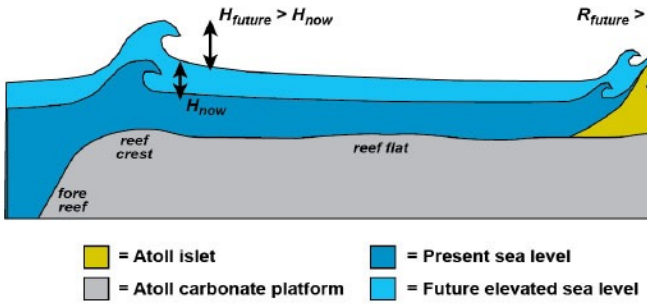


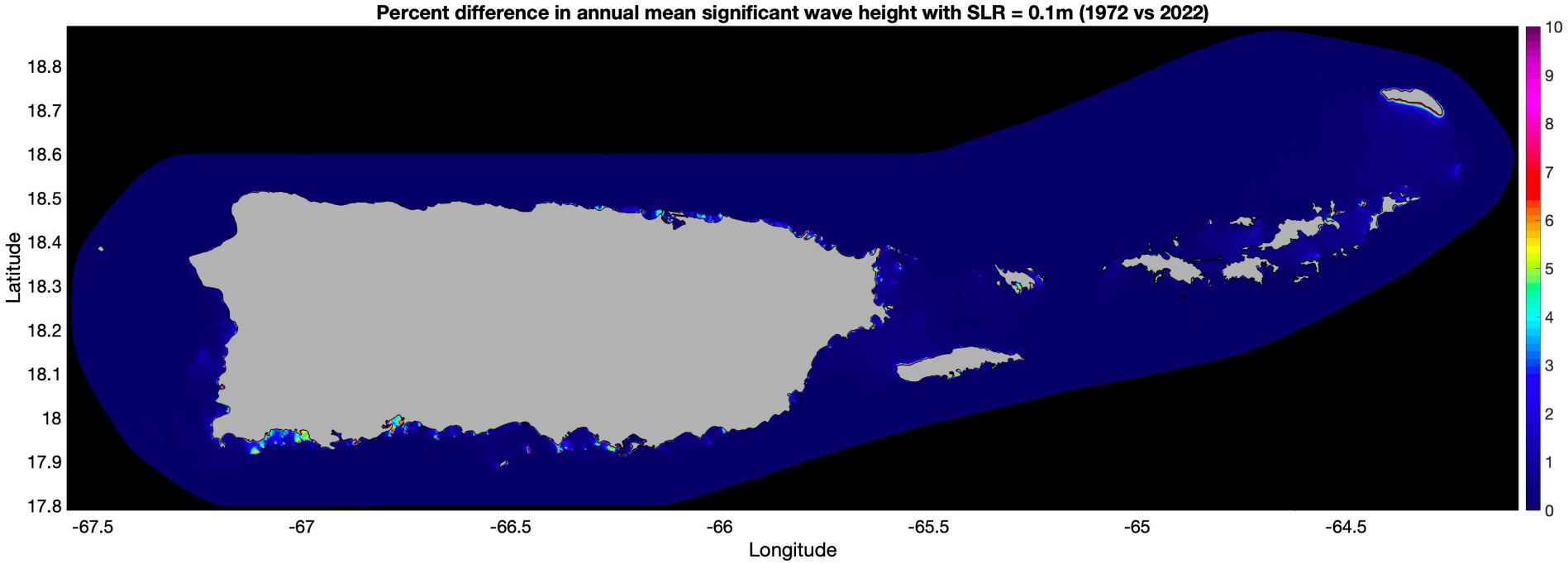
Fig. 6 Spatial trend (percent change per year) in mean Wave Power from 1985 to 2008. Hatched areas represent points that are statistically significant at the 95% confidence level according to the Mann–Kendall test and the Wang and Swail method for autocorrelation (see Methods). The trends are calculated for the period 1985–2008 (period with satellite-derived wave data) for comparison with[9]. Supplementary Figure 5 shows the spatial trends for other periods in the historical record

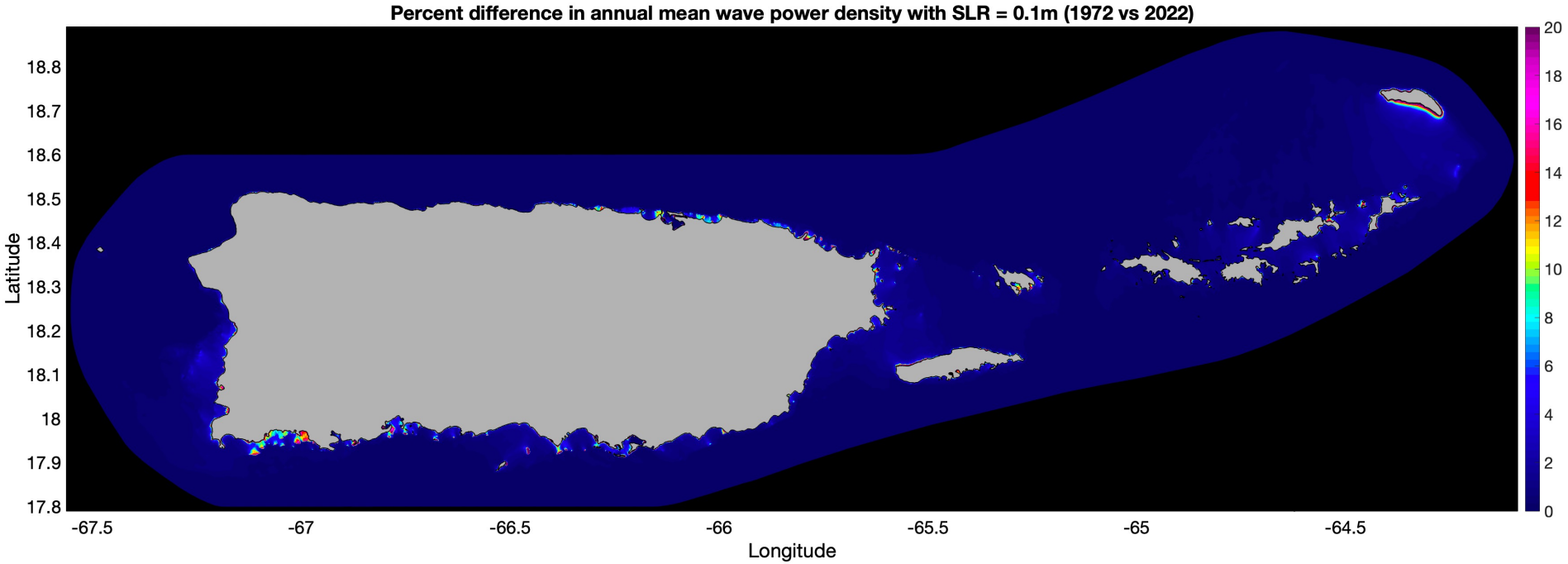
What about the nearshore wave climate?

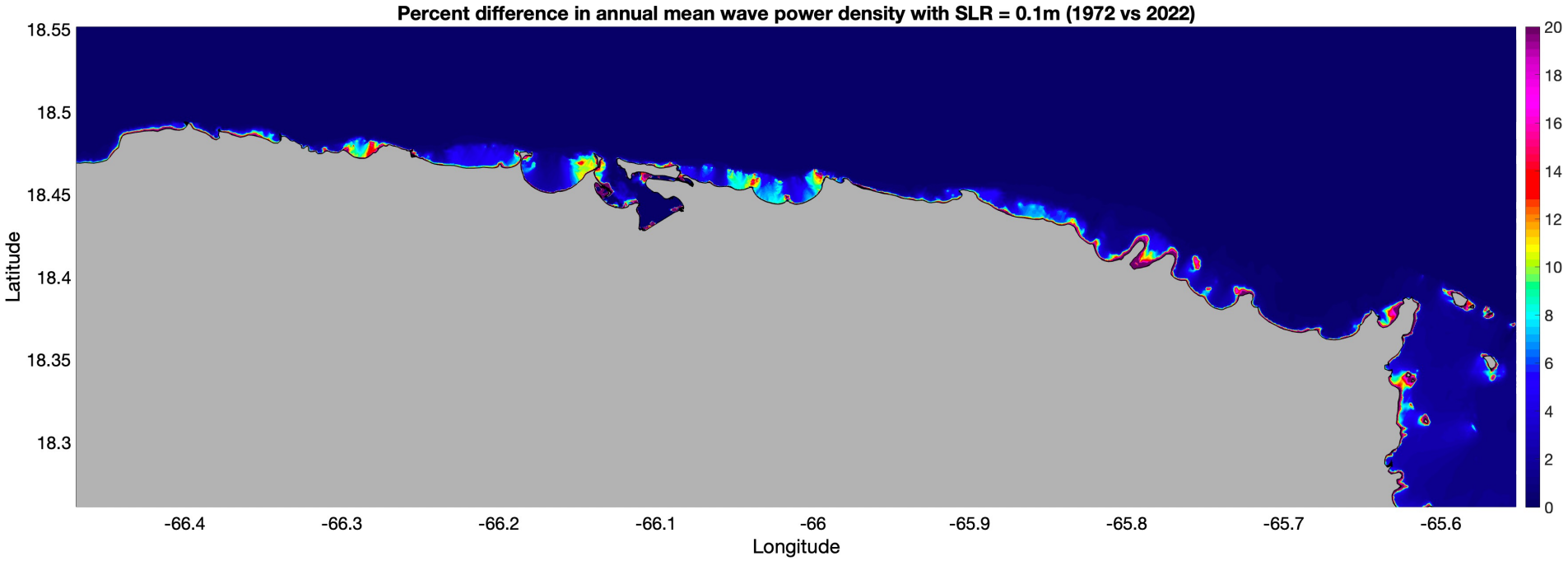
- Unfortunately we don't have long time series of wave heights near the beach (inside of surf zone) to detect a SLR signal in wave climate
- BUT – we can simulate effects of SLR on nearshore wave climate
- Let's simulate a HISTORIC scenario: How much has annu y increased in the near
  - A SLR above 1972's MSL

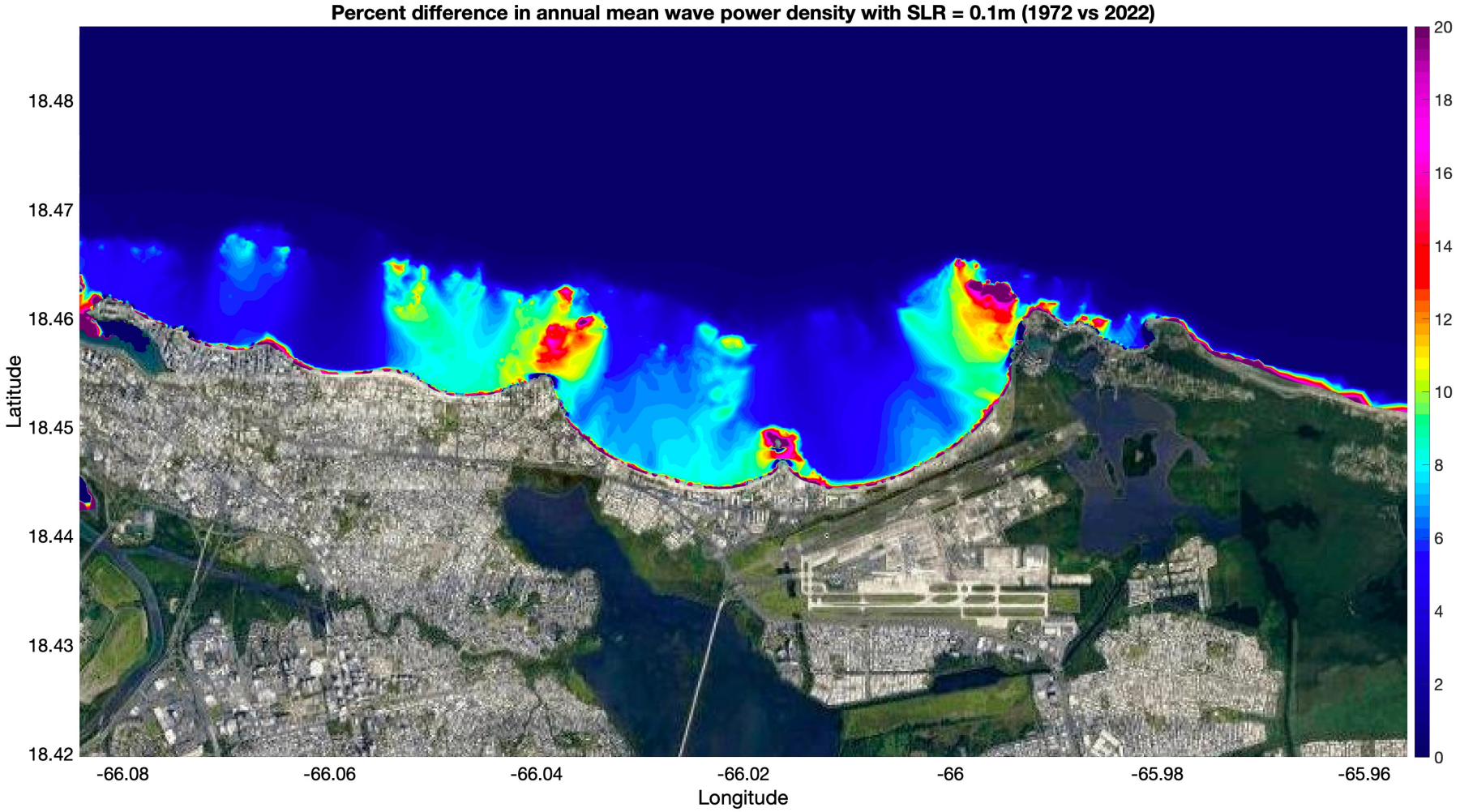


http://walrus.wr.usgs.gov/climate-change/atolls/background.html


Percent difference in annual mean significant wave height with SLR = 0.1m (1972 vs 2022)
Latitude
18.8
18.7
18.6
18.5
18.4
18.3
18.2
18.1
18
17.9
17.8
-67.5
-67
-66.5
-66
-65.5
-65
-64.5
Longitude
10
9
8
7
6
5
4
3
2
1
0

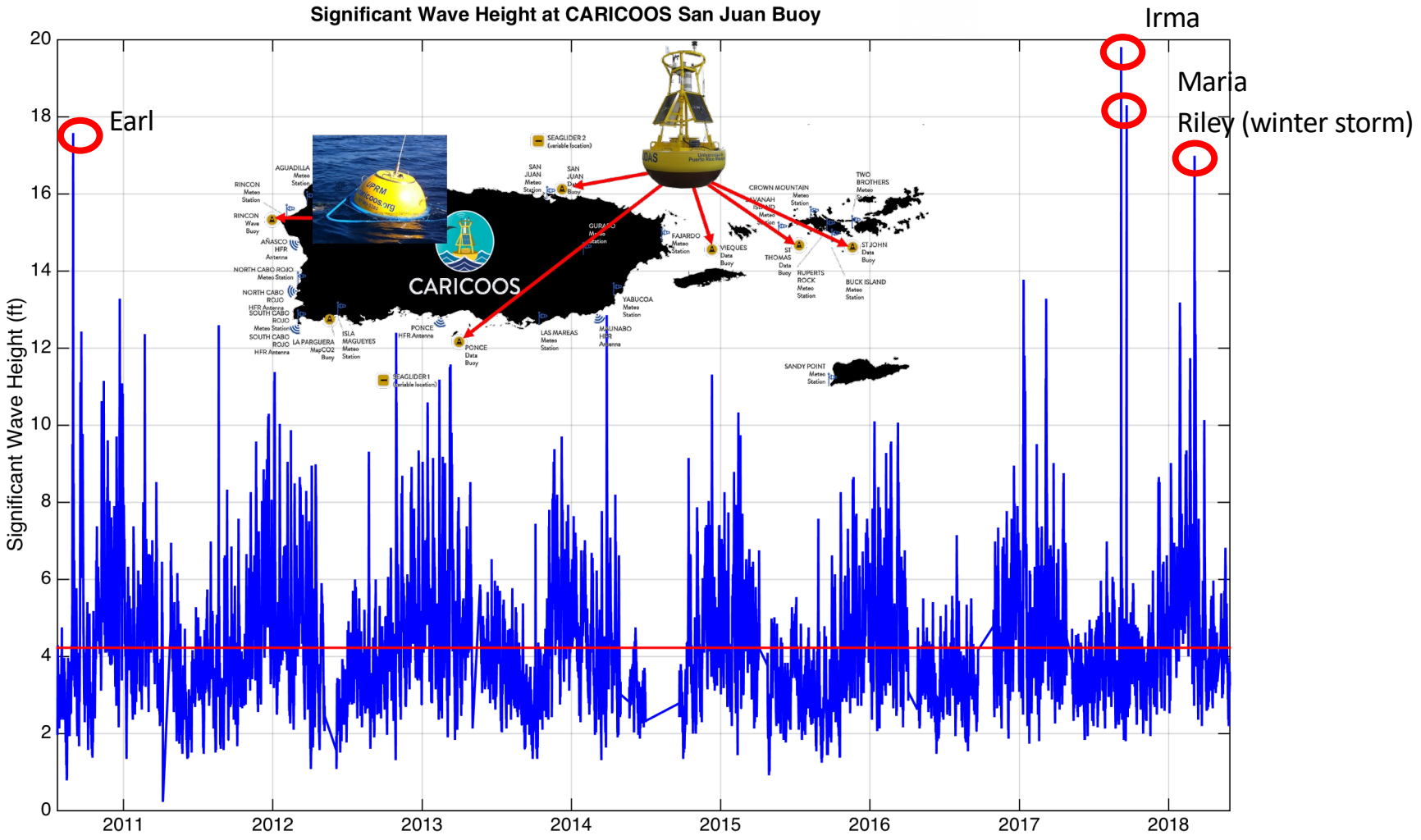

Percent difference in annual mean wave power density with SLR = 0.1m (1972 vs 2022)
Latitude
18.8
18.7
18.6
18.5
18.4
18.3
18.2
18.1
18
17.9
17.8
-67.5
-67
-66.5
-66
-65.5
-65
-64.5
Longitude
20
18
16
14
12
10
8
6
4
2
0


Percent difference in annual mean wave power density with SLR = 0.1m (1972 vs 2022)
Latitude
18.55
18.5
18.45
18.4
18.35
18.3
-66.4
-66.3
-66.2
-66.1
-66
-65.9
-65.8
-65.7
-65.6
Longitude
20
18
16
14
12
10
8
6
4
2
0


Percent difference in annual mean wave power density with SLR = 0.1m (1972 vs 2022)
Latitude
18.48
18.47
18.46
18.45
18.44
18.43
18.42
Longitude
-66.08
-66.06
-66.04
-66.02
-66
-65.98
-65.96
20
18
16
14
12
10
8
6
4
2
0

Concluding remarks

- Realistic simulations indicate that, **even in the absence of deep water wave climatology, nearshore wave climate has already changed** due to SLR in Puerto Rico
- These simulations are conservative and DO NOT include effects of coral reef damages on wave dissipation
- How will state agencies take this changing wave climate into account when formulating much needed public policy? For example:
  - Construction setbacks (JP)
  - Deslindes ZMT (DRNA)


Significant Wave Height at CARICOOS San Juan Buoy
Significant Wave Height (ft)
0
2
4
6
8
10
12
14
16
18
20
2011
2012
2013
2014
2015
2016
2017
2018
Earl
Irma
Maria
Riley (winter storm)
CARICOOS
SEAGLIDER 2
(variable location)
SEAGLIDER 1
(variable location)
AGUADILLA
RINCON
AÑASCO
NORTH CABO ROJO
SOUTH CABO ROJO
LA PARGUERA
ISLA MAGUEYES
PONCE
SAN JUAN
GUAYAMA
FAJARDO
VIEQUES
ST THOMAS
ST JOHN
CROWN MOUNTAIN
TWO BROTHERS
RUPERTS ROCK
BUCK ISLAND
YABUCOA
LAS MAREAS
MAUNABO
SANDY POINT


GRACIAS