Rip Current Model Output Statistics (RCMOS) Modeling

for Real-Time Probabilistic and Deterministic Forecasts at WFO OKX, NY

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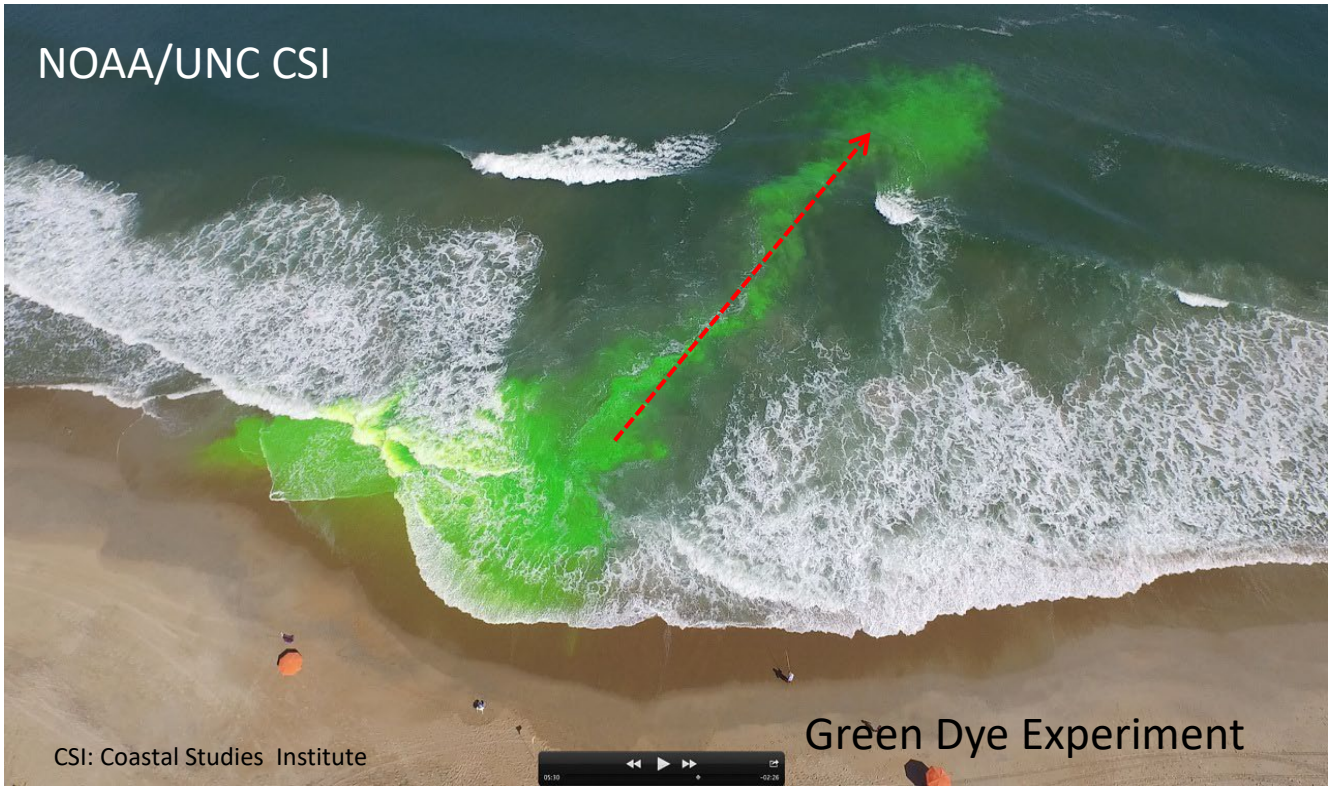
Thanks to Lifeguards, Nelson Vaz, Mike Churma, Steve Smith, Judy Ghirardelli, Greg Dusek

NWS NY Spring Weather Workshop
April 25, 2022

What is a Rip Current (RC)?



- **Rapid offshore-directed jets of water that originate in the surf zone.**
- **Mostly caused by alongshore variations in breaking waves.**
- **RCs are the number one public safety risk at the beach.**

Types of Rip Currents

based on dominant controlling forcing mechanism

Depend on the local wave climate and geomorphology.

1) **hydrodynamic**
2) **bathymetric**
3) **boundary along structures**
4) **mixed**

For all these types, the key common element is wave breaking that varies with space and time.

NWS Status for RC Predictions

- **Lushine RC Scale (LURCS) based model:**
  - Give the same weight to each predictor and sum the scores linearly.
  - Use empirically developed formula in each WFO.
  - Provide deterministic **official** WFO forecasts.
- **Perfect Prog (PP) model (OPR now):**
  - Provide probabilistic forecasts using **one** logistic regression equation.
  - Use default threshold probabilities of 0.25 and 0.5 for moderate and high risk forecasts, respectively.
  - Issue hourly 0-144-h forecasts at a spatial resolution of ~1 km along the US coasts.
  - Implemented into **NWS operations** as a component of the **NCEP's Nearshore Wave Prediction System (NWPS)**.
- **Model Output Statistics (MOS) model (RCMOS hereafter):**
  - Provide probabilistic forecast guidance using regional and seasonal MOS logistic regression equations.
  - Provide deterministic risk forecast guidance along with the MOS probabilistic forecast guidance using the optimum threshold probabilities found iteratively for moderate and high risks.
  - Started issuing hourly 0-144-h forecast guidance for the **beaches** where training data were available.

Benefits of the RCMOS model

- **Current OPR Perfect Prog (PP) Model*[1]:**
  - ✓ **1) Implicitly assumes the NWPS wave and tide forecasts (input data) are perfect.**

- **To address issue #1:**

  MOS*[2] approach is applied, which directly computes the logistic regression between NWPS model forecasts (predictors) and RC obs (predictand).

*[1]**PP model:** Makes no attempt to correct for possible Numerical Weather Prediction (NWP) model errors or biases, but makes an assumption that NWP forecasts are perfect.

*[2]**MOS model:** Determines a statistical relationship between NWP model output at a given time frame (i.e., forecast projection) and observations at that time, and thus can correct for biases of the NWP model.

Benefits of the RCMOS model

- **Current Operational PP Model:**
  - ✓ **2) Uses one logistic regression equation developed in Kill Devil Hills, NC during the summer, and applies the single equation to all locations and all seasons.**

- **To address issue #2:**

  We developed regional and seasonal MOS logistic regression equations for WFO beaches where training data were available.

Benefits of the RCMOS model

- **Current Operational PP Model:**
  - ✓ **3) Uses default threshold probabilities of 0.25 and 0.5 for moderate and high risk forecasts, respectively.**

- **To address issue #3:**

  We developed statistically calibrated threshold probability values for moderate and high risk forecast guidance for local WFO regions and warm/cool seasons.

RCMOS model

Predictand:

Rip Current Strength

(as observed by lifeguards)

Predictors:

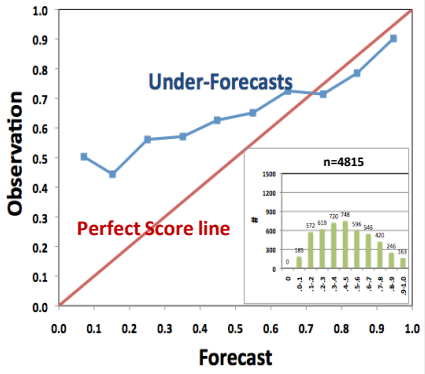
- **Significant Wave Height**
- **Mean Wave Direction**
- **Peak Wave Period**
- **Previous Wave Event**
- **Tide Water Level**

(as forecast by NWPS)

RCMOS for WFO OKX (New York, NY)

Operational PP Model

Reliability Diagram*



Brier Skill Score*

$BS_{NWPSforecast}$ = 0.268

$BS_{SampleClimate}$ = 0.235

$BSS_{NWPSoverClim}$ = -0.138

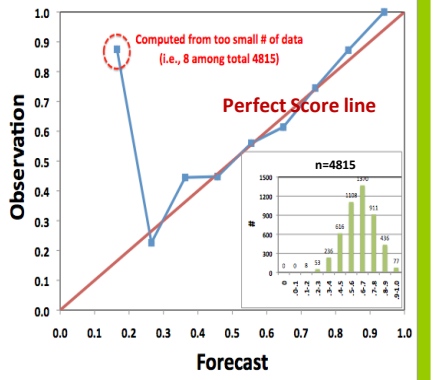
Physical meaning:
NWPS RC forecasts don't make improvement over the sample climate .
13.8% decline.

RCMOS Improvement

Jun 1 - Sep 28
2019
7 beaches
NY

RCMOS Model

Reliability Diagram*



Brier Skill Score*

$BS_{MOSforecast}$ = 0.217

$BS_{SampleClimate}$ = 0.235

$BSS_{MOSoverClim}$ = 0.077

Physical meaning:
MOS RC forecasts made 7.7 % improvement over the sample climate.

* Assumed moderate or strong RCs are hazardous in this verification.

RCMOS forecast guidance made

- Significant improvements in the Reliability Diagram (i.e., much closer to the perfect score line)
- 19.0% improvements over the PP model in Brier Skill Score

RCMOS for WFO OKX (New York, NY)

Development of Threshold Probabilities for the RCMOS guidance to make deterministic RC "strength" risk forecast guidance:

- Found optimum threshold probability values iteratively which **maximize "correct rate" for moderate risk** and **"equitable threat score" for high risk, within an allowable bias range (1+/-0.1).**
- **For OKX:**

  P=0.577 for moderate risk

  P=0.798 for high risk

Note: More detailed info can be found in my 2018 AMS presentation.
https://ams.confex.com/ams/98Annual/webprogram/Paper329097.html

Real-time RCMOS forecast guidance for WFO OKX (https://rcmos.mdl.nws.noaa.gov/downloads/OKX/)*

Upon WFO forecasters' request, "experimental" real-time deterministic risk forecast guidance (Low/Moderate/High) along with hazardous RC probabilistic forecast guidance is available.

- **Hourly forecast guidance for the next 6 days (0-144 hours).**
- **Daily average and maximum values for the next 6 days.**

YYYYMMDD.HH00	Longitude	Latitude	Prob(%)	Risk
20200806.1200	286.3430	40.5798	56.7	Low
20200806.1300	286.3430	40.5798	55.9	Low
20200806.1400	286.3430	40.5798	55.1	Low
20200806.1500	286.3430	40.5798	54.4	Low
20200806.1600	286.3430	40.5798	53.7	Low
20200806.1700	286.3430	40.5798	53.0	Low
20200806.1800	286.3430	40.5798	52.4	Low
20200806.1900	286.3430	40.5798	51.7	Low
20200806.2000	286.3430	40.5798	51.3	Low
20200806.2100	286.3430	40.5798	50.8	Low
20200806.2200	286.3430	40.5798	50.1	Low
20200806.2300	286.3430	40.5798	49.5	Low
20200807.0000	286.3430	40.5798	49.0	Low

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YYYYMMDD	Beach#	Longitude	Latitude	AvgProb(%)	AvgRisk	MaxProb(%)	MaxRisk
20200806	1	286.3430	40.5798	-99.9	NA	-99.9	NA
20200807	1	286.3430	40.5798	50.5	Low	56.6	Low
20200808	1	286.3430	40.5798	49.2	Low	54.5	Low
20200809	1	286.3430	40.5798	44.7	Low	47.6	Low
20200810	1	286.3430	40.5798	47.0	Low	54.5	Low
20200811	1	286.3430	40.5798	54.7	Low	62.7	Moderate
20200812	1	286.3430	40.5798	-99.9	NA	-99.9	NA
20200806	2	286.4550	40.5803	-99.9	NA	-99.9	NA
20200807	2	286.4550	40.5803	58.5	Moderate	65.5	Moderate
20200808	2	286.4550	40.5803	59.3	Moderate	64.4	Moderate
20200809	2	286.4550	40.5803	53.6	Low	55.2	Low
20200810	2	286.4550	40.5803	53.2	Low	59.6	Moderate
20200811	2	286.4550	40.5803	59.7	Moderate	66.9	Moderate
20200812	2	286.4550	40.5803	-99.9	NA	-99.9	NA
20200806	3	286.7190	40.6181	-99.9	NA	-99.9	NA
20200807	3	286.7190	40.6181	57.1	Low	63.2	Moderate
20200808	3	286.7190	40.6181	56.7	Low	62.0	Moderate
20200809	3	286.7190	40.6181	50.8	Low	52.6	Low
20200810	3	286.7190	40.6181	51.5	Low	59.3	Moderate
20200811	3	286.7190	40.6181	60.2	Moderate	65.8	Moderate
20200812	3	286.7190	40.6181	-99.9	NA	-99.9	NA
20200806	4	286.8450	40.6406	-99.9	NA	-99.9	NA
20200807	4	286.8450	40.6406	59.7	Moderate	66.5	Moderate
20200808	4	286.8450	40.6406	59.8	Moderate	64.7	Moderate
20200809	4	286.8450	40.6406	53.9	Low	55.9	Low
20200810	4	286.8450	40.6406	53.6	Low	62.4	Moderate
20200811	4	286.8450	40.6406	61.1	Moderate	66.0	Moderate
20200812	4	286.8450	40.6406	-99.9	NA	-99.9	NA
20200806	5	287.1400	40.7301	-99.9	NA	-99.9	NA
20200807	5	287.1400	40.7301	62.7	Moderate	67.5	Moderate
20200808	5	287.1400	40.7301	63.5	Moderate	67.6	Moderate
20200809	5	287.1400	40.7301	57.9	Moderate	59.8	Moderate
20200810	5	287.1400	40.7301	55.2	Low	60.1	Moderate
20200811	5	287.1400	40.7301	62.0	Moderate	65.9	Moderate
20200812	5	287.1400	40.7301	-99.9	NA	-99.9	NA
20200806	6	287.8090	40.9406	-99.9	NA	-99.9	NA
20200807	6	287.8090	40.9406	62.8	Moderate	66.4	Moderate
20200808	6	287.8090	40.9406	62.9	Moderate	66.6	Moderate
20200809	6	287.8090	40.9406	57.2	Low	60.5	Moderate
20200810	6	287.8090	40.9406	52.3	Low	54.6	Low
20200811	6	287.8090	40.9406	58.5	Moderate	61.9	Moderate
20200812	6	287.8090	40.9406	-99.9	NA	-99.9	NA
20200806	7	287.9920	41.0042	-99.9	NA	-99.9	NA
20200807	7	287.9920	41.0042	60.7	Moderate	65.4	Moderate
20200808	7	287.9920	41.0042	61.8	Moderate	65.0	Moderate
20200809	7	287.9920	41.0042	55.4	Low	59.2	Moderate
20200810	7	287.9920	41.0042	51.8	Low	54.6	Low
20200811	7	287.9920	41.0042	58.6	Moderate	61.6	Moderate
20200812	7	287.9920	41.0042	-99.9	NA	-99.9	NA

* Available to NOAA employees since August 2, 2020

Real-time RCMOS forecast guidance for WFO OKX (https://rcmos.mdl.nws.noaa.gov/downloads/OKX/)

YYYYMMDD	Beach#	Longitude	Latitude	AvgProb(%)	AvgRisk	MaxProb(%)	MaxRisk
20200806	1	286.3430	40.5798	-99.9	NA	-99.9	NA
20200807	1	286.3430	40.5798	50.5	Low	56.6	Low
20200808	1	286.3430	40.5798	49.2	Low	54.5	Low
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20200807	4	286.8450	40.6406	59.7	Moderate	66.5	Moderate
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20200807	5	287.1400	40.7301	62.7	Moderate	67.5	Moderate
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20200812	5	287.1400	40.7301	-99.9	NA	-99.9	NA
20200806	6	287.8090	40.9406	-99.9	NA	-99.9	NA
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20200809	7	287.9920	41.0042	55.4	Low	59.2	Moderate
20200810	7	287.9920	41.0042	51.8	Low	54.6	Low
20200811	7	287.9920	41.0042	58.6	Moderate	61.6	Moderate
20200812	7	287.9920	41.0042	-99.9	NA	-99.9	NA

Daily Forecast Guidance

- **Latitude/Longitude is the NWPS point closest to the beach obs point.**
- **If a day (e.g., 20200806) doesn't have all 24 hour forecasts available (0-23 UTC), I put -99.9 for Prob(%) and NA for Risk.**
- **Beach ID#:**
  - **#1 is Long Beach**
  - **#2 is Jones Beach**
  - **#3 is Robert Moses State Park**
  - **#4 is Ocean Beach**
  - **#5 is Smiths Point**
  - **#6 is East Hampton Main Beach**
  - **#7 is Hither Hills State Park**

Part 1 Summary

❖ MDL Goal:

Assist **NWS WFO forecasters** with providing reliable RC model forecast guidance in a timely manner to **save more lives together,** by cooperating with beach lifeguards, WFO forecasters/warning coordination meteorologists, NCEP NWPS model developers, NOS researchers, AFSO decision supporters, etc.

❖ MDL Progress Status for WFO OKX:

1. The OKX RCMOS equation and probability thresholds were developed using one year (**2019**) of training data, and the verification scores showed huge improvements over the NWPS RC PP model.
2. "Experimental" **real-time** hourly and daily RCMOS forecast guidance is available to NOAA employees at **https://rcmos.mdl.nws.noaa.gov/downloads/OKX/ during the summer (May 1 – October 31)**.
3. The RCMOS verification scores of RD and BSS computed for **2020 and 2021** showed similar improvements over the operational NWPS RC forecasts.
4. Started analyzing 3 years of training data obtained for 2019-2021.

Part 2
Using 3 Years of Training Data (2019-2021)

Statistical justification of NWPS predictors at OKX

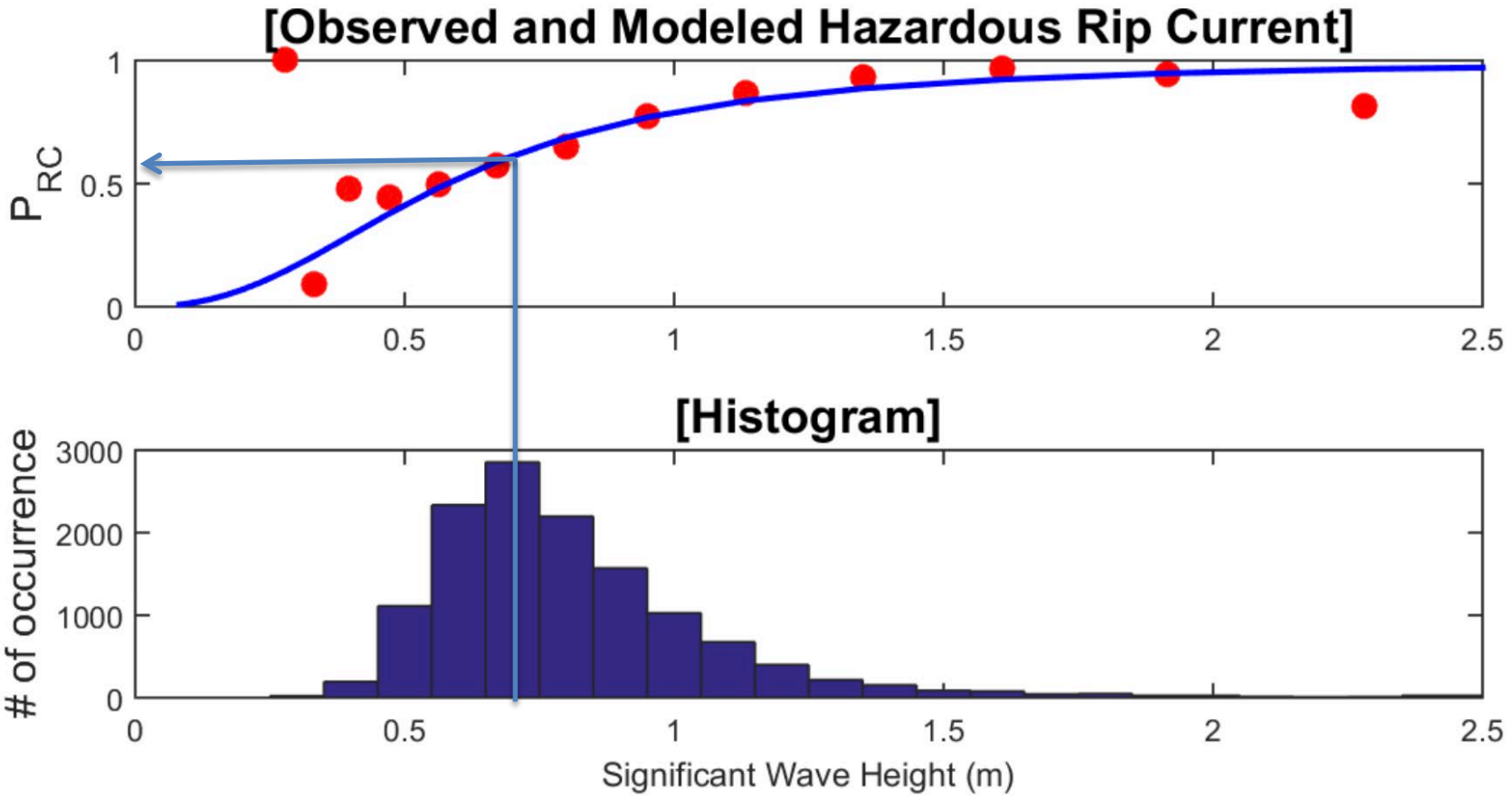
- Only Hs (significant wave height) was a useful predictor among all five NWPS predictors currently available.
- Quite different than the operational equation developed at KDH, NC.

- The following slides are to show simple and **intuitive** relationships between RC and Hs.

Yearly variations

All 7 beaches
RC <-> Hs for 3 years (2019-2021)

cc=0.28886 p=4.2589e-251



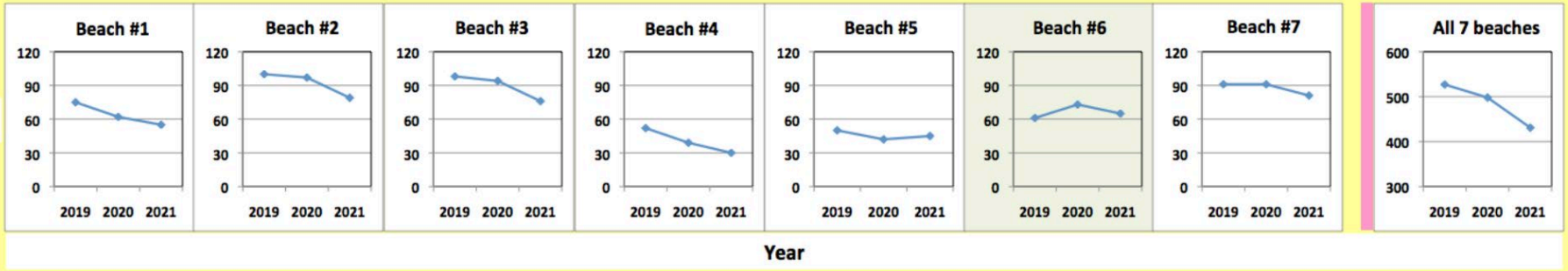
*Yearly variations were very small !!!

Spatial variations

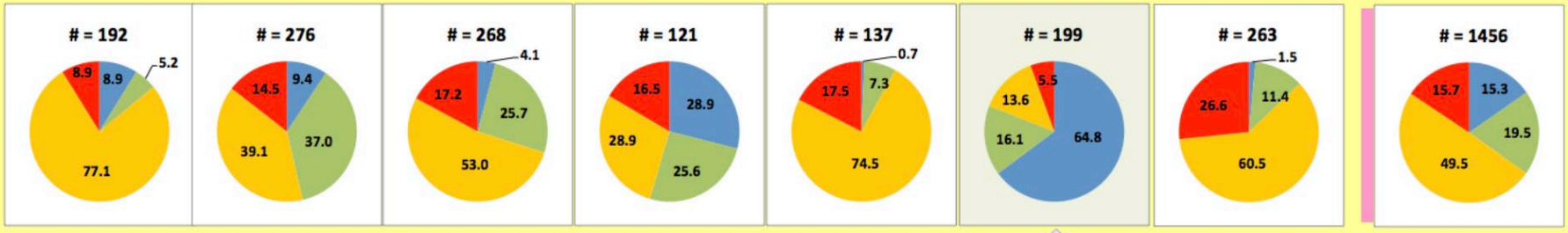
Obs data analysis using 3-year archive

7 Beaches, NY, WFO OKX
May 26 - Sep 28, 2019
May 26 - Sep 26, 2020
May 28 - Sep 18, 2021
1:Long, 2: Jones, 3:Robert Moses, 4:Ocean, 5:Smiths Point, 6:East Hampton Main, 7:Hither Hills

Total Number (#) of RC Obs (Strength 0, 1, 2, & 3) 2019 ---> 2021



RC Strength Obs (%) in 2019-2021

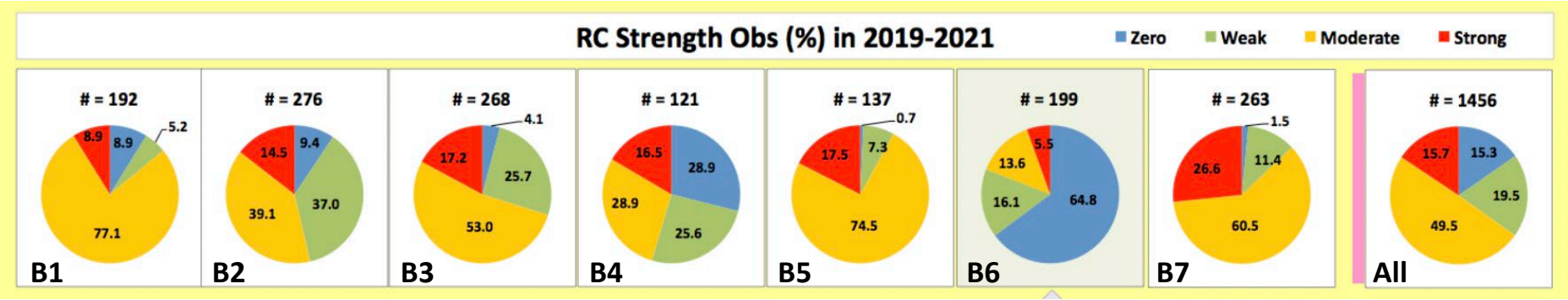


Obs by Mr. Minardi

Non-RCs (+weak) are really Rare at B1,B3,B5,& B7???

RC <-> Hs at each beach

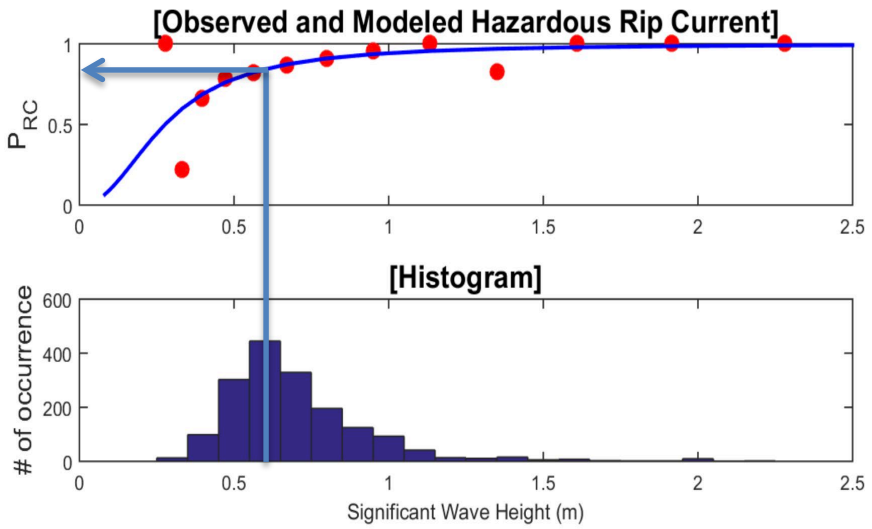
for 3 years (2019-2021)



Beach #1

RF=0.86

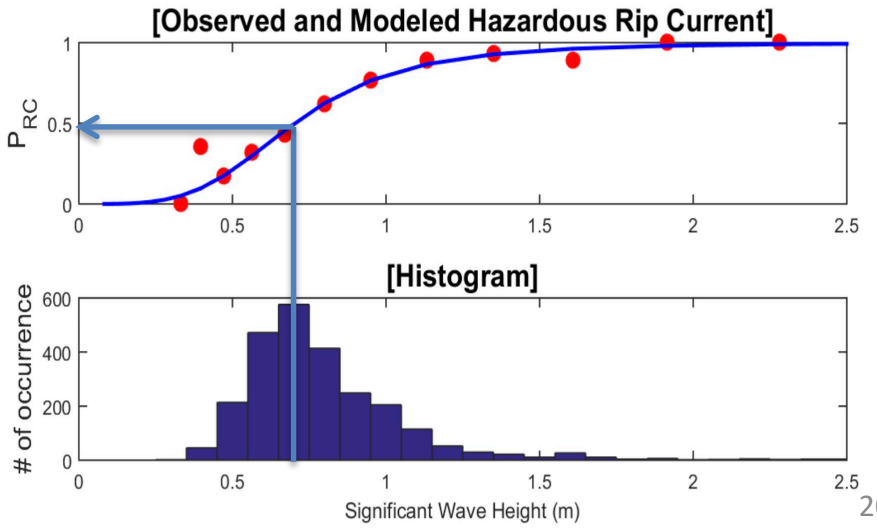
cc=0.2052 p=8.292e-18



Beach #2

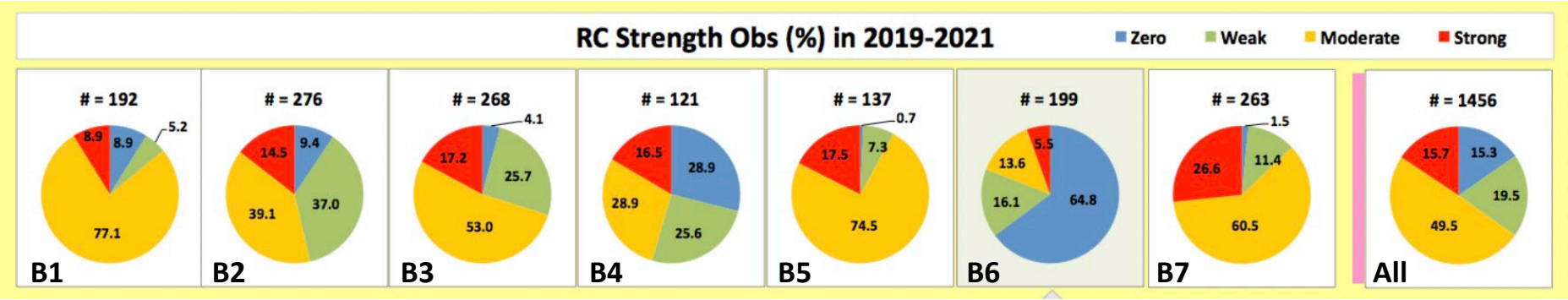
RF=0.56

cc=0.43269 p=1.7763e-113



RC <-> Hs at each beach

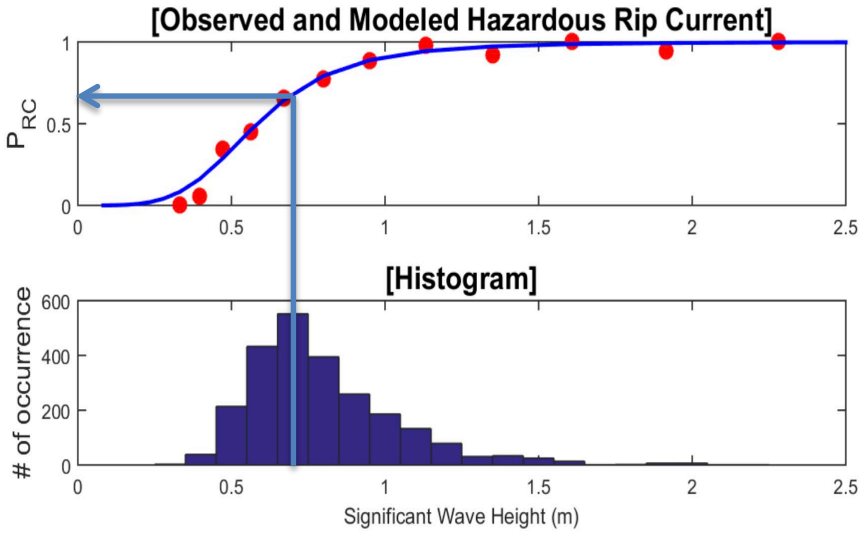
for 3 years (2019-2021)



Beach #3

RF=0.71

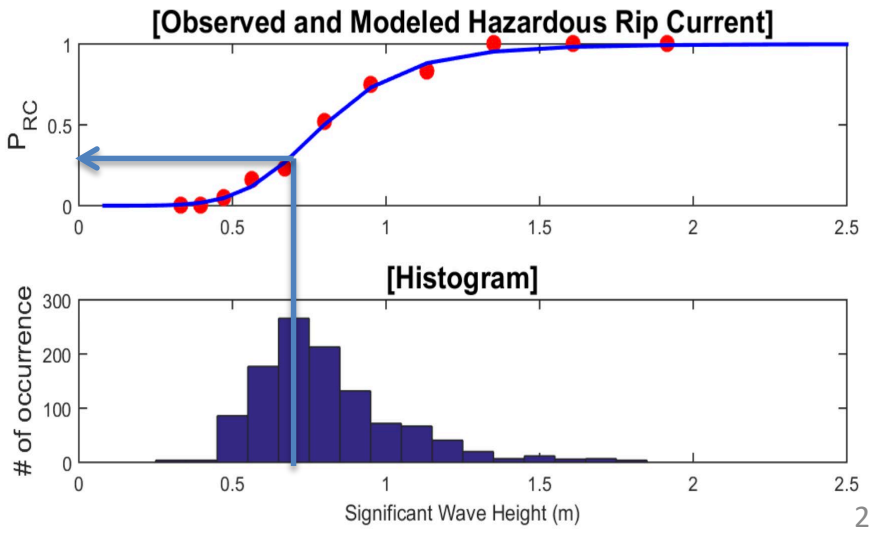
cc=0.4254 p=8.5948e-107



Beach #4

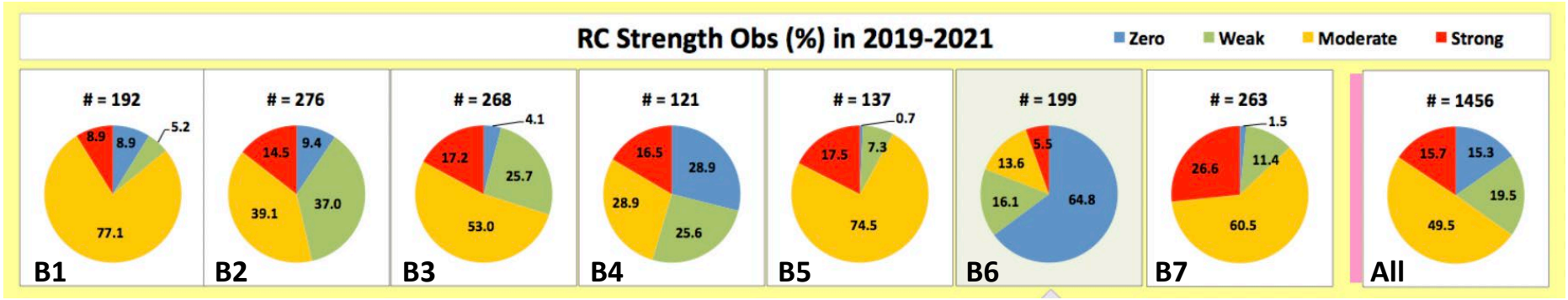
RF=0.46

cc=0.54933 p=3.886e-89



RC <-> Hs at each beach

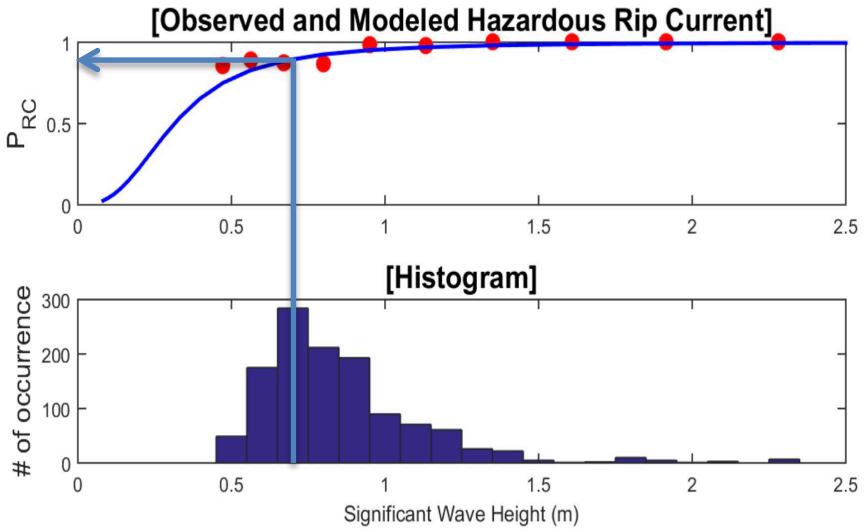
for 3 years (2019-2021)



Beach #5

RF=0.92

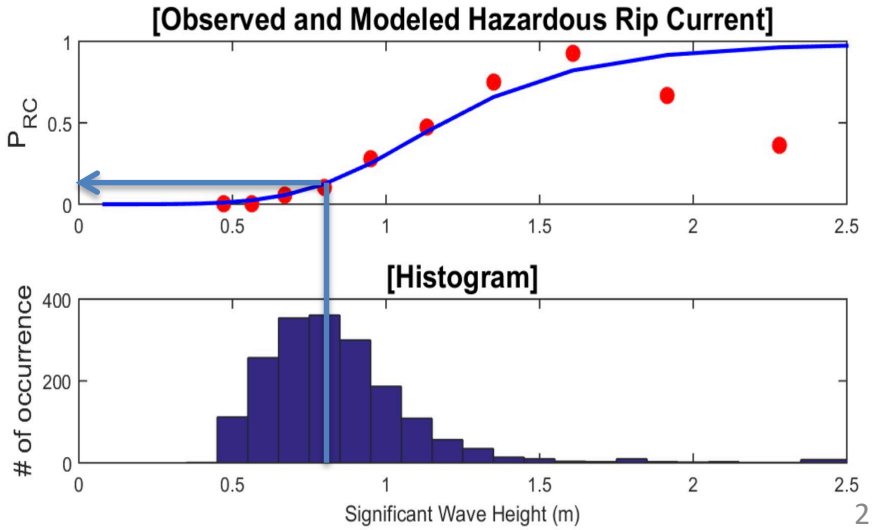
cc=0.14334 p=5.1299e-07



Beach #6

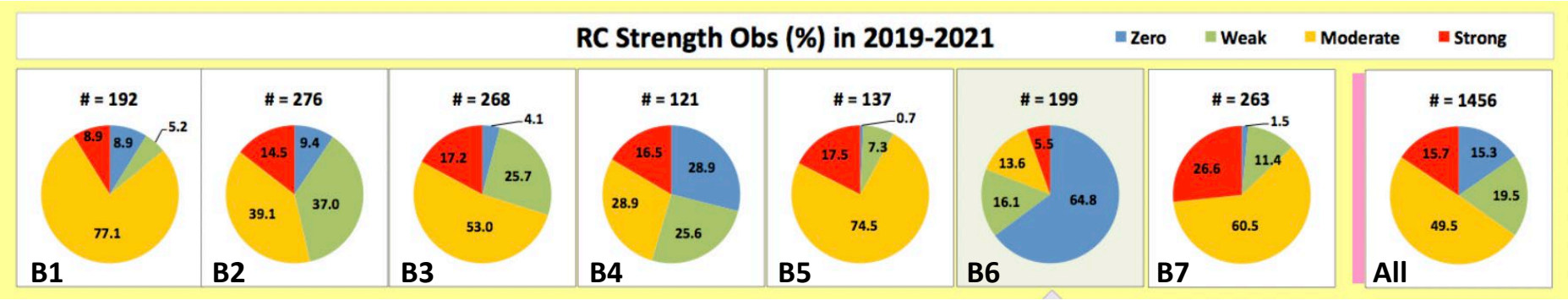
RF=0.19

cc=0.46819 p=1.8772e-100



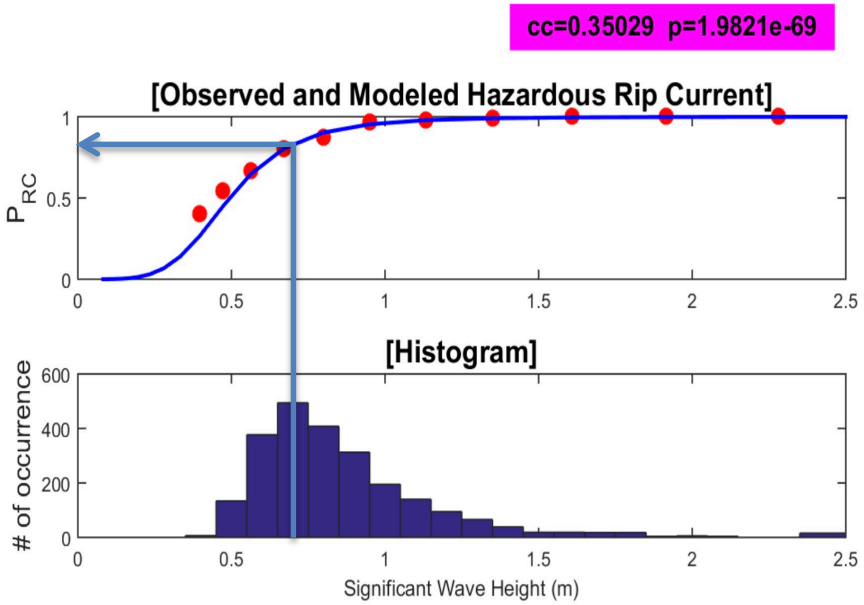
RC <-> Hs at each beach

for 3 years (2019-2021)



Beach #7

RF=0.86



Overall….

⇒ Shows AI/ML's strengths and/or weaknesses (Just **fits to obs (truth)**)

⇒ So obs quality/climatology are very important in any AI/ML!!

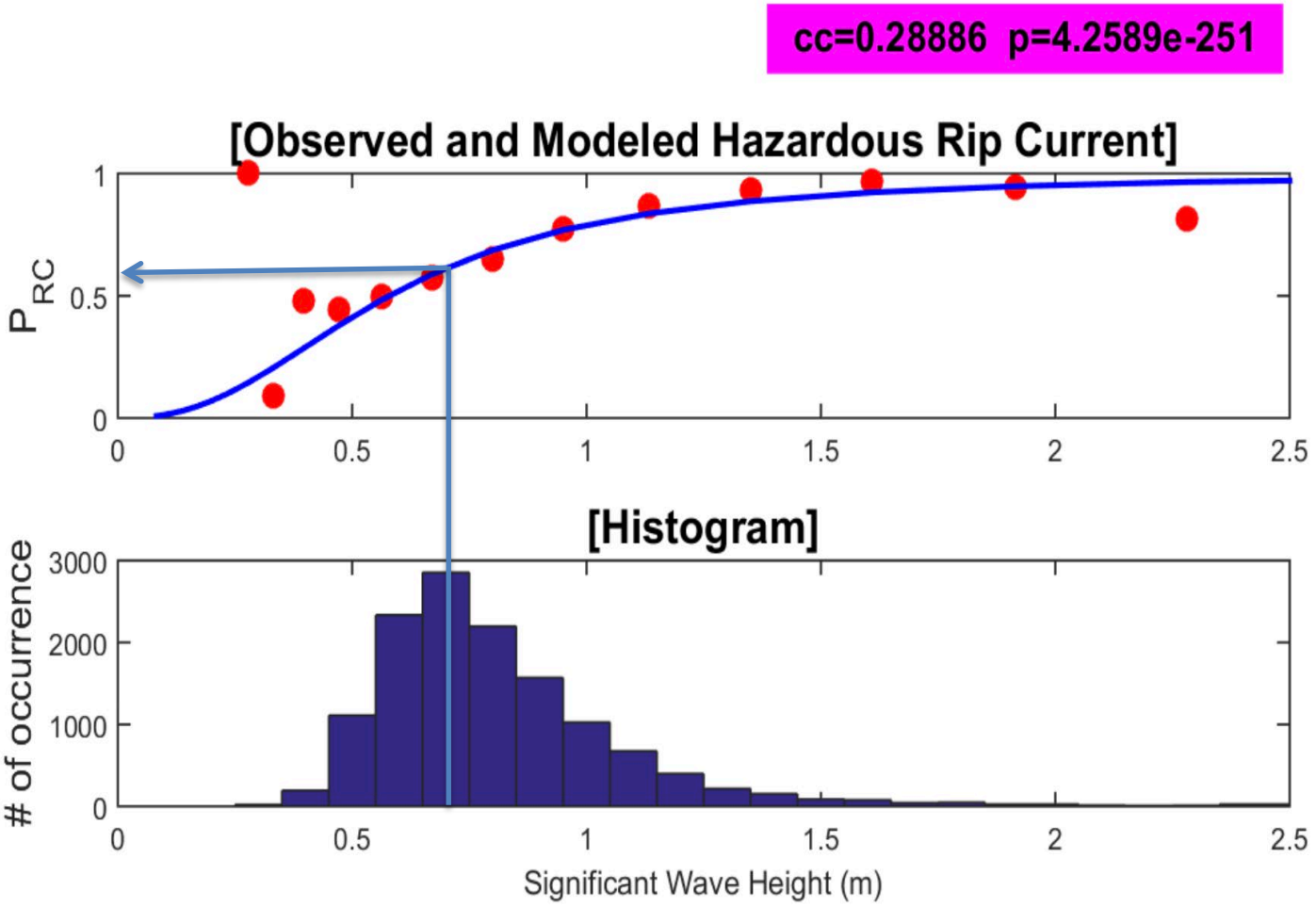
⇒ Non-RCs (+Weak) are really rare events at B#1, B#3, B#5, & B#7?

⇒ It is well-known that every beach has its own unique kind of RC…

⇒ If this OKX RC climatology at each beach is correct, we will be able to develop **beach specific RCMOS**.

RC <-> Hs at all 7 beaches for 3 years

Data from all 7 beaches was combined to have
enough # of "non-RC cases" as well as "RC cases"



Discussion

- I believe that improving obs data quality is the most important **first step** for improving forecast products. **Obs data are used** for **RC model development** (**predictand**) as well as **verification** (**truth**). Currently we are using **lifeguard obs** data which is an extremely valuable resource (thanks to their **service and sacrifices!!)**, but

  sometimes
  - obs **time** is questionable (i.e., reporting time instead) probably due to our portlet setup not being user-friendly for reporters
  - obs **location** (latitude/longitude) is not precise, or even specified
  - too many days are **missing** especially during warmer months probably due to more distractions
  - it seems that obs data are **omitted** more on days without RC than with RC, and

  always
  - data are available only once or twice a day at most.
- **Lifeguard** (i.e., **local beach expert**) **obs** data will be **a critical tool** for QC and calibrating automated continuous obs data such as **WebCam, drones**, **satellite/aerial imagery,** etc.

- **Predictors:** In addition to the predictors from the NWPS model, we need to investigate and add more physically meaningful **predictors to the MDL RCMOS model**.

RC Obs Standards (Requirements!) to Emphasize to Lifeguards

which will significantly improve the RC forecast model

- **Obs Time (hr):**
  When the rip/no-rip condition was seen <u>within ~1 hour</u> (even if reported later).

- **Obs Location (lat/lon):**
  If lat/lon coordinates aren't available, then a mention of a landmark or nearby street would help.

- **RC Strength (0, 1, 2, 3):**
  "No rip" conditions should be reported.

- **No Missing day:**
  Report every day, even on days with no rips.

Additional Requests if possible…

- **Duration (e.g., persistent, transient, etc.)**
- **Where (e.g., near structures such as piers/groins, open ocean, etc.)**
- **Coincident with "obliquely incident waves?"**

Why?

- I found a strong correlation between RC and **obliquely incident waves (i.e., southwesterly)** at some beaches **over Long Island.**

- **Physical justifications** based on literature reviews:
  - Highly oblique waves (wave-driven forcing) can drive a longshore current causing a dominant feeder current, then offshore-flowing RC...
  - Shear instability rips can occur on alongshore-uniform beaches when exposed to highly obliquely incident ocean swells...

Concluding Remarks

To improve any **"forecast"** model (i.e., traditional statistical model, deep machine learning model, etc.), the most necessary requirements are:

- **Enough quality training data**
  - **1) Obs data as predictand**
  - **2) Numerical Weather Prediction (NWP) model outputs as predictors**
- **Periodic upgrades**

Acknowledgements

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Thank You!!

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Supplementary slide

Verification Matrix

- Brier Score: Mean squared error between predicted probabilities and the observed values (0/1).
- **Brier Skill Score**
  - Over the reference sample climatology (RF):
    % improvement over climate
  - Over the reference model:
    % improvement over the reference model
- **Reliability Diagram:**

  A graph of the observed RF (Y-axis) plotted against the forecast probability (X-axis).