Rip Current Model Output Statistics (RCMOS) Modeling
for Real-Time Probabilistic and Deterministic Forecasts

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Paper 8.1 Wednesday, 13 January 2021, 1:10pm-1:15pm
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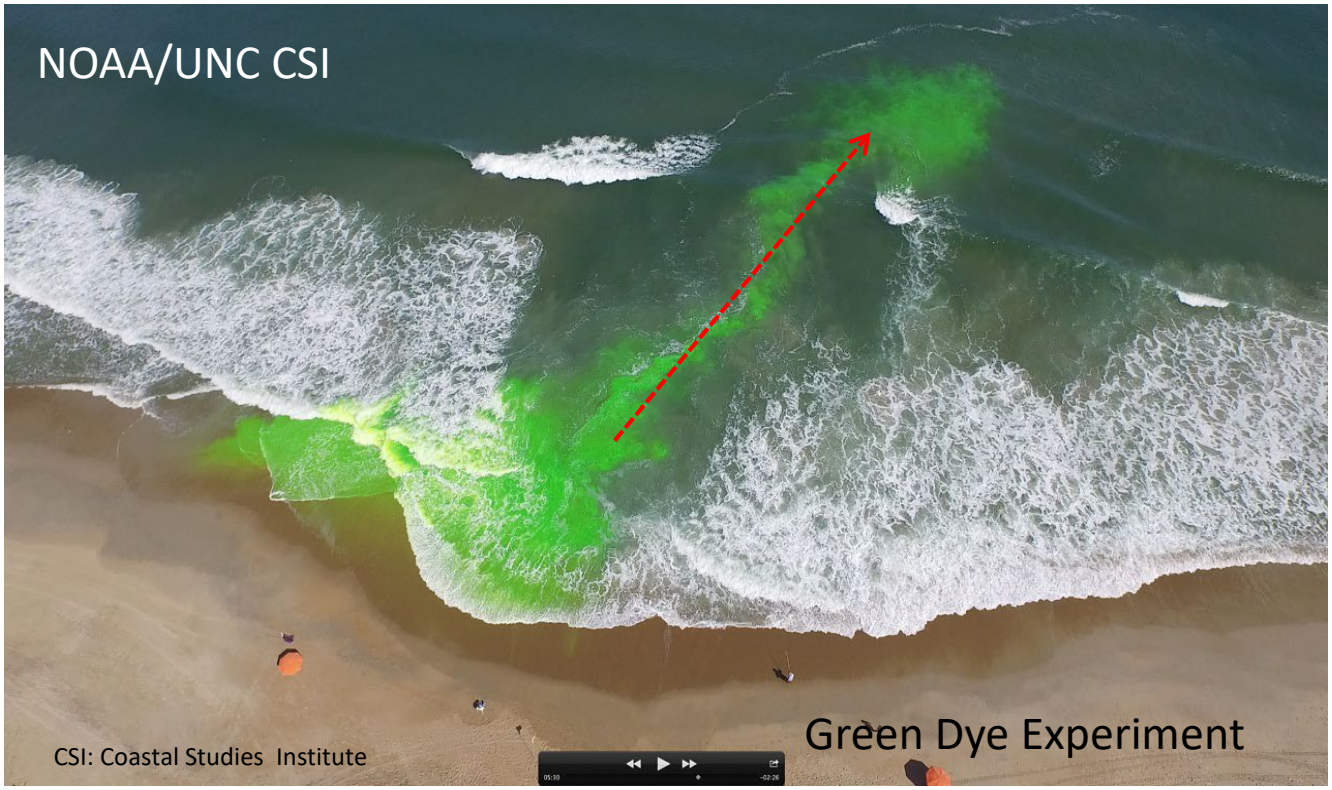
101st AMS Annual Meeting

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:**
  - Scheduled to be implemented into **NWS operations** as a component of the **NCEP's Nearshore Wave Prediction System (NWPS)**.
  - 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.
- **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 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).

*1PP 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.

*2MOS 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 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 quality training data were available.

Benefits of the RCMOS model

- **Current 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**

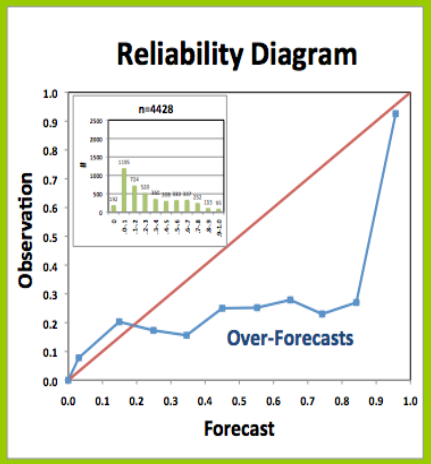
(as forecast by NWPS)

RCMOS for WFO CHS (Charleston, SC)

Perfect Prog Model

RCMOS Improvement

RCMOS Model

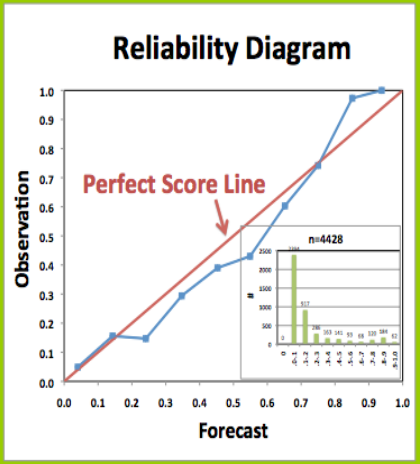


Brier Skill Score

$BS_{NCEPforecast}$ = 0.180
$BS_{SampleClimate}$ = 0.150
$BSS_{NCEPoverClim}$ = -0.193

Physical meaning:
PPM RC forecasts don't make improvements over the sample climate. 19.3% decline.

Jun 19 - Oct 20
2019
5 beaches
SC & GA



Brier Skill Score

$BS_{MDLforecast}$ = 0.092
$BS_{SampleClimate}$ = 0.150
$BSS_{MDLoverClim}$ = 0.386

Physical meaning:
RCMOS forecasts made 38.6 % improvement over the sample climate.

RCMOS forecast guidance made

- **Significant improvements in the Reliability Diagram (i.e., much closer to the perfect score line)**
- **48.9% improvements over the PP model in Brier Skill Score**

RCMOS for WFO CHS (Charleston, SC)

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

- Found optimum threshold probability values iteratively which **maximize equitable threat scores* within an allowable bias range (1+/-0.1)**

P=0.437 for moderate risk

P=0.795 for high risk

*Note1: For most other WFOs, the verification matrices of **"correct rate"** and **"equitable threat score"** were used to find threshold probabilities for **moderate** and **high** risk forecasts, respectively. But RC occurrences at the beaches in WFO CHS were very rare, so "**equitable threat score"** was used for moderate as well.

*Note2: 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 CHS (https://rcmos.mdl.nws.noaa.gov/downloads/CHS/)*

Upon CHS 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
20200826.0000	280.2160	32.7791	62.9	Moderate
20200826.0100	280.2160	32.7791	60.5	Moderate
20200826.0200	280.2160	32.7791	57.8	Moderate
20200826.0300	280.2160	32.7791	55.1	Moderate
20200826.0400	280.2160	32.7791	52.7	Moderate
20200826.0500	280.2160	32.7791	50.4	Moderate
20200826.0600	280.2160	32.7791	48.2	Moderate
20200826.0700	280.2160	32.7791	46.0	Moderate
20200826.0800	280.2160	32.7791	43.7	Moderate
20200826.0900	280.2160	32.7791	41.2	Low
20200826.1000	280.2160	32.7791	38.5	Low
20200826.1100	280.2160	32.7791	35.5	Low
20200826.1200	280.2160	32.7791	32.6	Low
20200826.1300	280.2160	32.7791	29.8	Low
20200826.1400	280.2160	32.7791	27.4	Low
20200826.1500	280.2160	32.7791	25.5	Low
20200826.1600	280.2160	32.7791	23.9	Low
20200826.1700	280.2160	32.7791	22.8	Low
.				
.				
20200831.2200	279.1590	32.0086	2.7	Low
20200831.2300	279.1590	32.0086	3.0	Low
20200901.0000	279.1590	32.0086	3.1	Low

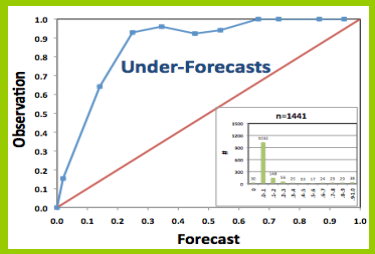
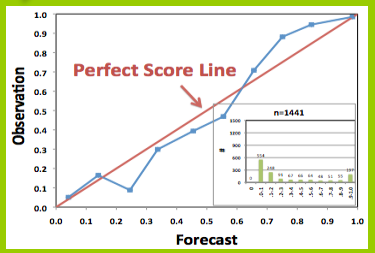
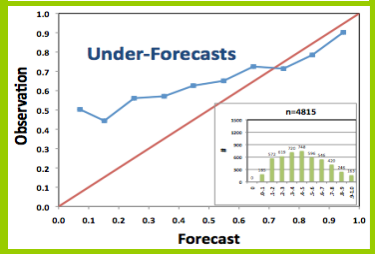
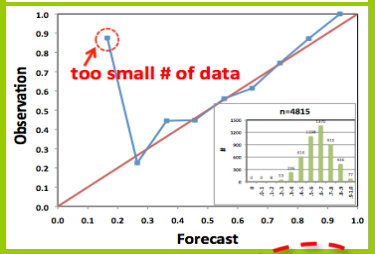
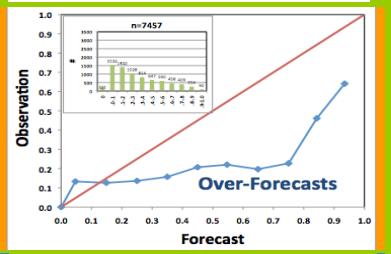
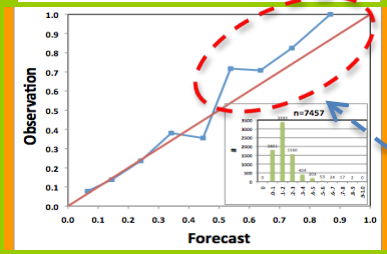
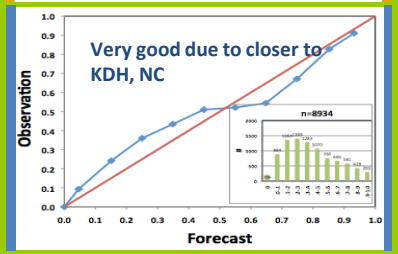
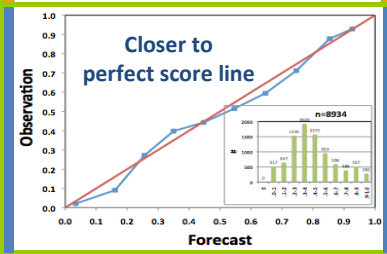
YYYYMMDD	Beach#	Longitude	Latitude	AvgProb(%)	AvgRisk	MaxProb(%)	MaxRisk
20200826	1	280.2160	32.7791	36.2	Low	62.9	Moderate
20200827	1	280.2160	32.7791	10.1	Low	14.7	Low
20200828	1	280.2160	32.7791	14.0	Low	18.1	Low
20200829	1	280.2160	32.7791	23.2	Low	30.6	Low
20200830	1	280.2160	32.7791	11.8	Low	28.3	Low
20200831	1	280.2160	32.7791	3.8	Low	6.9	Low
20200901	1	280.2160	32.7791	-99.9	NA	-99.9	NA
20200826	2	280.0450	32.6389	38.6	Low	65.9	Moderate
20200827	2	280.0450	32.6389	10.6	Low	16.1	Low
20200828	2	280.0450	32.6389	15.2	Low	19.1	Low
20200829	2	280.0450	32.6389	25.2	Low	31.5	Low
20200830	2	280.0450	32.6389	13.4	Low	28.8	Low
20200831	2	280.0450	32.6389	3.9	Low	6.0	Low
20200901	2	280.0450	32.6389	-99.9	NA	-99.9	NA
20200826	3	279.8800	32.5832	31.6	Low	55.9	Moderate
20200827	3	279.8800	32.5832	8.5	Low	12.1	Low
20200828	3	279.8800	32.5832	12.7	Low	16.1	Low
20200829	3	279.8800	32.5832	19.9	Low	24.0	Low
20200830	3	279.8800	32.5832	9.7	Low	22.3	Low
20200831	3	279.8800	32.5832	3.2	Low	4.9	Low
20200901	3	279.8800	32.5832	-99.9	NA	-99.9	NA
20200826	4	279.2530	32.1372	28.1	Low	44.3	Moderate
20200827	4	279.2530	32.1372	7.3	Low	11.7	Low
20200828	4	279.2530	32.1372	8.0	Low	12.1	Low
20200829	4	279.2530	32.1372	10.4	Low	14.7	Low
20200830	4	279.2530	32.1372	4.6	Low	10.3	Low
20200831	4	279.2530	32.1372	1.6	Low	2.3	Low
20200901	4	279.2530	32.1372	-99.9	NA	-99.9	NA
20200826	5	279.1590	32.0086	30.5	Low	49.1	Moderate
20200827	5	279.1590	32.0086	7.7	Low	12.4	Low
20200828	5	279.1590	32.0086	7.9	Low	10.7	Low
20200829	5	279.1590	32.0086	9.8	Low	13.9	Low
20200830	5	279.1590	32.0086	4.4	Low	8.1	Low
20200831	5	279.1590	32.0086	2.1	Low	3.0	Low
20200901	5	279.1590	32.0086	-99.9	NA	-99.9	NA

* Available to NOAA employees

RCMOS for WFO MOB,OKX,ILM

(Real-time forecast guidance at https://rcmos.mdl.nws.noaa.gov/downloads/)*

* Experimental and Available to NOAA employees

	PP Model	RCMOS Improvement	RCMOS Model	
Southern Region WFO MOB (Mobil/ Pensacola)		**Jun 18 - Oct 11 2019 Pensacola Beach, FL**		❖**BSS: 48.9 %** improvement over PP model ❖**Threshold P:** 0.466 for mod risk 0.829 for high risk
Northern Region WFO OKX (New York, NY)		**Jun 1 - Sep 28 2019 7 beaches, NY**		❖**BSS: 19.0 %** improvement over PP model ❖**Threshold P:** 0.577 for mod risk 0.798 for high risk
Eastern Region WFO ILM (Wilmington, NC)		**Jun 17 - Oct 29, 2019 Apr 23 - Jul 31, 2020 Southern 3 beaches facing ~south SC, NC**		❖**BSS: 30.9 %** improvement over PP model ❖**Threshold P:** 0.249 for mod risk 0.476 for high risk
		**Jun 17 - Oct 29, 2019 Apr 23 - Jul 31, 2020 Northern 3 beaches facing ~east NC**		❖**BSS: 4.8 %** improvement over PP model ❖**Threshold P:** 0.448 for mod risk 0.786 for high risk

RCMOS for WFO HGX

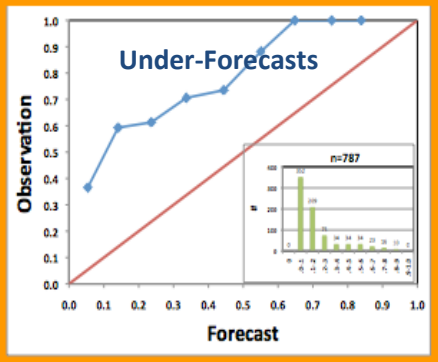
(Real-time forecast guidance at https://rcmos.mdl.nws.noaa.gov/downloads/HGX)*

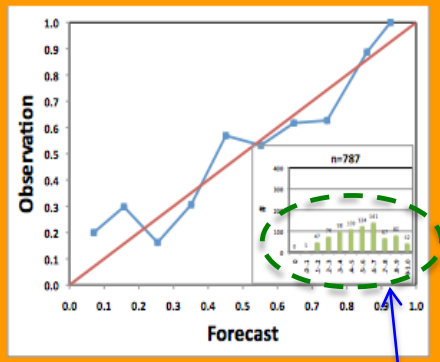
* Experimental and Available to NOAA employees

Southern Region
WFO HGX
Houston/ Galveston TX

PP Model	RCMOS Improvement	RCMOS Model

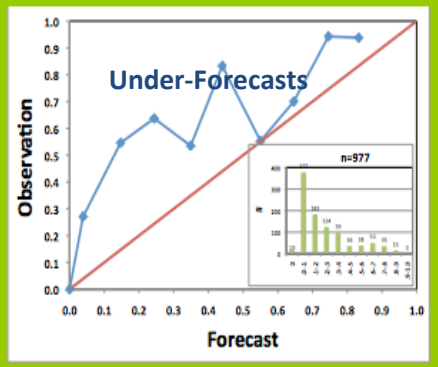
Warm Season

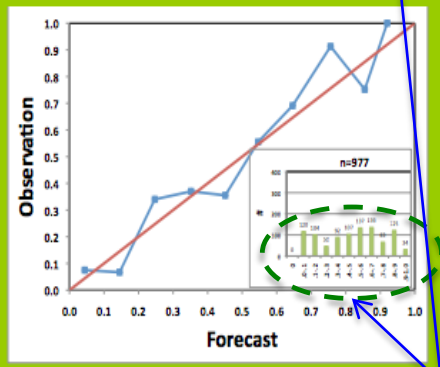




- ❖BSS: 40.3 % improvement over PP model
- ❖Threshold P:
  - 0.503 for mod risk
  - 0.787 for high risk

Cool Season





- ❖BSS: 38.7 % improvement over PP model
- ❖Threshold P:
  - 0.518 for mod risk
  - 0.876 for high risk

"Improved sharpness in addition to accuracy"

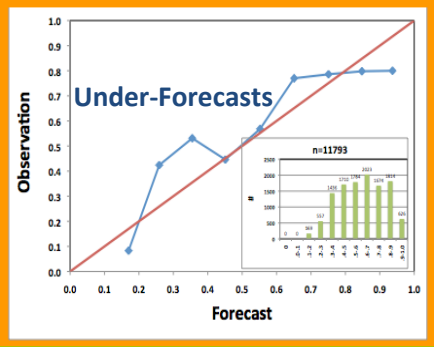
Galveston Beach, TX Jun 19, 2019 – Apr 28, 2020

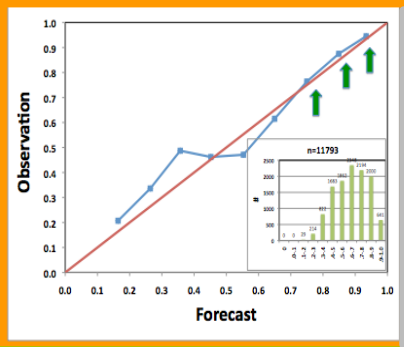
RCMOS for WFO SGX

Western Region
WFO SGX
San Diego
CA

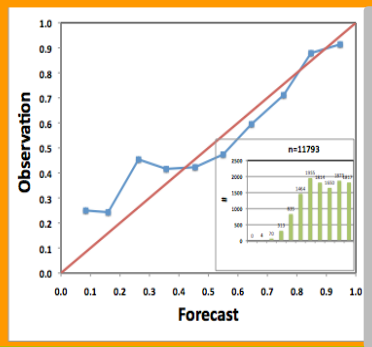
PP Model Logistic Regression	MOS Model Logistic Regression	MOS Model Naïve Bayesian Classifier

Warm Season



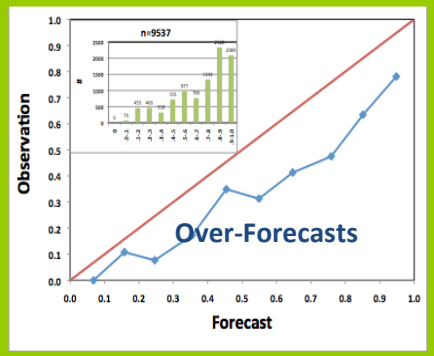


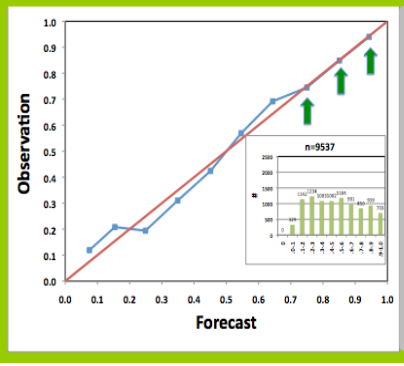
❖BSS: 5.2 % improve-ment over PP model



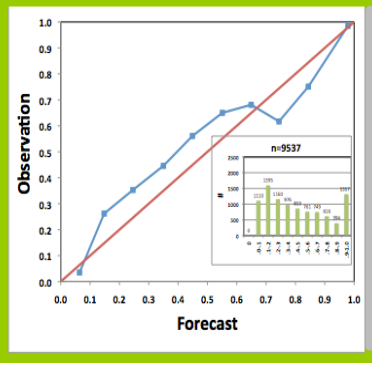
❖BSS: 8.5 % improve-ment over PP model

Cool Season





❖BSS: 24.1 % improve-ment over PP model



❖BSS: 25.7 % improve-ment over PP model

Mission Beach, CA May 2017 – September 2018

Summary

- Upon our **collaborative evaluation**, the **probabilistic RC forecast model (Perfect Prog model)** is now scheduled to be implemented into NWS operations.
- Concurrently, significant improvements over the Prefect Prog model were made by developing **regional and seasonal MOS models for probabilistic forecast guidance**, and corresponding optimum **threshold probabilities for deterministic risk forecast guidance**.
- "Experimental" **real-time** hourly and daily RCMOS forecast guidance is available to NOAA employees at https://rcmos.mdl.nws.noaa.gov/downloads/.

Discussion

- #1. **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, NCEP NWPS model developers, NOS researchers, AFSO decision support, etc.

- #2. 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, but

  sometimes
  - obs **time** is questionable (i.e., reporting time instead) probably due to the 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 warm 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.

- #3. 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**, etc., which MDL and NOS are now pursuing collaboratively.

Discussion

- #4. At present the **NWPS predictors** used in the RCMOS model as well as the PP model are only bulk-averaged wave parameters and tide water level, which is more applicable to predicting bathymetry-induced RCs.

- #5. MDL is now working collaboratively with NWPS developers to:
  - add **more predictors** such as wave partitions from wave spectrum, shear instabilities to predict hydrodynamic RCs, etc.
  - improve **quality** of mean wave direction from **shore-normal**
  - improve **quality** of previous wave event predicting **bathymetry changes** after strong storm events
  - get NWPS **retrospective run data** on time when upgrading the NWPS model

- #6. In addition to the predictors from the NWPS model, MDL and NOS are now collaboratively investigating the use of **satellite** or **aerial imagery** to identify rip channels or rip favorable bathymetry.

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

Special thanks to

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- **Casey Oswant, Noel Isla, Ivory Small, Brandt Maxwell, and Dan Gregoria (NWS San Diego, CA)**
- **Andre van der Westhuysen (NWS/NCEP/EMC)**
- **John Kuhn (NWS AFSO)**

Thank You!!

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