Using Evolutionary Programming to Generate Improved Tropical Cyclone Intensity Forecasts

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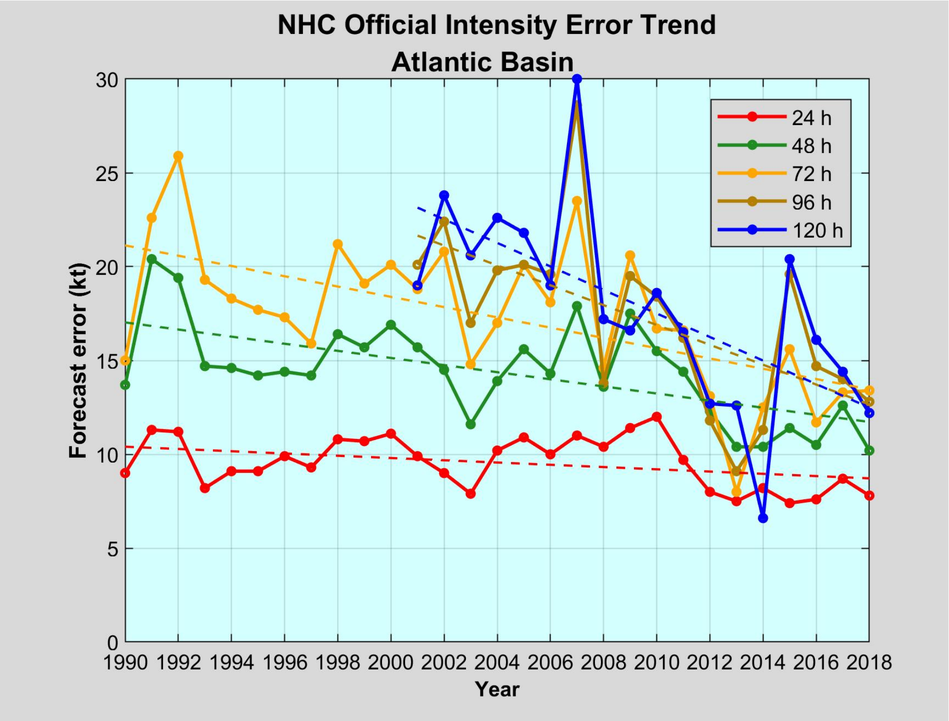
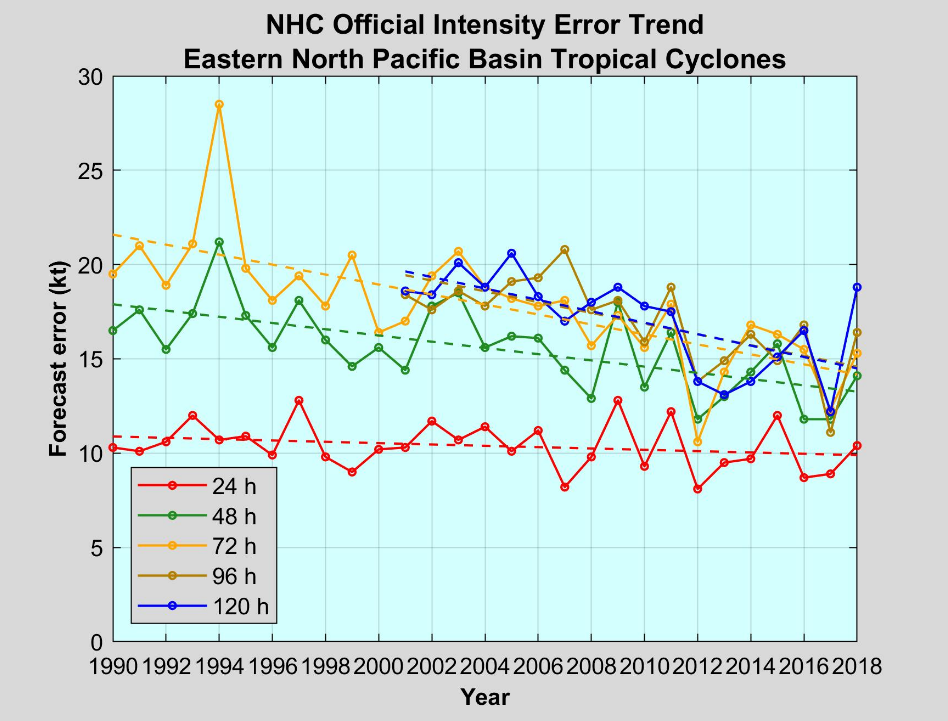
Image Credit: ESA/NASA-A. Gerst

Motivation





TC intensity forecasts have seen only slow improvements over the last 25 years (track errors have improved significantly)

Image Credit: NHC (https://www.nhc.noaa.gov/verification/verify5.shtml)

Our Approach Summarized

Using advanced machine learning approaches with 17 years of archived “large-scale” analysis data, we hypothesize that we can develop a statistical-dynamical model which can be used to provide alternative, competitive forecasts of TC intensity.

Limitations: no mesoscale structural details; errors in the large-scale environment (esp. at longer leads) will influence the model’s intensity forecasts

Model Structure

- Based on evolutionary programming form of machine learning
- Separate models for the North Atlantic and eastern/central North Pacific basins
- Produce deterministic TC intensity forecasts every 12 h out to 120 h and probabilistic forecasts for RI and RW at the standard operational RI thresholds

Data

- 2000-2016 SHIPS developmental data for all TCs, with variables converted to standard anomalies relative to their respective climatologies
- Split into training, validation, and independent test data (model later applied to real-time data from 2017-18 for verification and 2019 for real-time testing)

Prior history

Shear

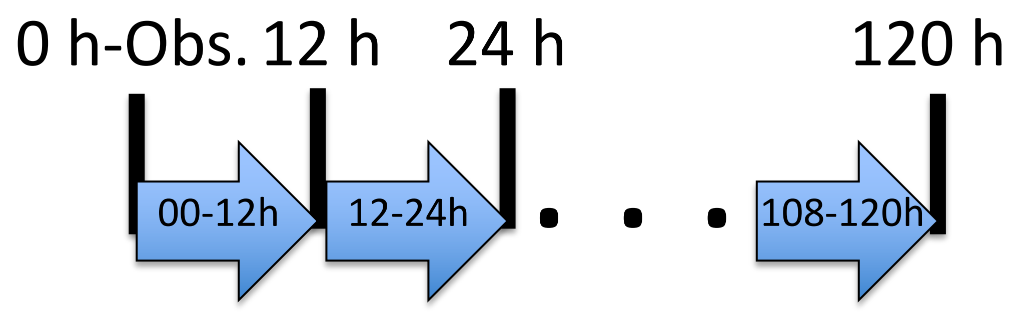
Moisture

DELV	Change in intensity over the prior 12 h
CD26	Climatological depth of the 26˚C isotherm from the 2005-2010 NCODA analysis
U20C	200 hPa zonal wind (r=0-500 km)
D200	200 hPa divergence (r=0-1000 km)
TWAC	0-600 km average symmetric tangential wind at 850 hPa from NCEP analysis
SHDC	850-200 hPa shear magnitude (kt *10) (200-800 km) with vortex removed and averaged from 0-500 km relative to 850 hPa vortex center
VMPI	Maximum potential intensity from Kerry Emanuel equation
CFLX	Dry air predictor based on the difference in surface moisture flux between air with the observed (GFS) RH value, and with RH of air mixed from 500 hPa to the surface.
CONS	Constant value of 10

Model Outline

- Calculate a 12-h adjustment to a persistence forecast using the chosen predictors derived from the forecast fields of the GFS, iterated out to 120 h.

- Perfect-prognostic approach with noise added to the analysis fields (to mimic observational uncertainty and forecast errors).



- Exception: over land (uses inland wind-decay model).

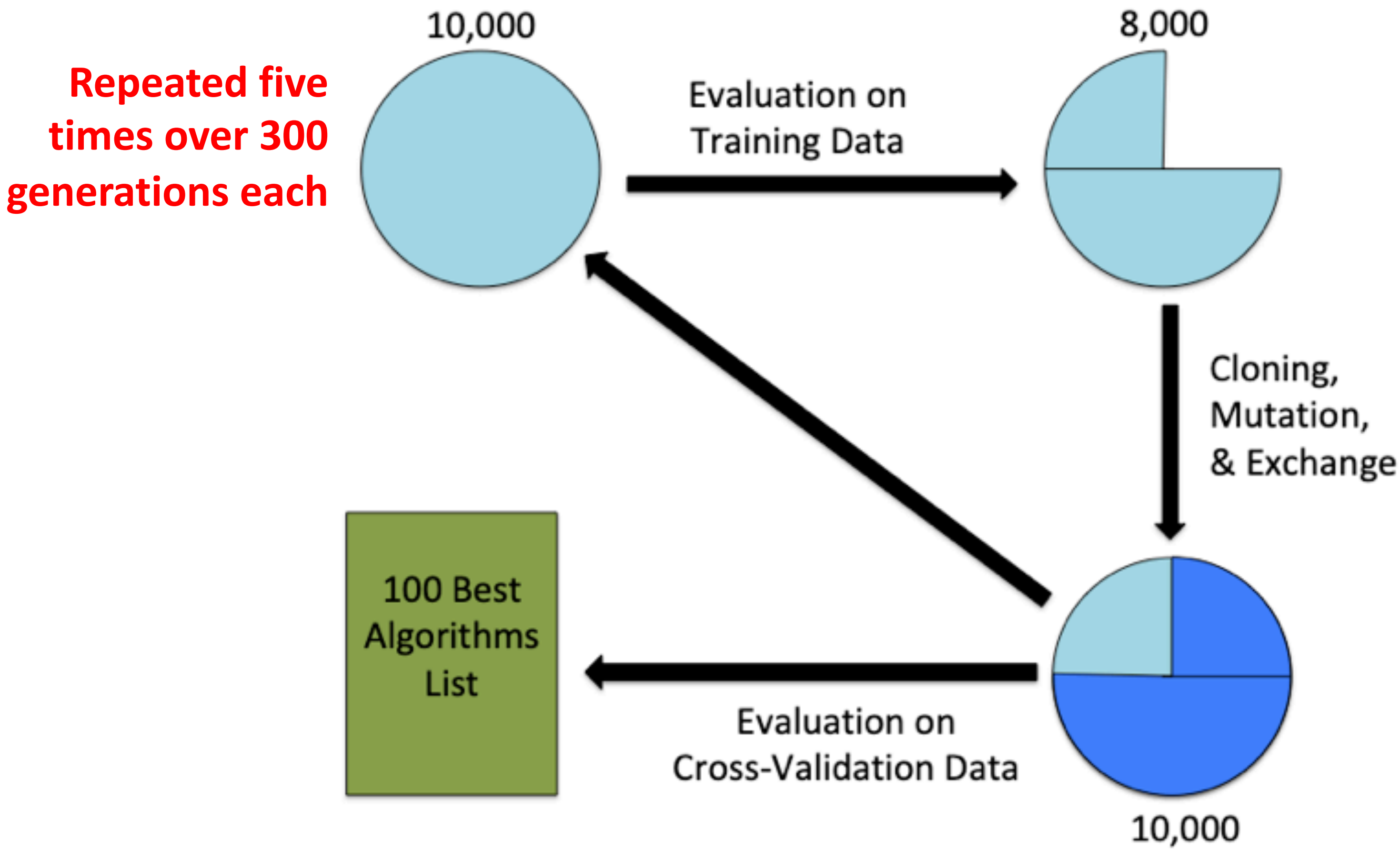
Algorithm Structure

Each algorithm has five IF-THEN statements that sum together to provide a 12-h intensity-change forecast.

1	IF	TWAC	>	VMPI	THEN	0.36679*CFLX	*	0.55976*TWAC	+	-0.03705*DELV
2	IF	CFLX	<=	DELV	THEN	0.16784*CFLX	*	0.83909*DELV	*	0.58132*TWAC
3	IF	SHDC	>	D200	THEN	-0.12243*VMPI	+	0.31332*TWAC	+	0.01871*CD26
4	IF	D200	<=	D200	THEN	-0.89092*TWAC	*	0.28928*TWAC	+	-0.1396*CFLX
5	IF	VMPI	<=	VMPI	THEN	0.6716*VMPI	+	-0.44336*VMPI	+	0.42004*DELV

Example algorithm from the Pacific model; weighting = 0.25, bias = -0.07.

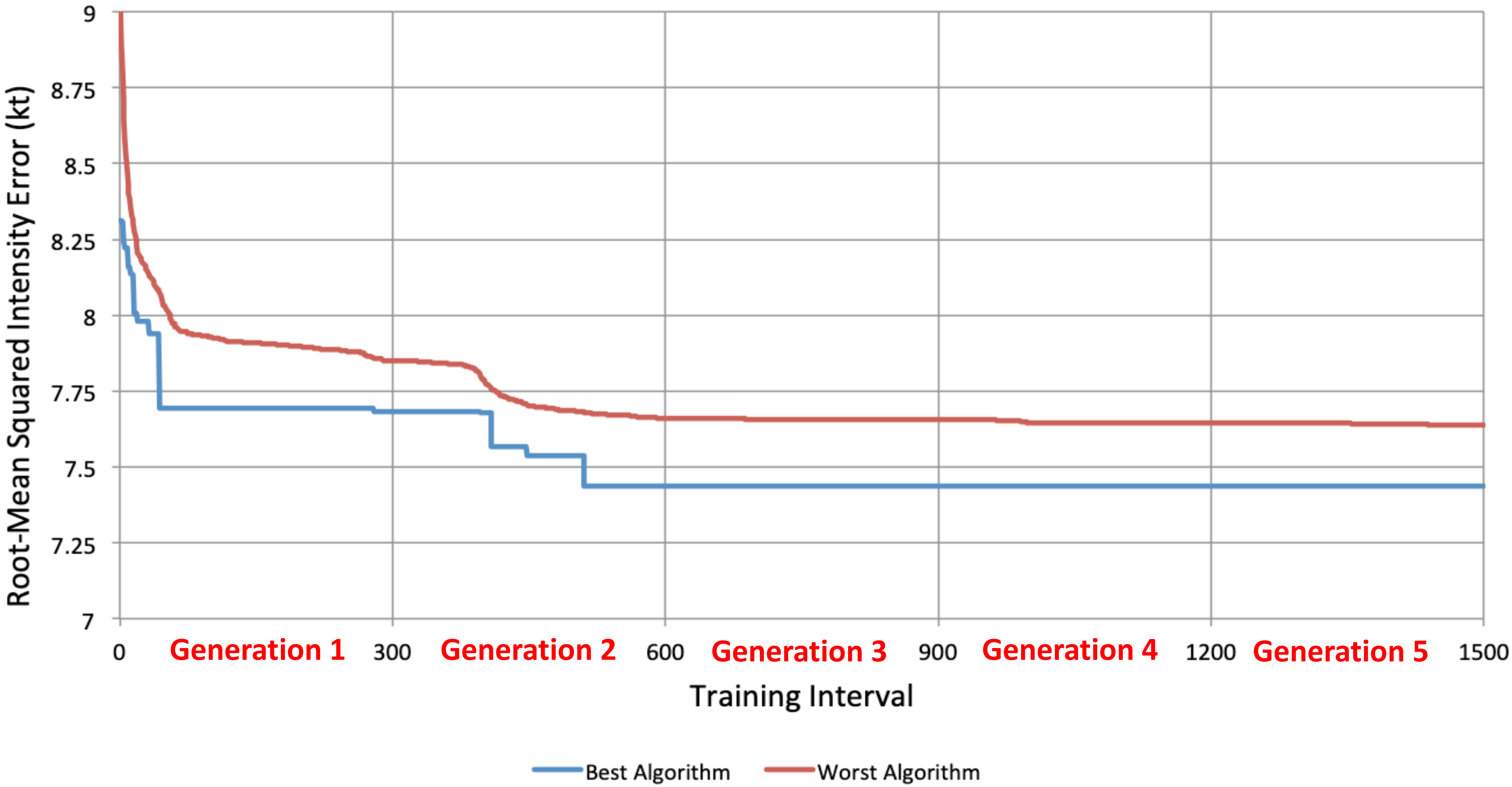
Model Development Procedure



At end of training:

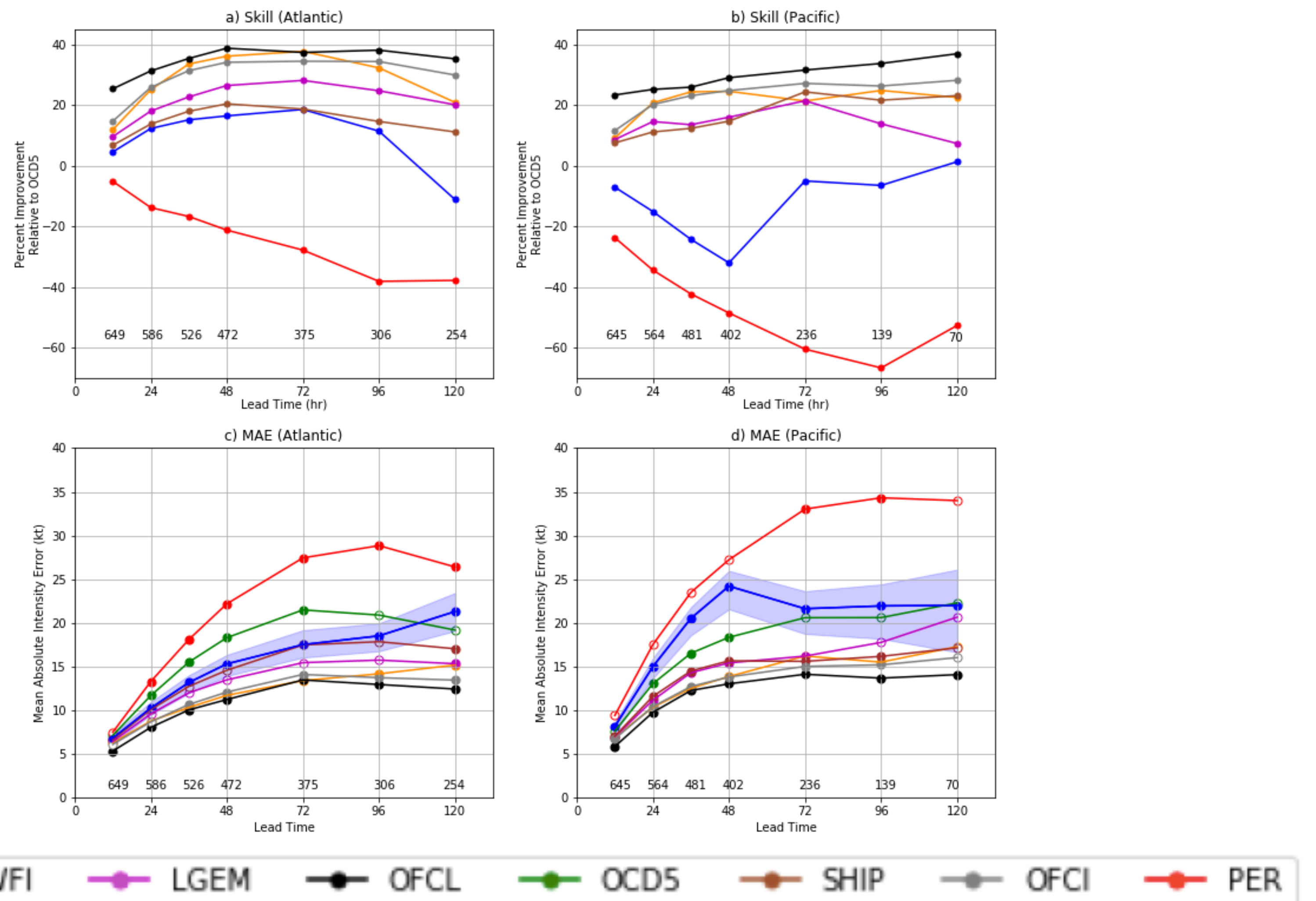
- bias correction
- use Bayesian Model Combination (weight multiple selected algorithms as an ensemble)

Training Progress (Pacific Example)



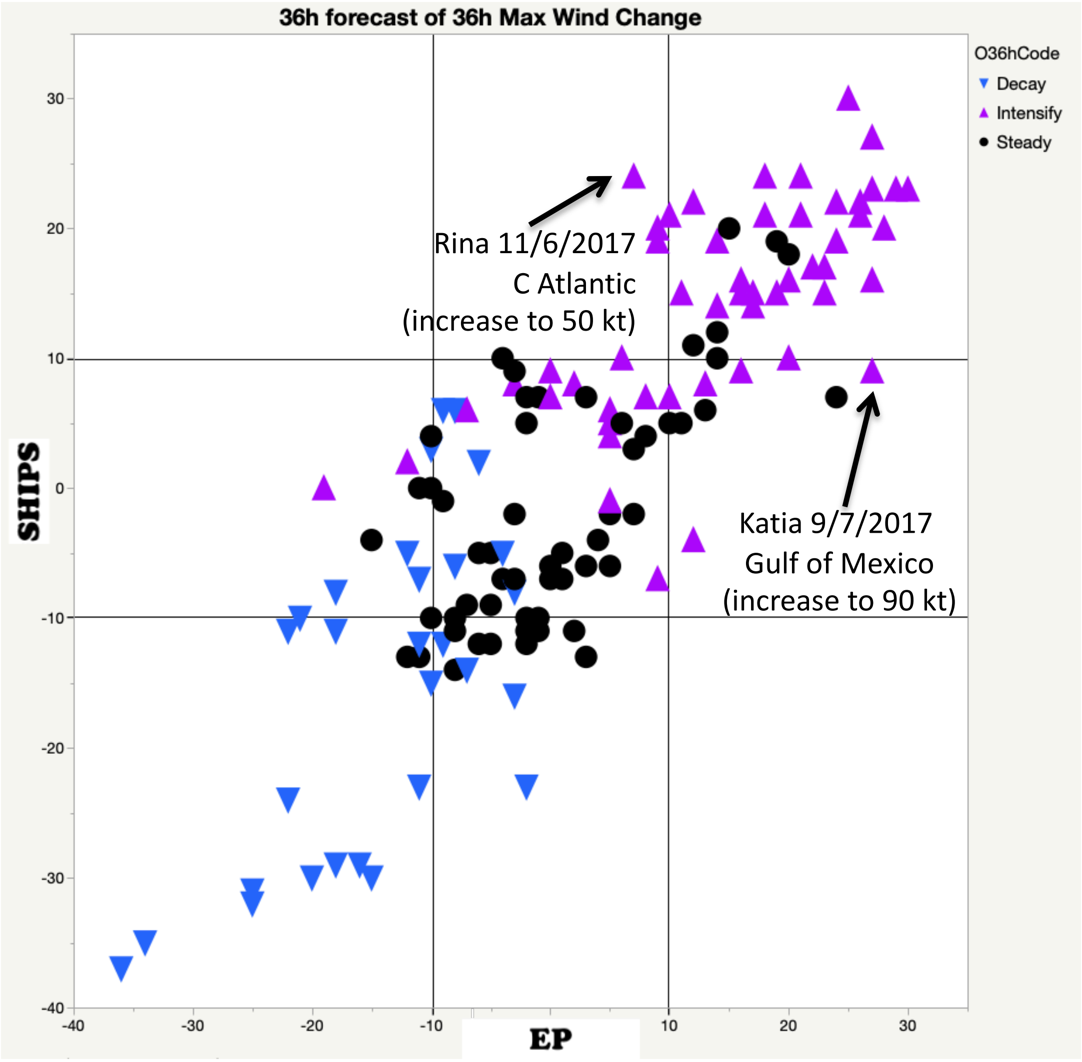
(of those on 100-best algorithms list)

Deterministic Forecast Skill

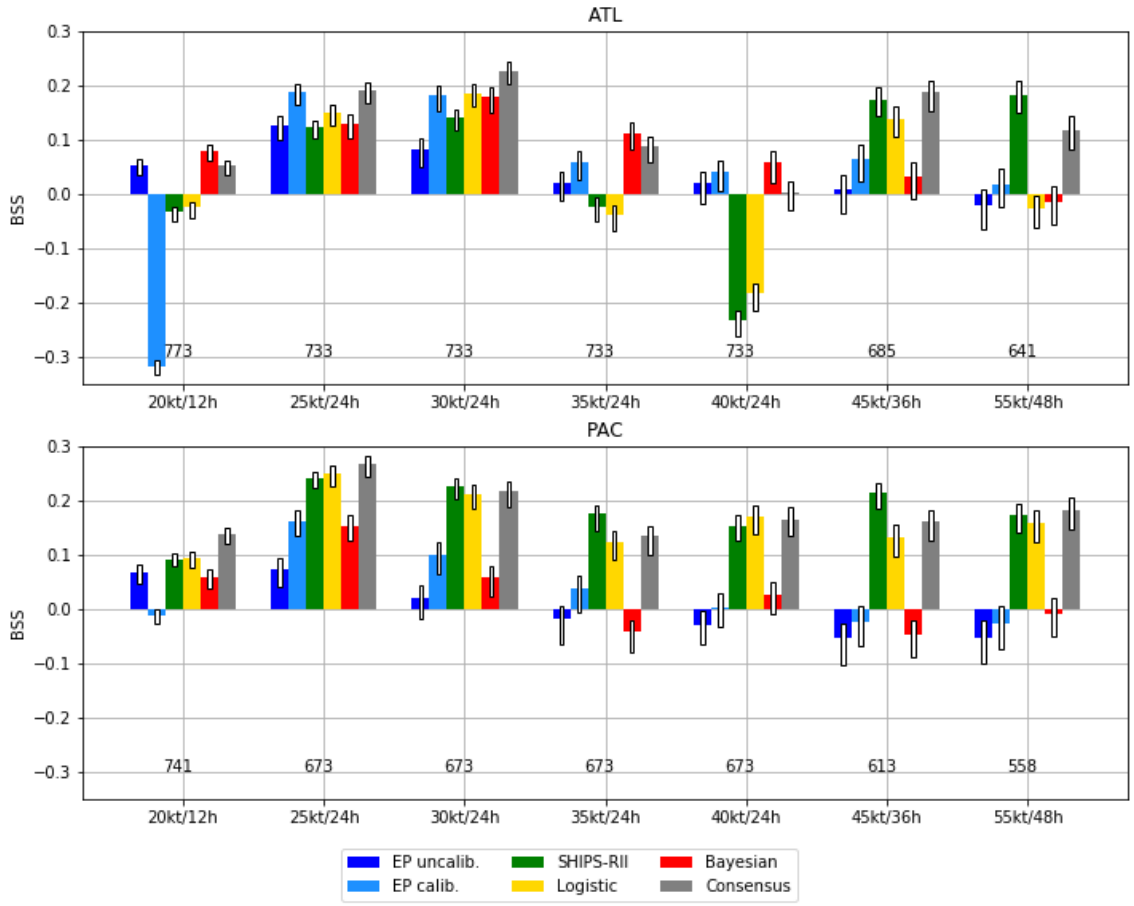


Atlantic performance is comparable to SHIPS and LGEM to 96 h.
Pacific performance is not competitive except at 96-120 h.

Forecast Independence from SHIPS

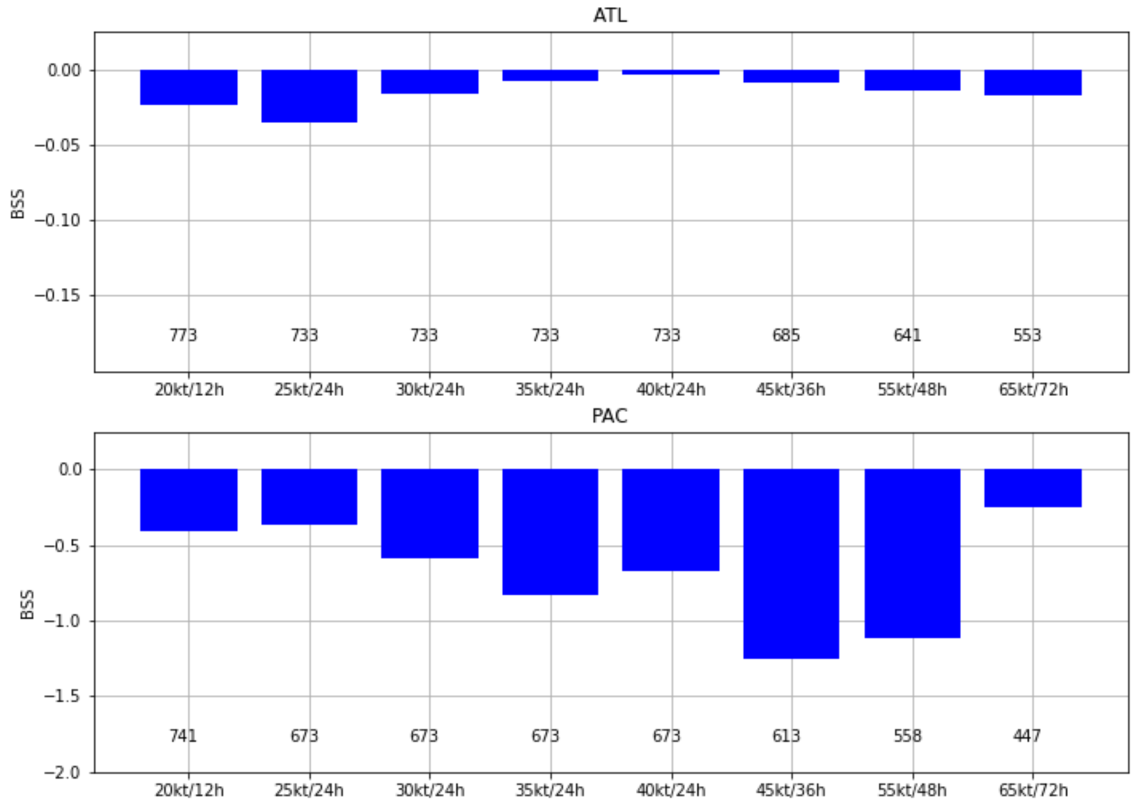


Rapid Intensification Forecast Skill



RI forecasts at the 25-40 kt per 24-h thresholds are competitive with operational RI guidance in the Atlantic, less so in the Pacific.

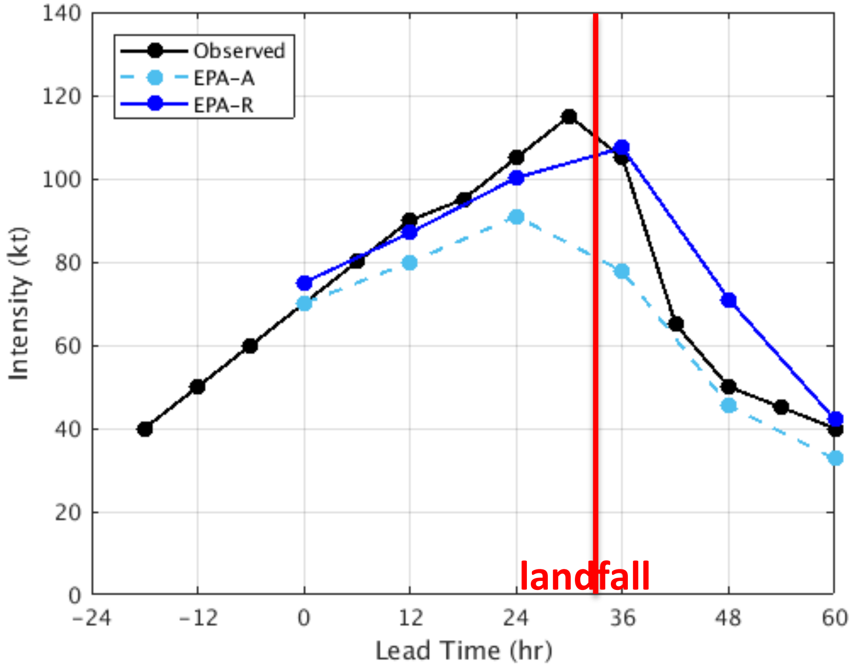
Rapid Weakening Forecast Skill



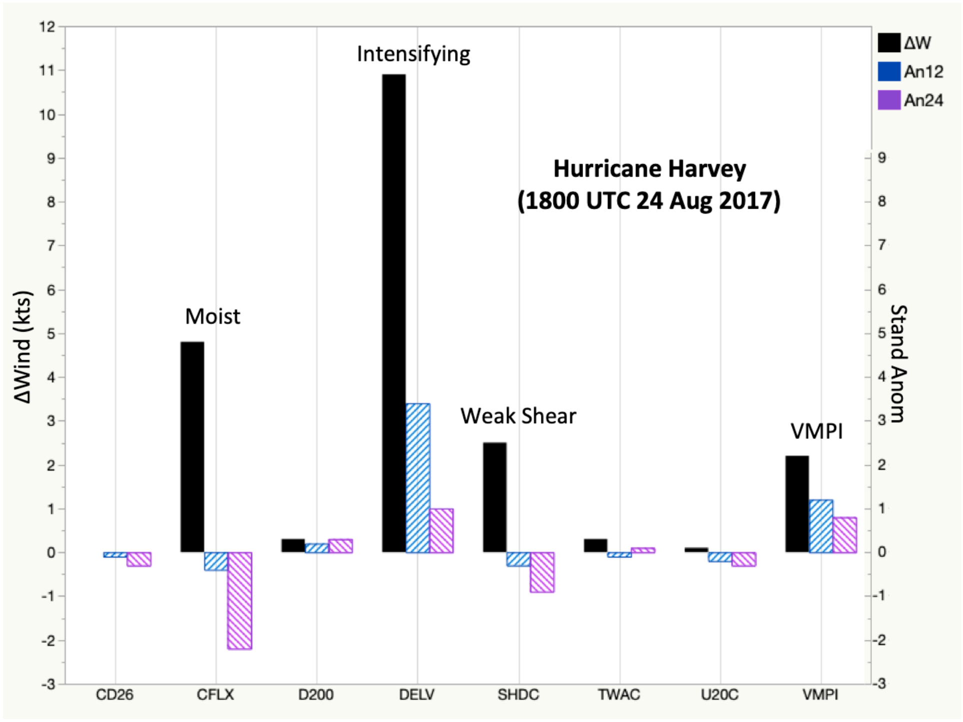
The EP-based RW model is not skillful at any threshold in either basin. **Note: over-land cases are excluded in this evaluation.**

Case Study: Harvey (2017)

EP Forecast vs. Best-Track

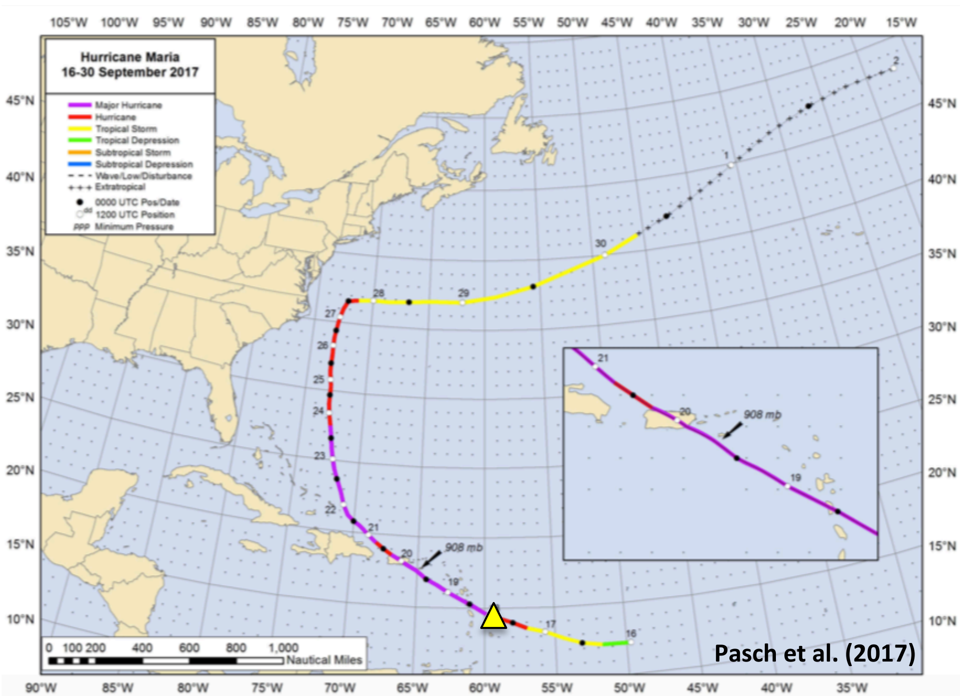


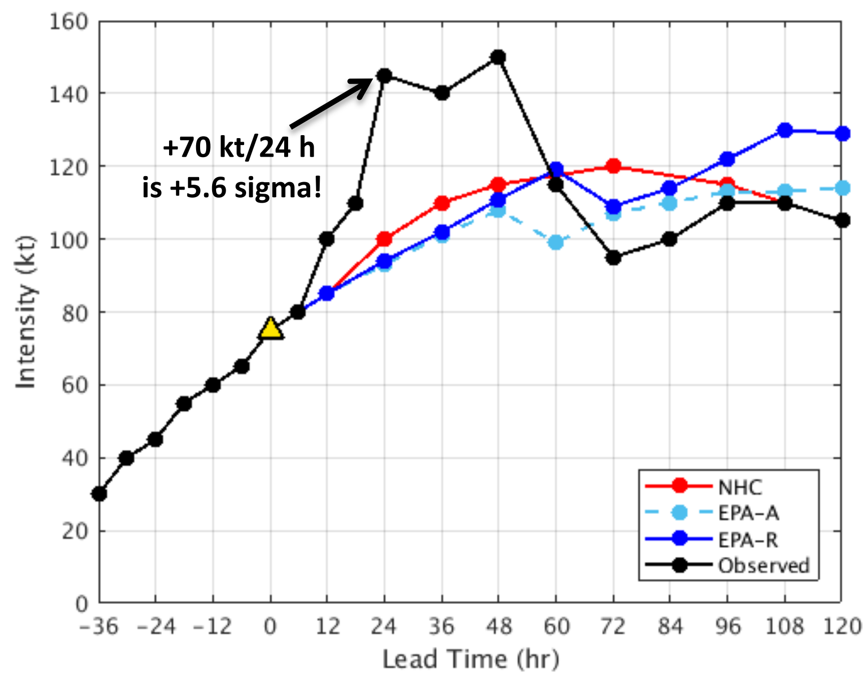
Predictor Contributions



The real-time EP-model forecast (EPA-R) provides a skillful short-range forecast of Harvey's pre-landfall rapid intensification, largely driven by the moist, low-shear, high-SST environment.

Case Study: Maria (2017)





The real-time EP-model forecast keyed in on a favorable environment, predicting a 19 kt/24 h intensity increase (in the 98th percentile of all 24-h EP forecasts), but did not replicate the >99th percentile observed intensification.

Possible Future Directions

- Can we use mesoscale information from other sources (e.g., microwave imagery) to improve inner-core TC representation?
- How many predictors are optimal, given available training data (duration and quality)?
- Alternative approaches to probabilistic forecast generation and improvements to the Pacific deterministic forecast model.

Questions?