IMPROVEMENTS TO THE OPERATIONAL STATISTICAL TROPICAL CYCLONE INTENSITY FORECAST MODELS USING WIND STRUCTURE AND EYE PREDICTORS

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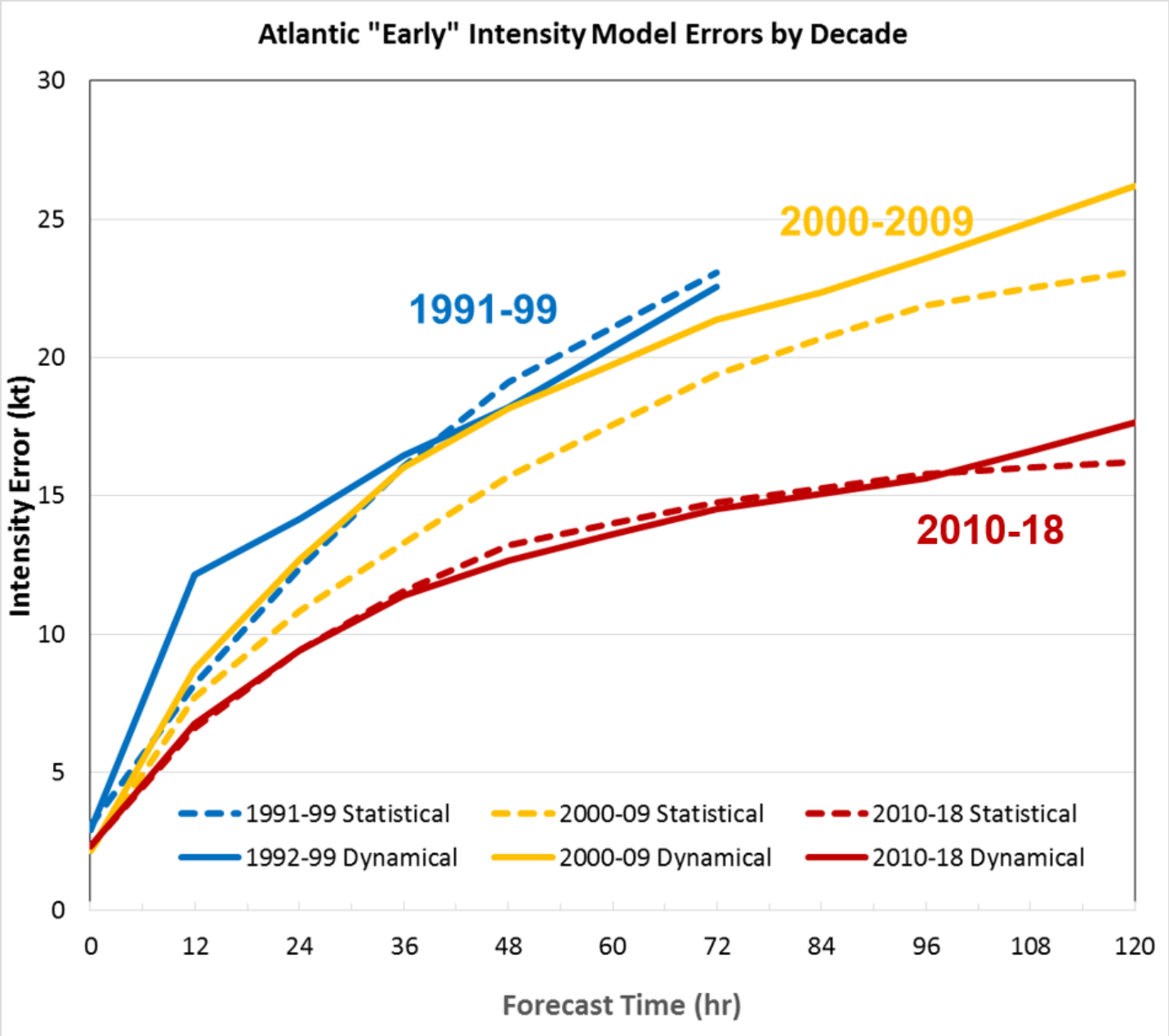
Intensity Forecast Skills: Statistical vs Dynamical Models

The best performing dynamical and statistical model is used for each curve.



From DeMaria and Chirokova, 2018

Percentiles of over-water tropical cyclone intensity change used as thresholds for statistical RI models (1995-2019)

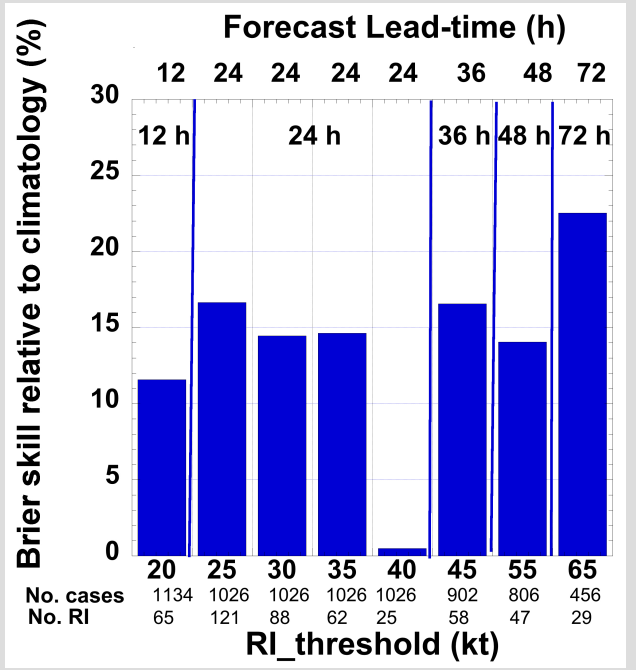
dv/dt (kt h^{-1})	Atlantic	E. Pacific
20-kt/12h	***95***	***94***
25-kt/24h	89	87
30-kt/24-h	***93***	***92***
35-kt/24-h	96	94
40-kt/24-h	98	96
45-kt/36-h	***95***	***93***
55-kt/48-h	***95***	***94***
65-kt/72-h	***95***	***95***

SHIPS-RII operational multi-lead time verification (2016-2019)

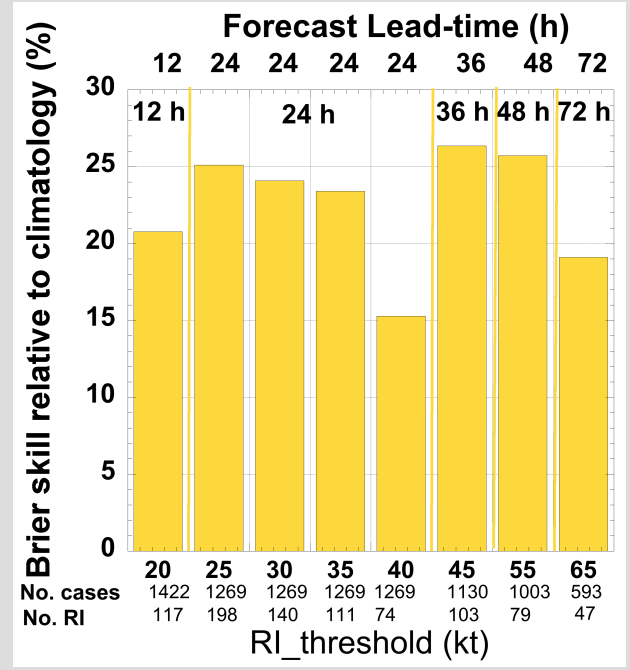
2016-2019* verification of probabilistic operational statistical SHIPS-RII forecasts:

- verified all over-water TC forecasts
- forecasts were at least somewhat skillful
  - Exception: the 40-kt RI threshold in the Atlantic basin
- Reliability:
  - Atlantic basin: fair
  - Eastern/Central Pacific basin: good

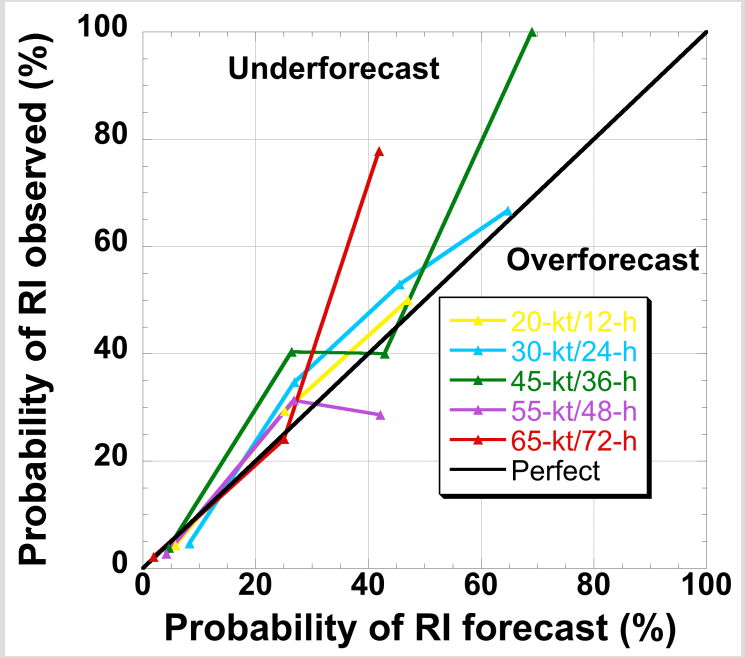
*2019 verification used preliminary best track data available as of Oct. 15

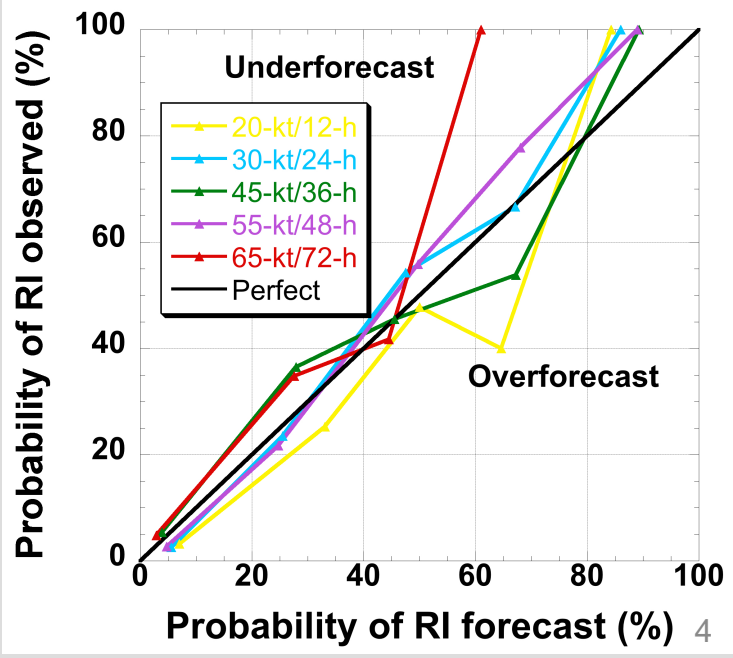


Atlantic



Eastern/Central Pacific





Project Goal

Add

- TC Structure
- Satellite Eye Detection Routine (SEDR)

Predictors to

- Statistical Hurricane Intensity Prediction Scheme (SHIPS)
- Logistic Growth Equation Model (LGEM)
- Rapid Intensification Index (RII) predictors

Develop improved versions of SHIPS, LGEM, and RIIs using the best combination of TC Structure and SEDR predictors

Project Summary: about 90% complete

Task	% completed	% of total work
Database of structure predictors	100%	25%
Database of SEDR predictors	100%	35%
SHIPS/LGEM with structure predictors	90%	40%
SHIPS/LGEM with SEDR predictors	90%	
RII with structure predictors	75%	
RII with SEDR predictors	75%	
Final updated SHIPS/LGEM	50%	
Final updated RII	50%	
Complete final verification	0%	

TC SIZE and Intensification

TC size is important for TC intensification

- Carrasco et al. 2014, Knaff et al. 2014, Xu and Wang 2015

Both TC Intensification and the likelihood of undergoing RI are related to storm size

- Smaller storms found to be more likely to intensify
- Wind structure parameters are strongly negatively correlated with the rate of change of intensity
    - radius of maximum winds (RMW)
    - average radius of gale-force winds (R34),
    - objective size parameter (R5, Knaff et al, 2014a)

SHIPS Structure Database

Available Data for RMW and R34

- 1989 – 2001 – Extended Best Track
- 1990 – present: ATCF A-decks, CARQ
- 2001 – present: ATCF Best Track, BEST

Example: SHIPS diagnostic file:

```
1071   246   303 9999 9999 9999 9999 9999 9999 9999   800   800   200   200 9999 9999 9999 9999 9999 9999 9999 STR0
1315   208   297 9999 9999 9999 9999 9999 9999 9999  1025  1025   250   300 9999 9999 9999 9999 9999 9999 9999 STR1
1173   233   301 9999 9999 9999 9999 9999 9999 9999   950   925   300   300 9999 9999 9999 9999 9999 9999 9999 STR2
1075   247   304 9999 9999 9999 9999 9999 9999 9999   950   925   300   300 9999 9999 9999 9999 9999 9999 9999 STR3
 962   263   308 9999 9999 9999 9999 9999 9999 9999  1067  1000   400   400 9999 9999 9999 9999 9999 9999 9999 STR4
```

STR0:

- 0 R34 Climatology
- 1 RMW Climatology
- 10,11 R34 from ATCF Best Track (10) and CARQ (11)
- 12,13 RMW from ATCF Best Track (12) and CARQ (13)

STR1, STR2, STR3, STR4 – same as STR0 for t = -6h, -12h, -18h, and -24h

TC EYE and Intensification

- The appearance of the eye is strongly related to TC intensity and often indicates the beginning of RI
  - Weatherford and Gray 1988, Willoughby 1990, Vigh 2012
- The current intensity combined with the intensification trend over the last 12 hours was shown to be one of the most important predictors for TC intensity
  - Fitzpatrick, 1997
- In operations eye-detection is performed manually by forecasters
- The CIRA's automated objective IR Satellite Eye-Detection Routine (SEDR)
  - Knaff and DeMaria, 2017
- SEDR allows to automate eye-detection making it possible to use eye-existence probability predictors for statistical intensity forecast models

SEDR data and method

SEDR Data:

- GOES IR imagery
  - 1982 – 1996: 8 km resolution : doesn't work well
  - 1997 – 2016: 4 km resolution : training data
  - 2017 – 2018: 2 km resolution (GOES-16/17, Himawari)
- ATCF: Vmax, Lat, 2 components of storm motion vector

SEDR Method:

- Quadratic Discriminant Analysis (QDA)
- Linear Discriminant Analysis (LDA)

SEDR data available at non-synoptic times:

- bin available SEDR probabilities into seven 15-minutes bins for t_{start} = -90 minutes, t_{end} = +15 minutes
- Use probability averaged over several bins to smooth noisy data

SHIPS and LGEM need to run at all forecast times:

- use ATCF only version when no IR data available

	QDA	LDA
SEDR_full	IR+ATCF	IR+ATCF
SEDR_IR	IR Only	IR Only
SEDR_ATCF	ATCF	ATCF

Versions of SEDR for 1982 – 2017

1) Basic: only uses ATCF data (Vmax, Lat, components of storm translational speed)
2) IR only: only uses GOES IR data
3) Full: Uses both GOES IR data and 4 ATCF parameters

For 1), 2), 3) have both QDA and LDA versions – total 6 versions

SHIPS SEDR Database

54	276	99	51	22	1	8	9999	9999	9999	40	298	82	41	20	2	6	9999	9999	9999	9999	EDRA
9999	10	8	5	4	3	2	9999	9999	9999	9999	4	1	0	0	0	0	9999	9999	9999	9999	EDR0
9999	137	9999	119	131	170	201	9999	9999	9999	9999	513	9999	622	673	692	684	9999	9999	9999	9999	EDR1
9999	90	87	77	68	58	54	9999	9999	9999	9999	65	61	73	96	144	171	9999	9999	9999	9999	EDR2
9999	18	20	25	31	35	37	9999	9999	9999	9999	17	13	12	19	43	91	9999	9999	9999	9999	EDR3
9999	33	29	9999	9999	25	9999	9999	9999	9999	9999	3	2	9999	9999	7	9999	9999	9999	9999	9999	EDR4
9999	3	3	4	4	5	5	9999	9999	9999	9999	0	0	0	0	0	0	9999	9999	9999	9999	EDR6
9999	2	3	4	4	5	4	9999	9999	9999	9999	79	41	23	25	25	26	9999	9999	9999	9999	EDR8

EDRA:

- 0 – 6 LDA at t = 0h, -6h, -12, -18h, -18h, -24h, -36h, -48h
- 10 – 16 – same for QDA

EDR0:

- 0 – 6 LDA binned in 15 minutes bins
  - from (Synoptic Time t = 0 h – 90 minutes) to (Synoptic Time t = 0 h +15 minutes)
- 10 – 16 same for QDA

EDR1, 2, 3, 4, 6, 8 – same for t = -6h, t = -12h, t = -18h, t = -24h, t = -36h, and t = -24h

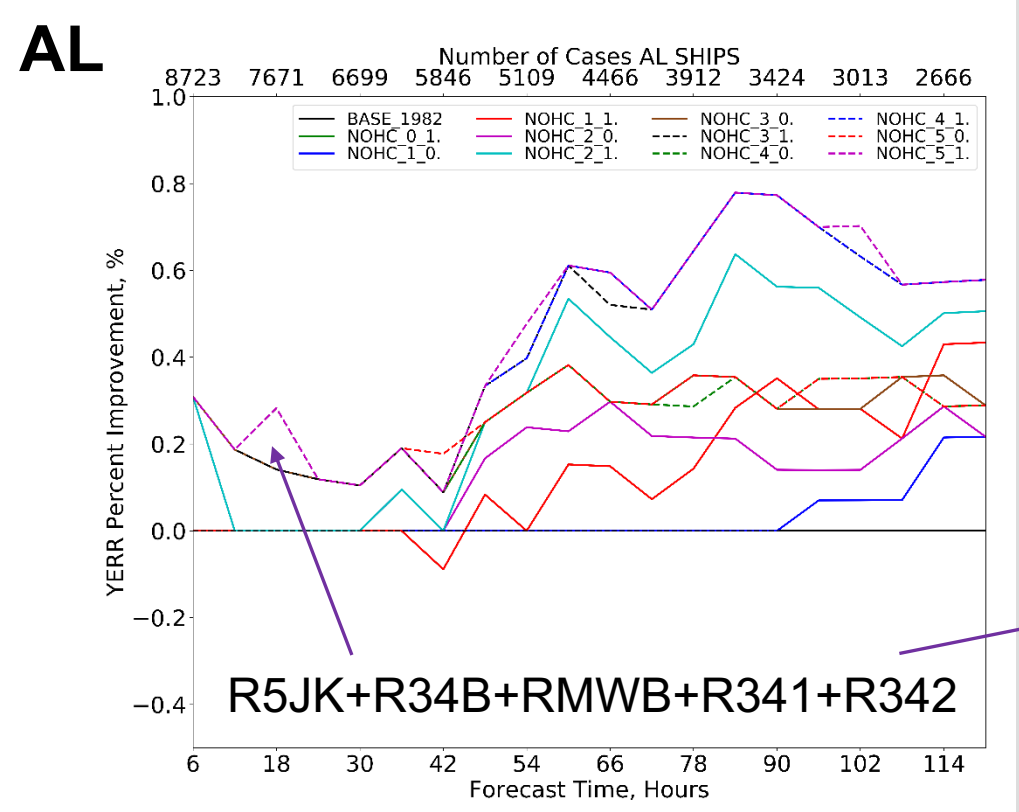
Use as predictor for each synoptic time SEDR probability averaged over several 15-minute bins.

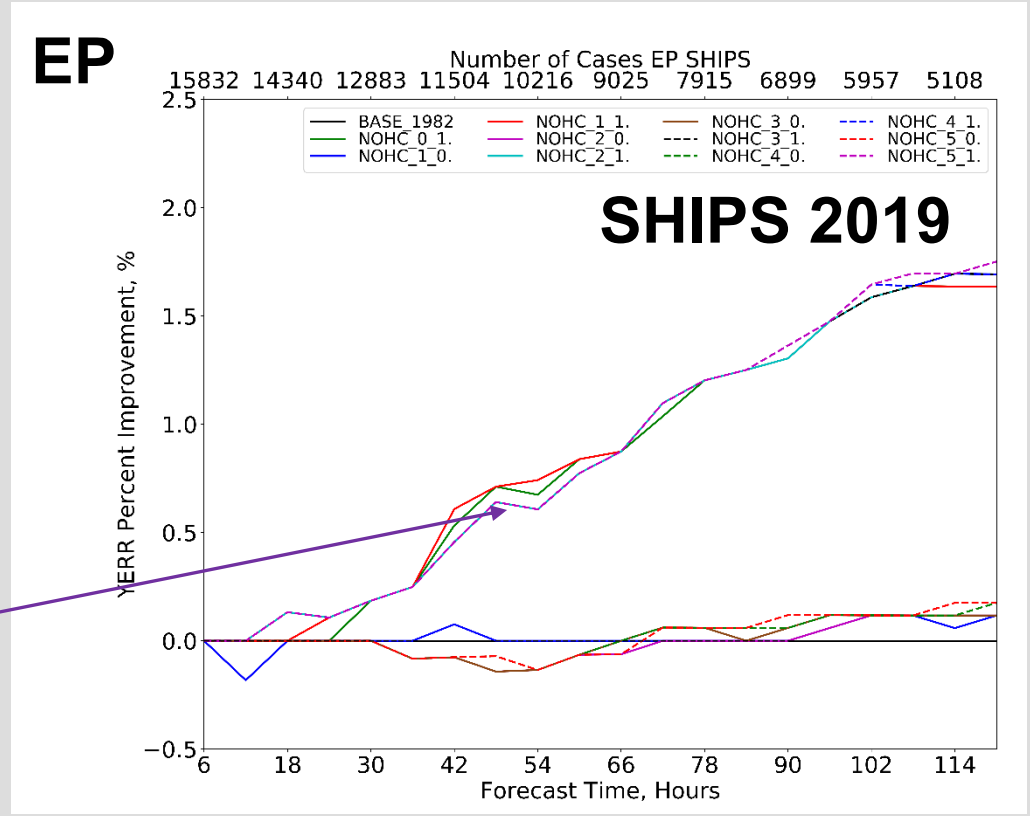
- That helps with noisy data

SHIPS: Structure Predictors Dependent Sample Tests

- New size predictors:
  - R5JK – IR objective TC Size
  - R34B – non-zero-averaged R34 from Best Track
  - RMWB – RMW from Best Track
  - R341 - R34 at t = - 6 h
  - R342 – R34 at t = -12 h

- Best results: all 5 predictors added + time-averaged latitude (TLAT)





Percent Improvement in mean absolute error (kt)

SHIPS-RII - new structural version

The SHIPS-RII skill is somewhat limited, particularly in the Atlantic:

- A new structurally-based version of the SHIPS-RII has been derived (initially for the Atlantic basin) utilizing predictors from the structural SHIPS diagnostic file for the period 1998-2017.

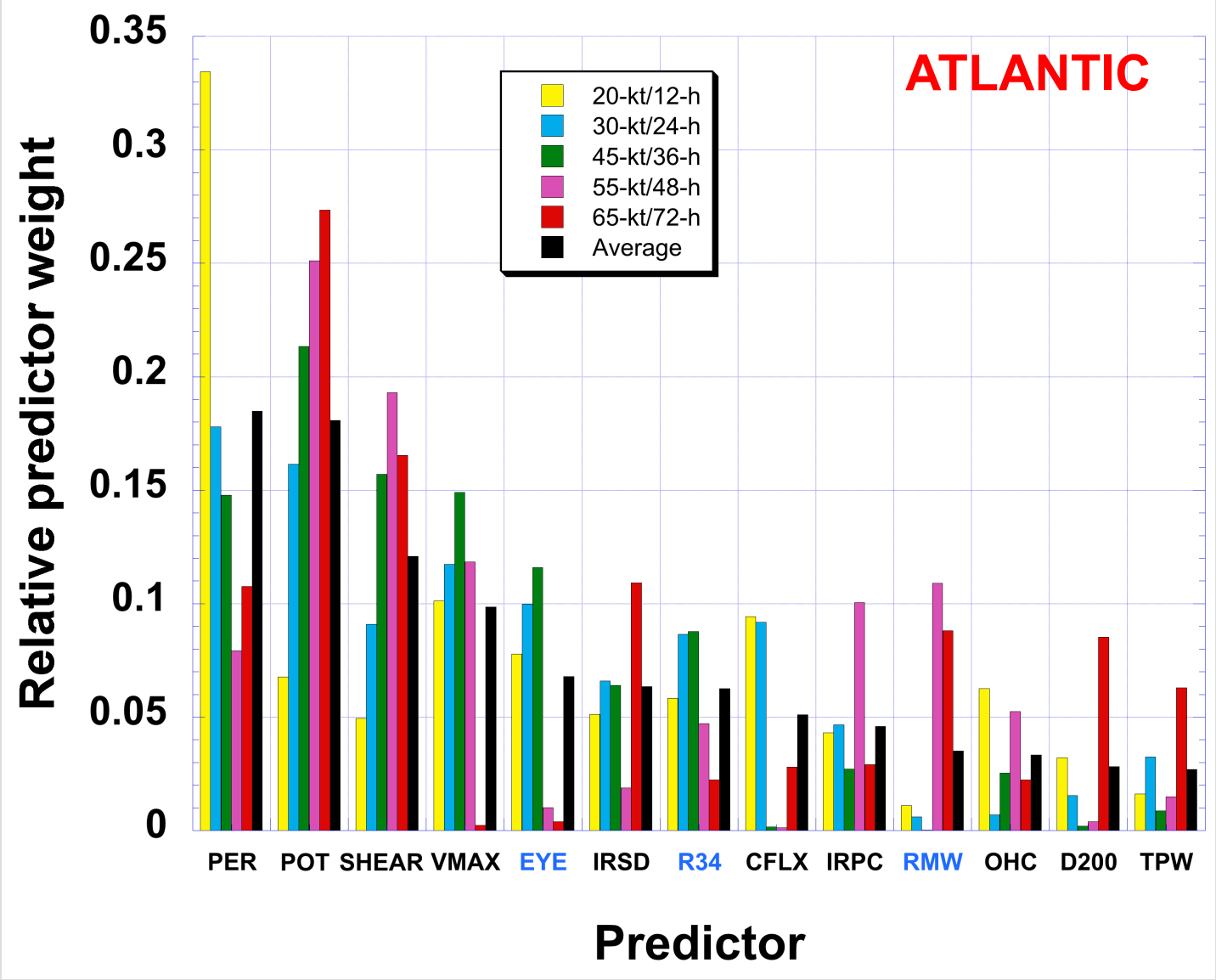
- The new structural SHIPS-RII employs:
  - ten predictors from the operational SHIPS-RII
  - three additional predictors:
    - non-zero-averaged R34 - radius of 34 knot wind
    - RMW - the radius of maximum wind
    - EYE - SEDR probability of eye existence at t=0 h

Predictors Used in Operational/Structural (JHT) SHIPS-RII

Predictor	Definition	More Favorable
PER	Previous 12-h intensity change	Larger
VMAX	Deviation from RI sample mean maximum wind (t=0 h)	Smaller
IRSD	Std. dev. of 50-200 km GOES-IR brightness temperatures (t= 0 h)	Smaller
IRPC	2nd principle component of GOES-IR image (0-440 km radius) (t= 0 h)	Smaller
SHEAR	850-200-hPA shear 0-500 km radius (time-avg.)	Smaller
D200	200-hPA divergence from 0-1000 km radius (time-avg.)	Larger
TPW	Percent area with TPW < 45 mm within 500 km 90 deg. up-shear (t=0 h)	Smaller
CFLX	Inner-core dry-air predictor/flux (time-avg.)	Smaller
POT	Potential intensity (Current intensity – MPI) (time-avg.)	Larger
OHC	Oceanic heat content (time-avg.)	Larger
RMW	***NHC Radius of maximum wind estimate (t=0 h)***	***Smaller***
R34	***Radius of 34-kt winds (non-zero) (t=0 h)***	***Smaller***
EYE	***Probability of eye existence (t=0 h)***	***Larger***

Relative weights of predictors in the new Atlantic Structural SHIPS-RII (1998-2017)

- The black bars: the average relative weight for each predictor of the RI thresholds shown
- The new structural predictors are comparable or greater in importance to many of the existing operational SHIPS-RII predictors.

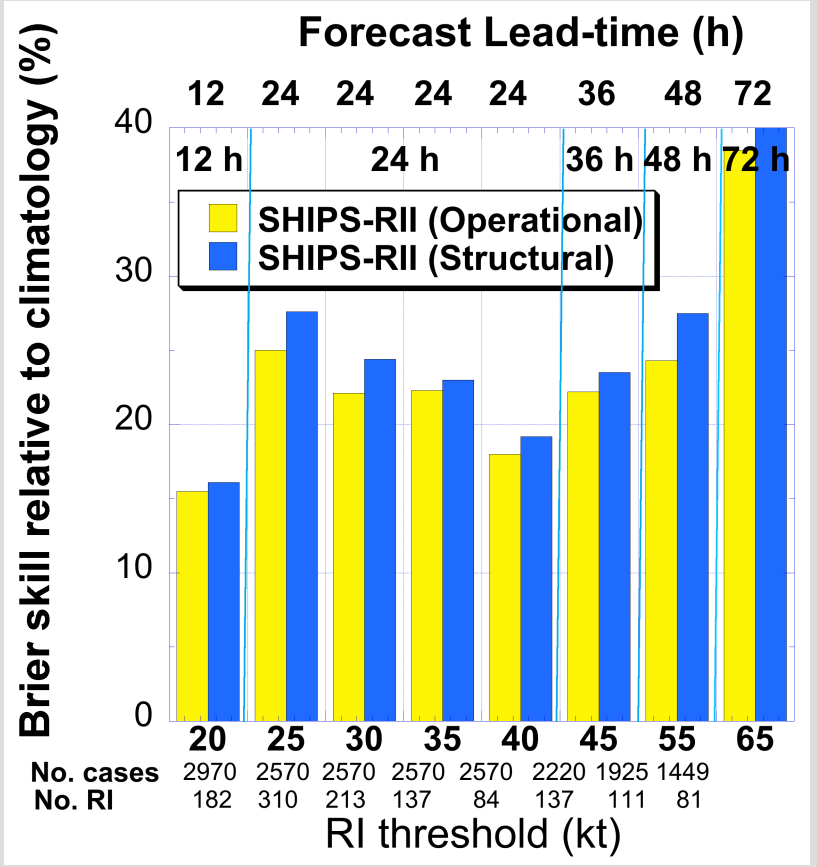


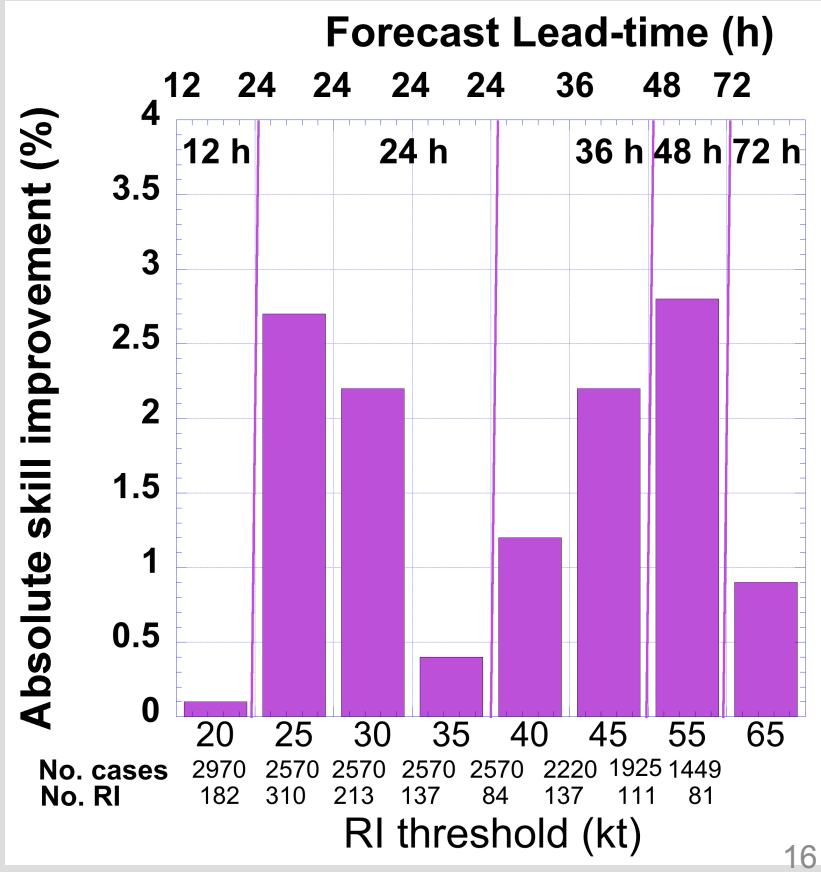
Comparison of skill of Atlantic basin Structural versus operational SHIPS-RII

Atlantic

The skill of the new Atlantic structural SHIPS-RII

- Developmental sample:
  - 1998 - 2017
- exceeds that of the operational SHIPS-RII for each of the operational RI thresholds
- absolute improvement:
  - Up to 2.8%





Summary and Conclusions

Results:

- Completed databased development and dependent tests for SHIPS, LGEM, and RII
- Both SHIPS/LGEM and RII show increased skills with added structure and SEDR predictors

Remaining tasks:

- Complete independent tests
- Select final set of structural and SEDR predictors to use:
  - Both SHIPS and LGEM already use rather large number of predictors, thus adding several new predictors is undesirable:
    - Select a total 2 – 3 new structure and SEDR predictors that provide best improvement
    - Consider removing some existing predictors that are no longer significant.
      - For example: the ADAY predictor is much less significant compared to other predictors and can probably be removed
- Coordinate with NHC on the possibility of doing some real-time testing for 2020 season