Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors

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Project Goal

Add

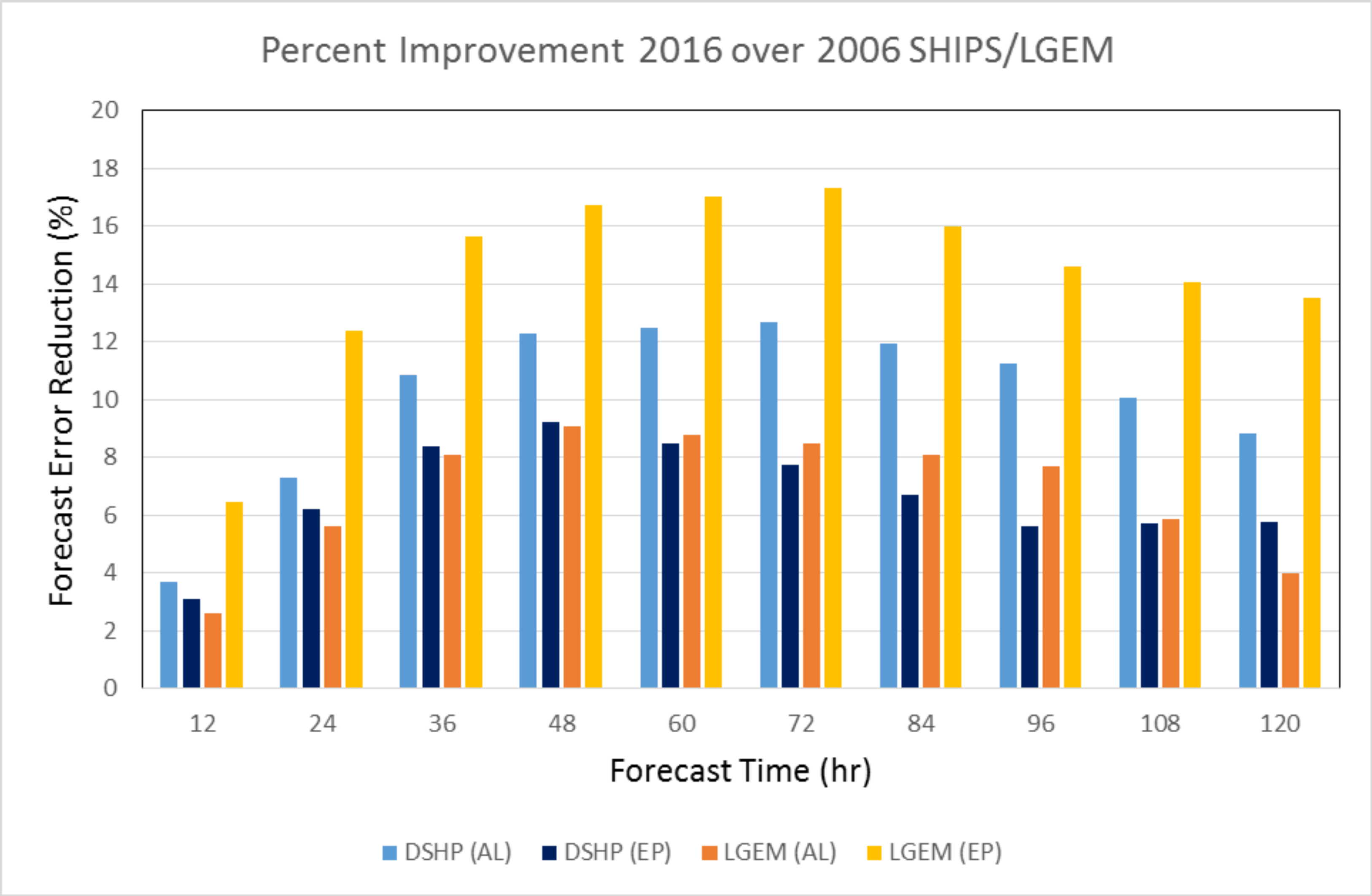
- TC Structure
- Satellite Eye Detection Routine (SEDR)

Predictors to

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

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

SHIPS, LGEM Improvements 2006 - 2016



From DeMaria et al, 2016

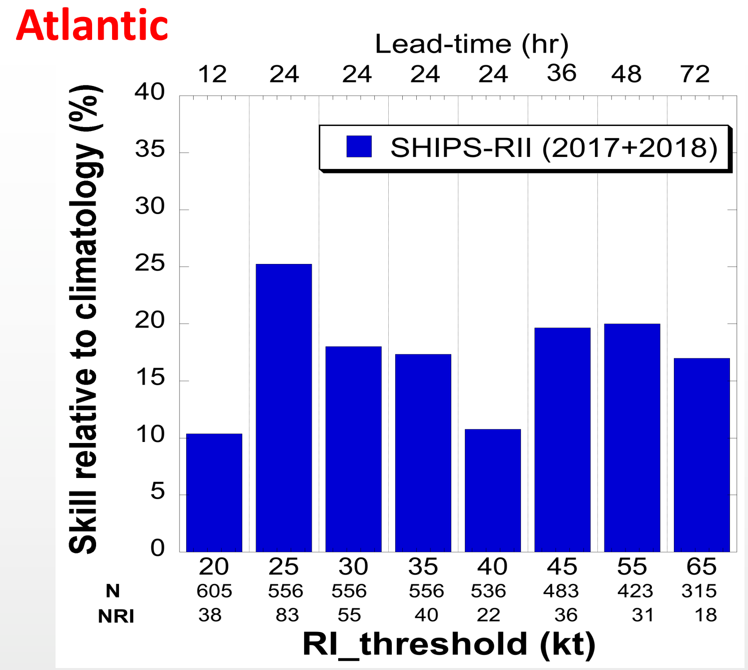
SHIPS-RII Operational 2017-2018 Verification

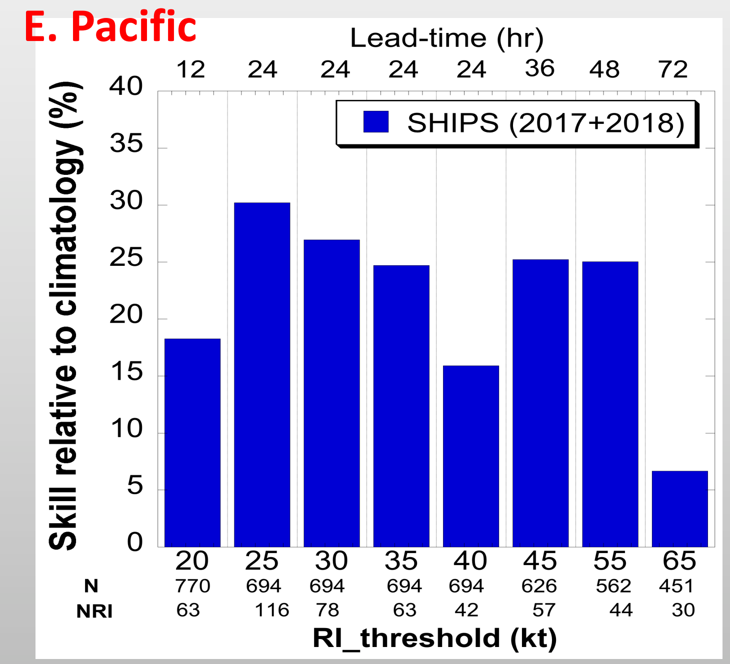
Verification Rules:

- Operational RII forecasts verified for all over water cases that remained subtropical or tropical during forecast period based upon NHC best track data
- Skill measured relative to climatological RI probabilities (1995-2016)

Verification Results:

Operational SHIPS-RII forecasts exhibited skill at all lead times in both the Atlantic and E. Pacific basin for the combined 2-year (2017+2018) sample





Project Summary: about 75% complete

Task	% completed	Due Date	% of total work
Database of structure predictors	100%	Nov 2017	25%
Database of SEDR predictors	100%	Nov 2018	35%
SHIPS/LGEM with structure predictors	90%	Jun 2018	40%
SHIPS/LGEM with SEDR predictors	70%	Mar 2019	
RII with structure predictors	70%	Jun 2018	
RII with SEDR predictors	0%	Mar 2019	
Final updated SHIPS/LGEM	0%	Jul 2019	
Final updated RII	0%	Jul 2019	
Complete final verification	0%	Jul 2019	

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)

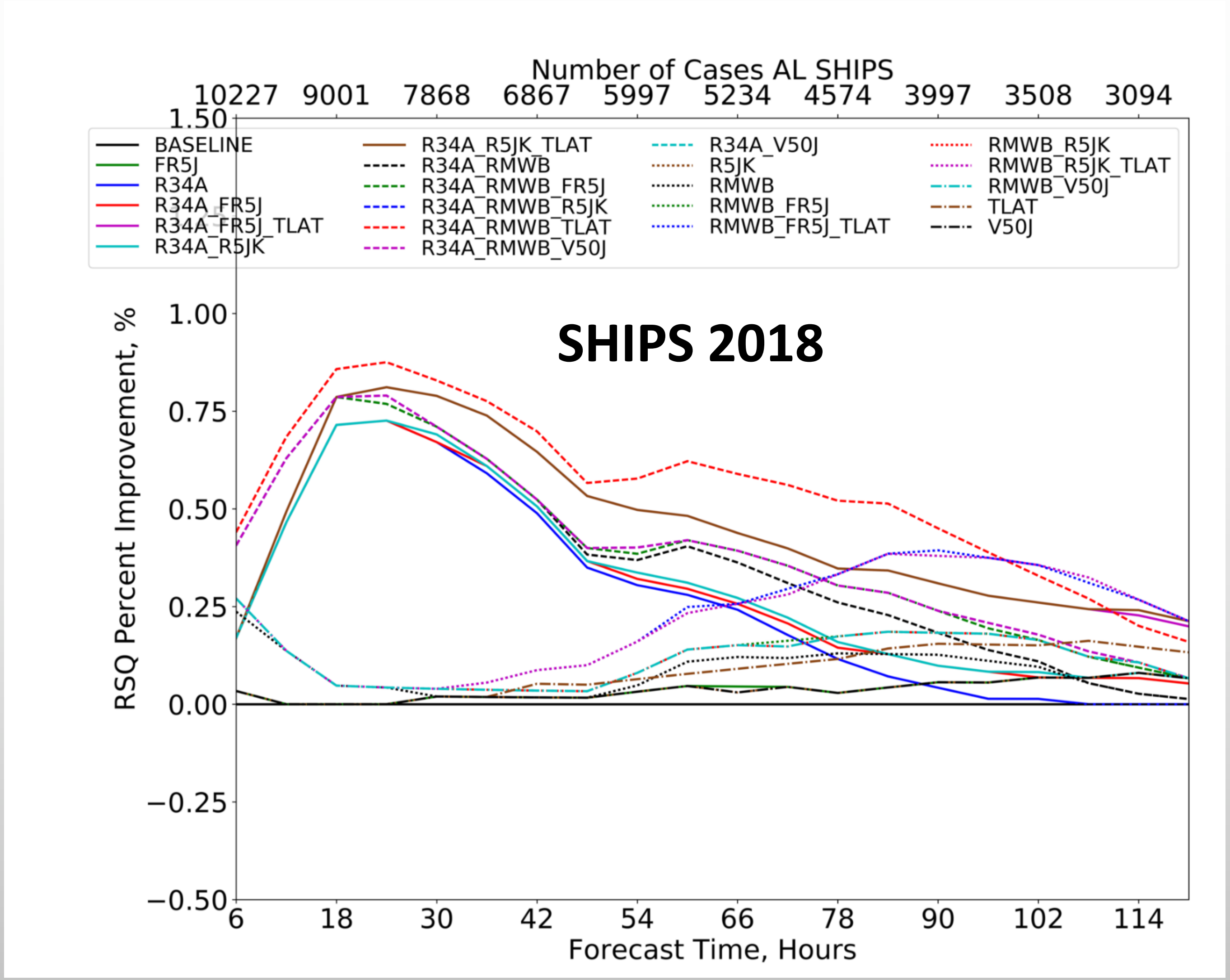
Structure Predictors Dependent Sample Tests SHIPS 2018

SHIPS,LGEM:
adding 3 new predictors consistently produces best results

- R34A
- RMWB
- TLAT

R34A – improves short-term forecast 6 – 48 hours

RMWB – improves longer term forecast

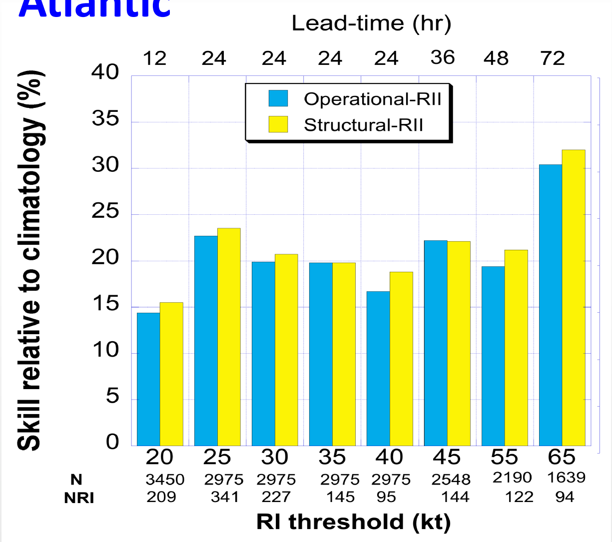


Structural-based RII dependent results (1998-2017)

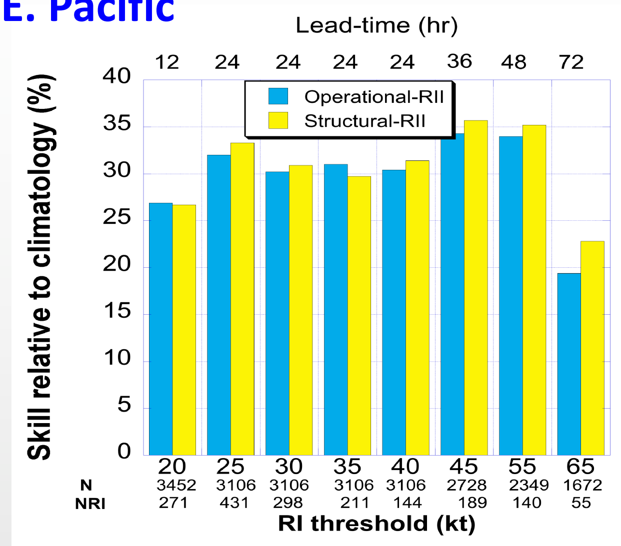
Structural-based RII model:

- the base 10 SHIPS-operational RII predictors (Kaplan et al. 2015)
- 3 new predictors
  - RMW
  - Objective Storm Size R5 (Knaff et al. 2014)
  - Sine of Latitude
- is more skillful than the present operational version when tested on 1998-2017 development data
  - at most lead times
  - in both basins

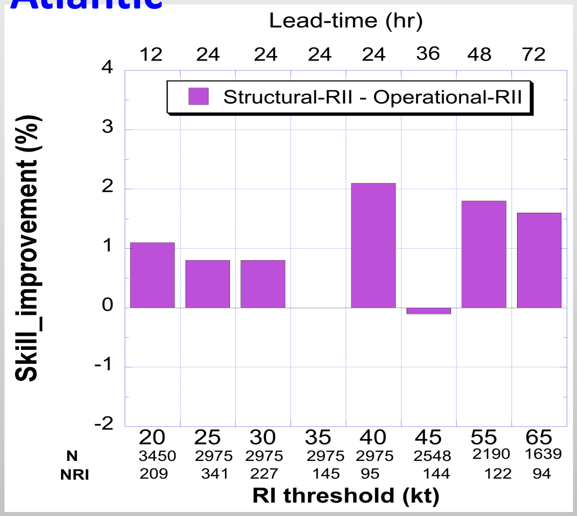
Atlantic



E. Pacific



Atlantic



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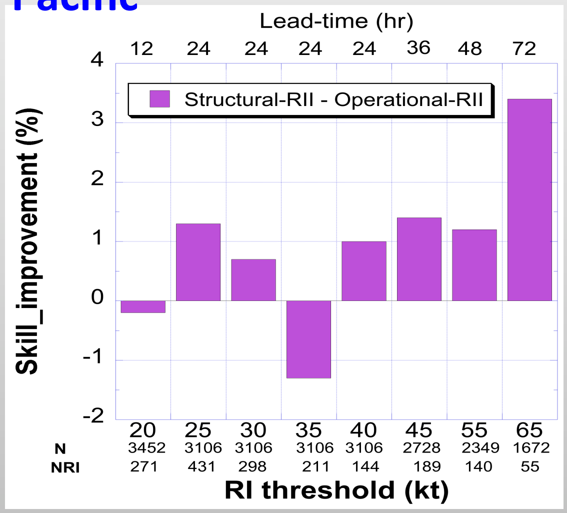


TC EYE and Intensification

- 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:

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

SEDR Method:

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

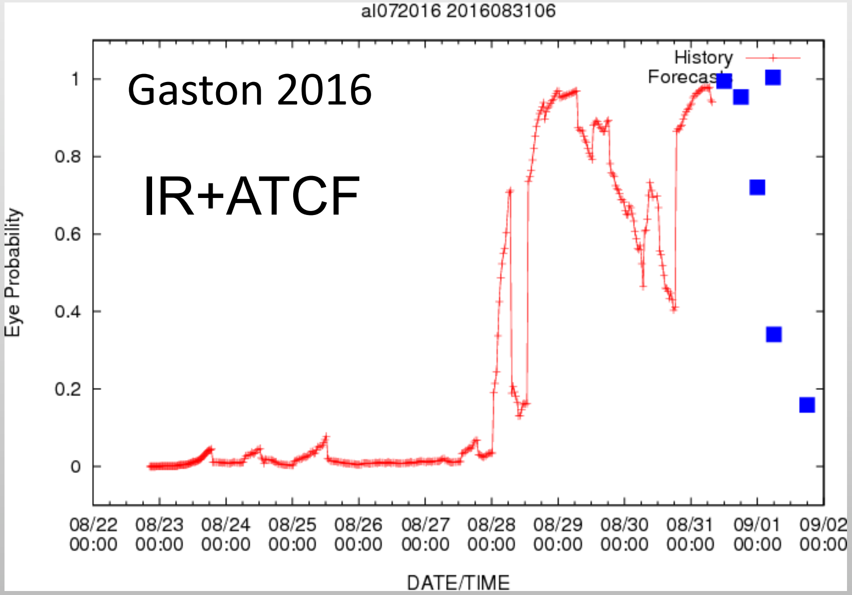
SHIPS and LGEM need to run at all forecast times: need to fill in missing values:

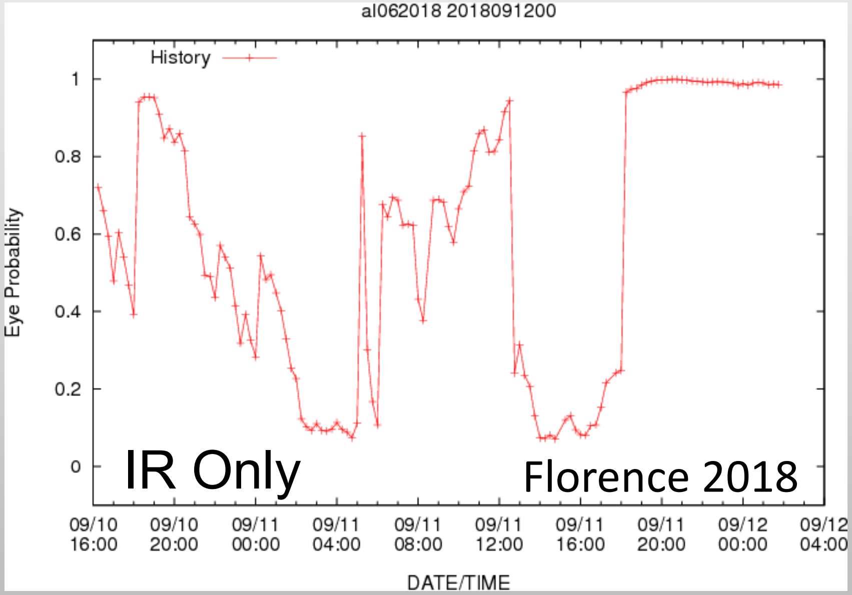
6 versions of SEDR:

	QDA	LDA
SEDR	IR+ATCF	IR+ATCF
SEDR	IR Only	IR Only
SEDR Climo	ATCF	ATCF

SHIPS SEDR database

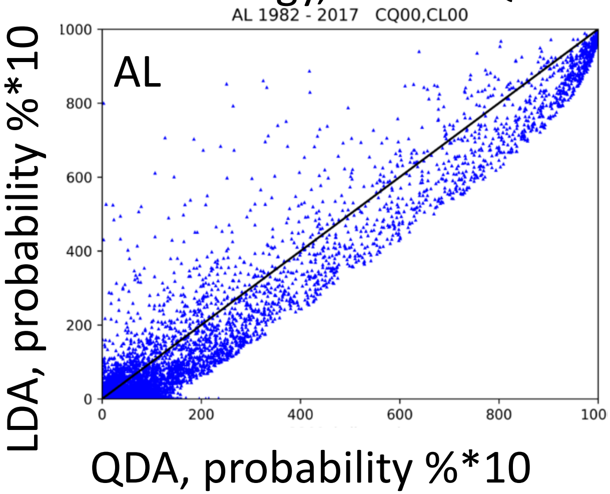
- Reprocessed 6 versions of SEDR for 1982 – 2017
- Developed Fortran 90 code for adding SEDR data to SHIPS developmental database
  - SEDR data available at non-synoptic times
  - Each synoptic time: bin available SEDR probabilities into seven 15- minutes bins for t_{start} = -90 minutes, t_{end} = +15 minutes
  - Use probability averaged over several bins. That helps with noisy data



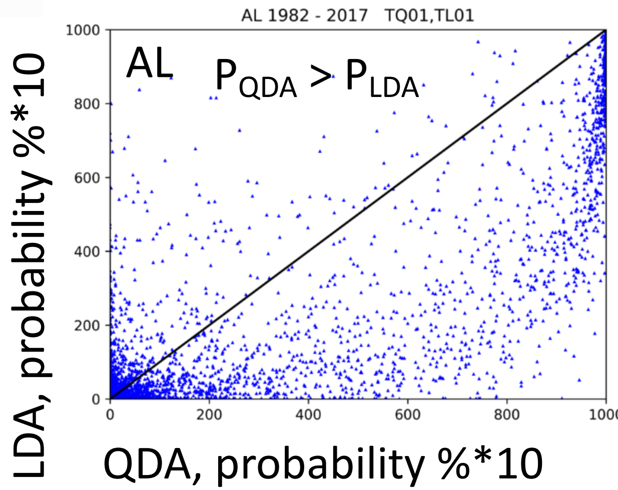


SEDR Versions

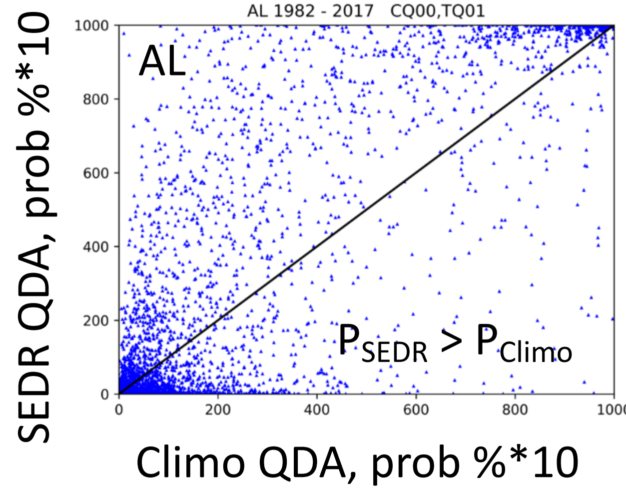
Climatology, LDA vs QDA

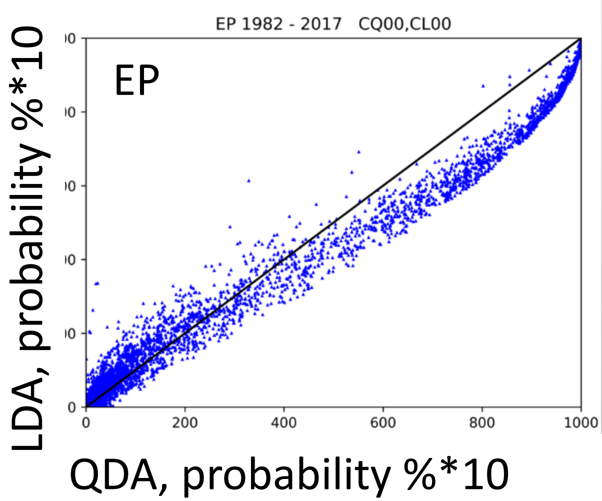


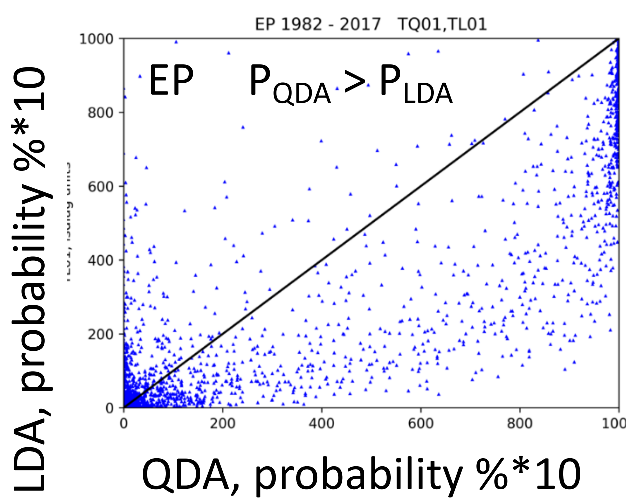
SEDR LDA vs QDA

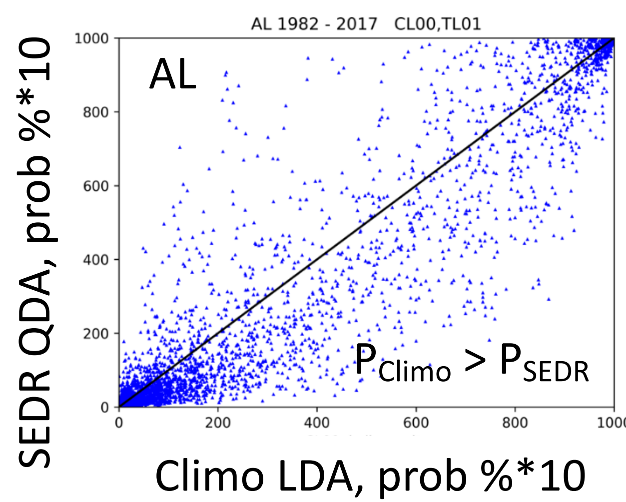


AL SEDR vs Climo









SHIPS with SEDR+Climo predictors dependent sample tests: 1982 – 2017

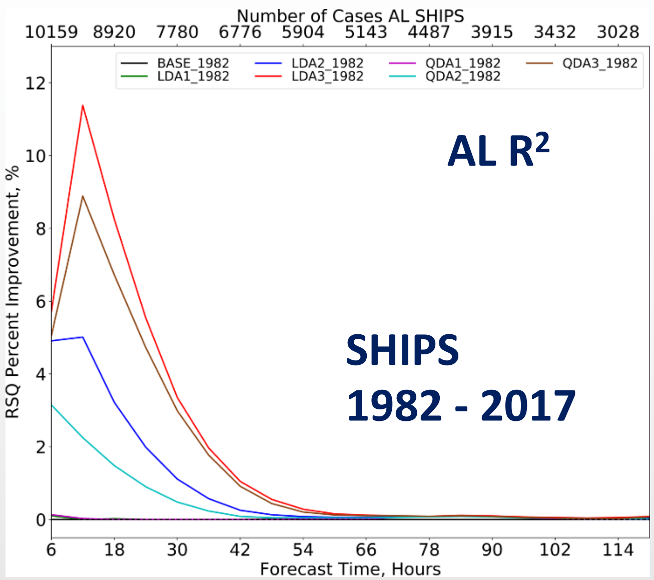
Added 3 SEDR predictors:

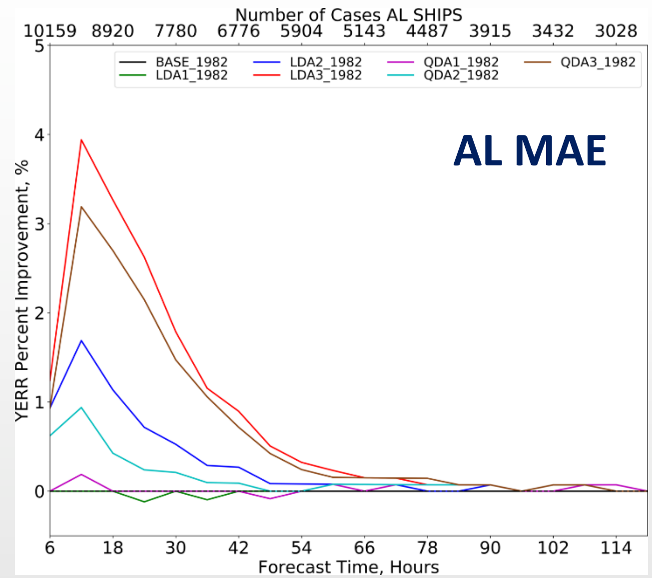
P1: P($SEDR_{eye}$) at t = 0 h
P2: P($SEDR_{eye}$) at t = -6 h
P3: P($SEDR_{eye}$) at t = -12 h

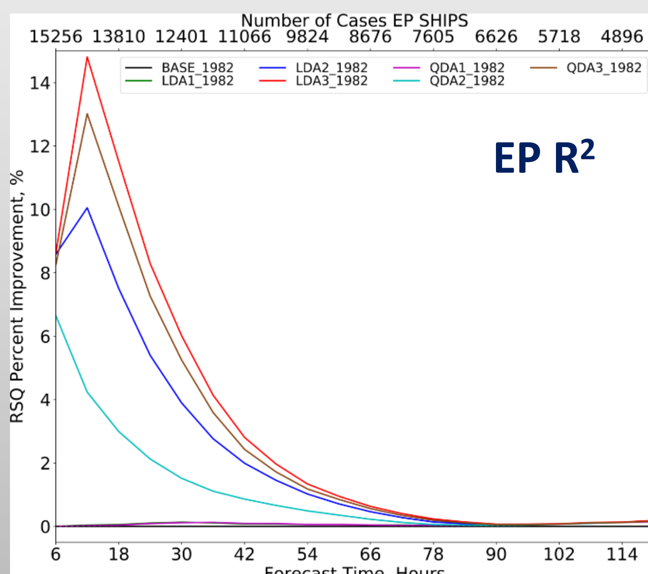
1982-1996: Climo
1997-2017: SEDR

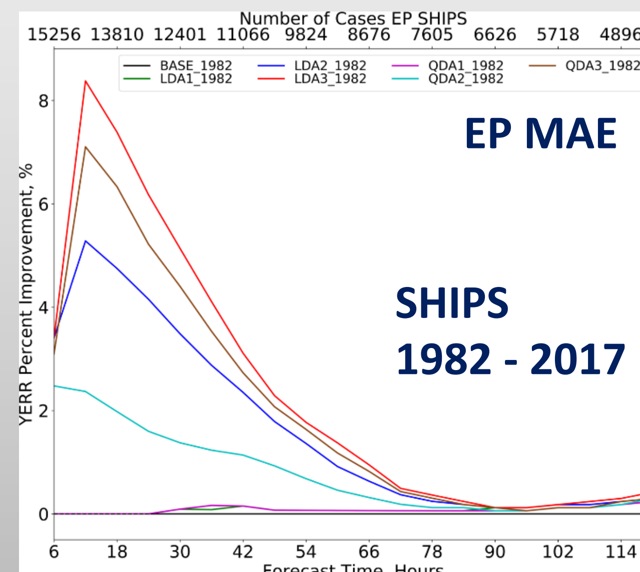
Added predictors:
LDA1, QDA1 – P1
LDA2, QDA2 - P1, P3
LDA3, QDA3 - P1, P2, P3

Best: LDA P1+P2+P3









Summary and Conclusions

- Completed dependent sample tests for SHIPS, LGEM and RIIs with structure predictors
  - SHIPS: R34A,RMW, TLAT up to 0.8 % improvement at 18 h FLT
  - Structural-RII: RMW, R5, LAT up to 2% (3.5%) more skill in the AL (EP)
- Created global database of SEDR predictors for 1982 - 2017
  - QDA and LDA
  - IR+ATCF, IR-only, and Climatology (ATCF-only) versions
- Developed Fortran 90 code for adding SEDR predictors to SHIPS diagnostic files
- Completed SHIPS dependent sample tests using 1982-2017:
  - Best results with adding 3 SEDR LDA predictors:
    $P(SEDR_{eye})$ at (1) t = 0 h, (2) t = -6 h, ands (3) t = -12 h
  - Atlantic: up to 4 % improvement in forecast MAE at FLT = 18 h
  - east/central Pacific: up to 8% improvement in forecast MAE at FLT = 18 h

- Further steps:
  - Complete retrospective runs with structure and SEDR predictors
  - Complete depended sample tests for global SHIPS and LGEM
  - Develop final updated versions of SHIPS, LGEM, RIIs with best combination of structure and SEDR predictors
  - Setup parallel runs for 2019 season

UPDATE on PREVIOUS JHT PROJECT:
Improvements to Operational Statistical TC Intensity Forecast Models (completed in Sep 2018)

Use depth-averaged temperature (DAVT) to estimate a vertical average of the initial (pre-hurricane) ocean ***T*** *(Price, 2009),* which is better estimate of ocean-TC interaction than OHC

Ocean Heat Content (vertical integral of temperature):

$$OHC(x,y) = \rho_0 C_p \int_{Z_{26}}^{0} (T_i\,(x,y,z)\ - 26)\, dz$$

Depth-Averaged Temperature (vertical average of temperature):

$$T_{\overline{d}}(x,y) = \frac{1}{d}\int_{-d}^{0} T_i\,(x,y,z)dz,$$

d – depth of vertical mixing caused by TC

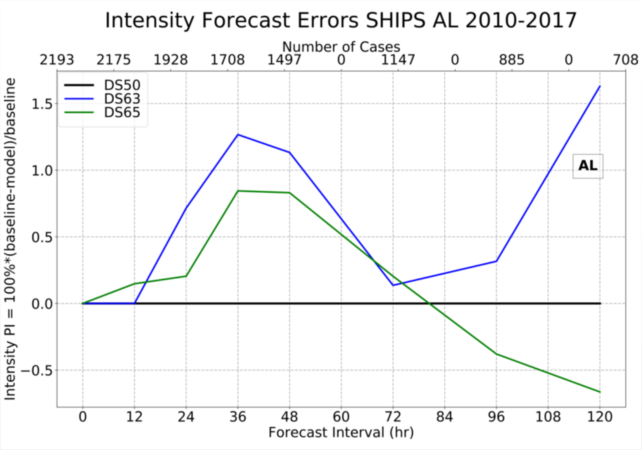
- Well correlated over the deep ocean (OHC > 75 kJcm^{-2})
- Poorly correlated for low OHC (OHC < 50 kJcm^{-2}): (a) cold water (b) shallow continental shelf

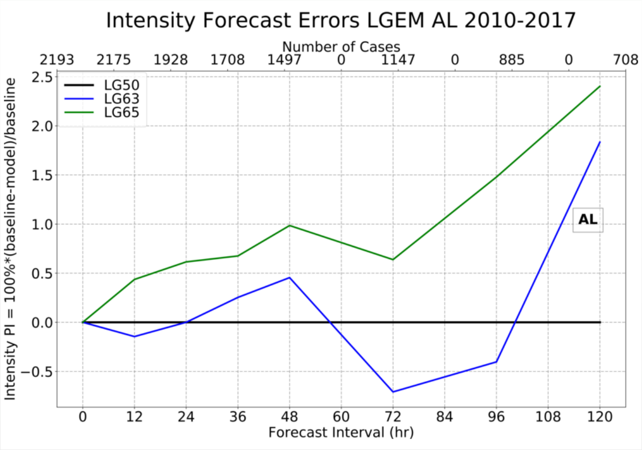
UPDATE on PREVIOUS JHT PROJECT:
Improvements to Operational Statistical TC Intensity Forecast Models (completed in Sep 2018)

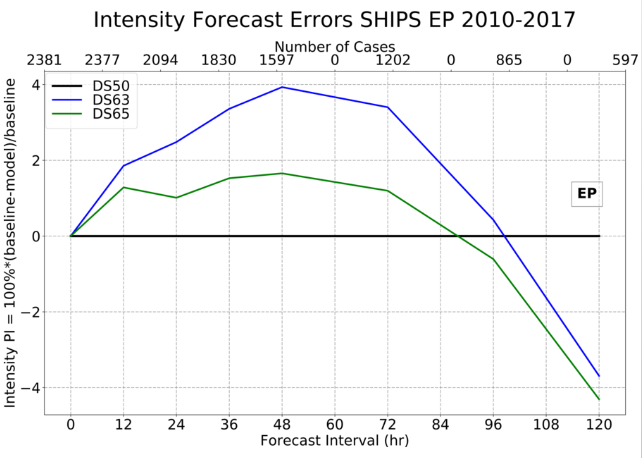
2010-2017 SHIPS/LGEM reruns with Depth-Averaged Temperature (DAVT) - independent sample

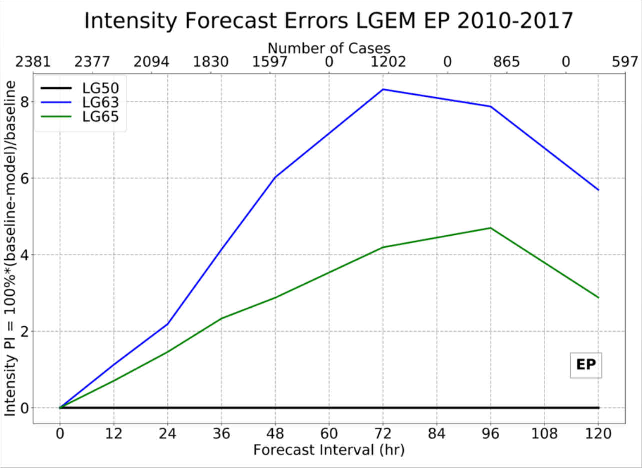
Blue – SST replaced with DAVT assuming varying mixing depth (DSOA)

Green – OHC replaced with DAVT assuming varying mixing depth (RTOA)









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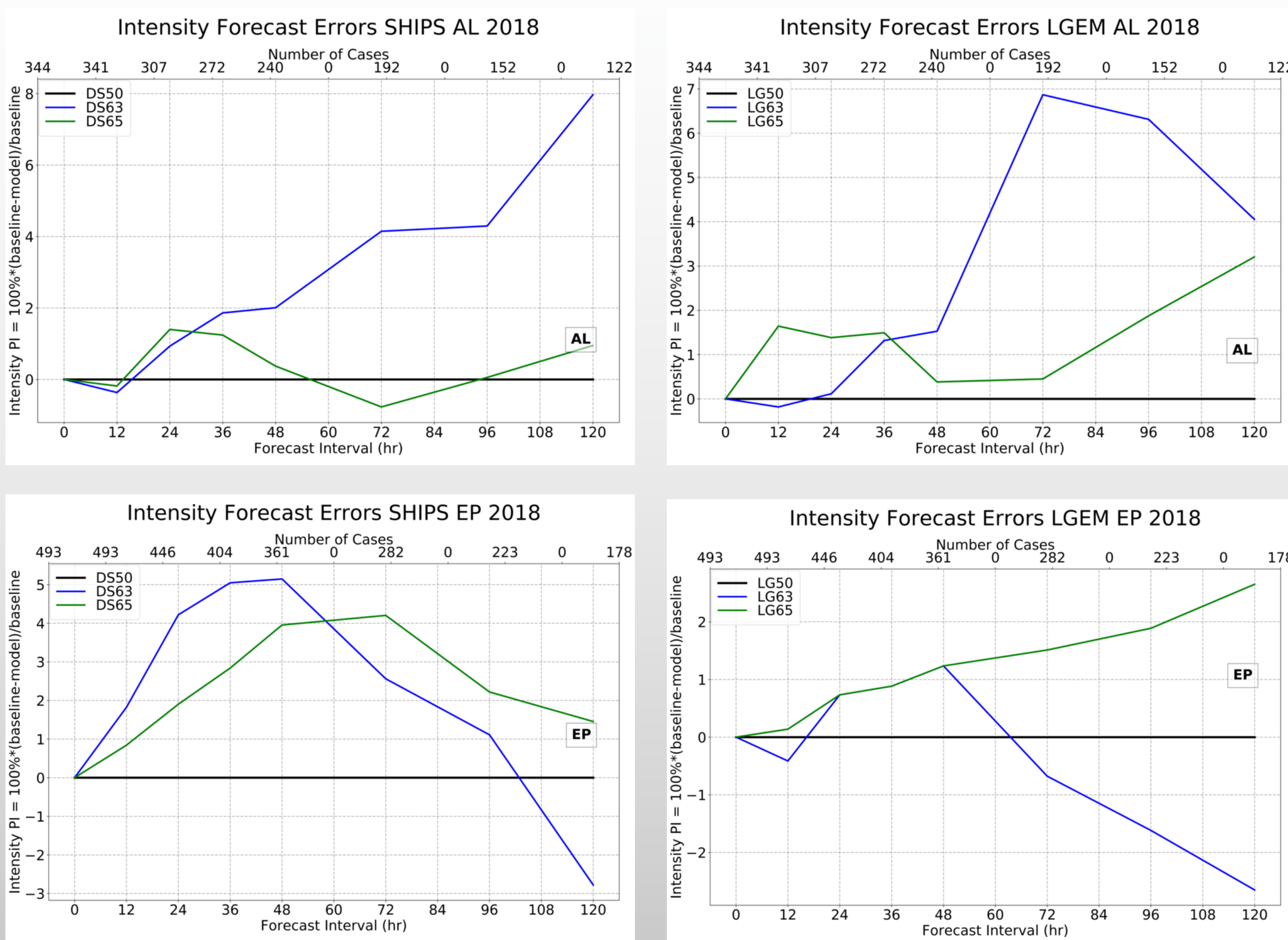

Transitioned to operations:

NHC (2018) :

- Daily Reynolds SST
- Extended OHC dataset – includes SST, OHC, ocean subsurface data

JTWC (2017): SHIPS Wind Radii Forecast (DSWR, Knaff et al 2017)