JHT PROJECT 7:
ENSEMBLE-BASED PRE-GENESIS WATCHES AND WARNINGS FOR ATLANTIC AND NORTH PACIFIC TROPICAL CYCLONES

Russell L. Elsberry
University Colorado-Colorado Springs

Hsiao-Chung Tsai
Tamkang University

Timothy Marchok
Geophysical Fluid Dynamics Lab

OBJECTIVE

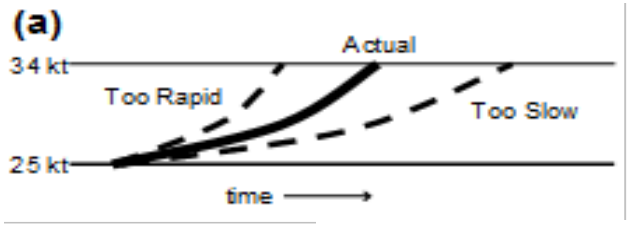
- Provide guidance products for pre-genesis watches and warnings based on the NOAA Global Ensemble Forecast System (GEFS) and European Center for Medium-range Weather Forecasts (ECMWF) ensemble track forecasts
- Genesis time and location along the Weighted-Mean Vector Motion (WMVM) ensemble storm tracks provided by Tim Marchok is key input to Weighted Analog Intensity Atlantic (WAIA) and corresponding Pacific (WAIP) intensity and intensity spread forecasts to seven days

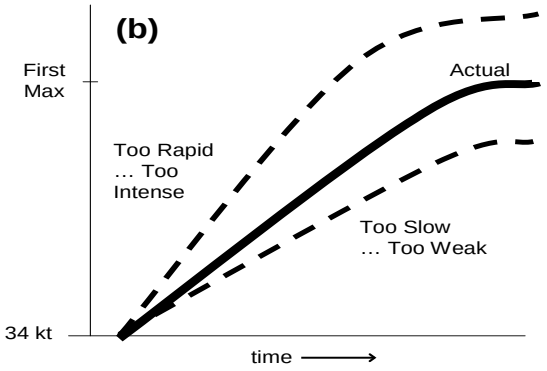
2018 Interdepartmental Hurricane Conference, 13-15 March 2018, Miami, Florida

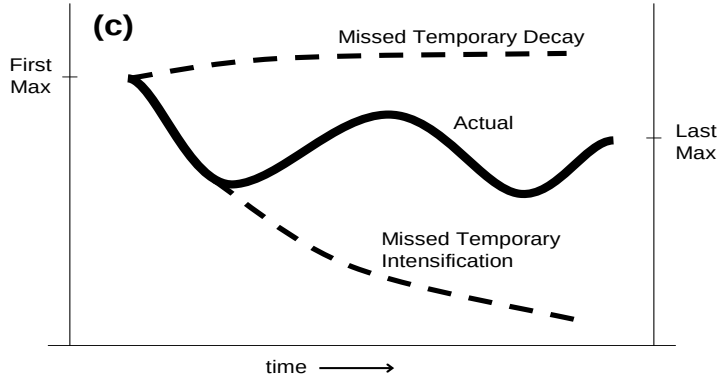
BACKGROUND

- National Hurricane Center (NHC) criteria for pre-genesis watches are that genesis is possible within 48 h and for warnings that genesis is expected within 36 h – for storms that are likely to make landfall
- Tsai and Elsberry (2017a, *Weather and Forecasting*) describe the modification of the 7-day WAIA to ensure that appropriate analogs were selected for “ending storm situations” such as landfall, post-recurvature, and non-development or delayed intensification within the 7-day forecast interval
- Tsai and Elsberry (2017b, Weather and Forecasting) have recently developed an ending storm version of the 7-day WAIP for western North Pacific (WPAC) tropical cyclones
- Objective is now to address the pre-genesis (formation for WPAC) stage in the framework of the 7-day WAIA and 7-day WAIP to provide early watch and warning guidance that will include the subsequent track, intensity, and intensity spread to 7 days

TROPICAL CYCLONE LANDFALL MAY OCCUR DURING ANY OF FOUR INTENSITY STAGES OF LIFECYCLE



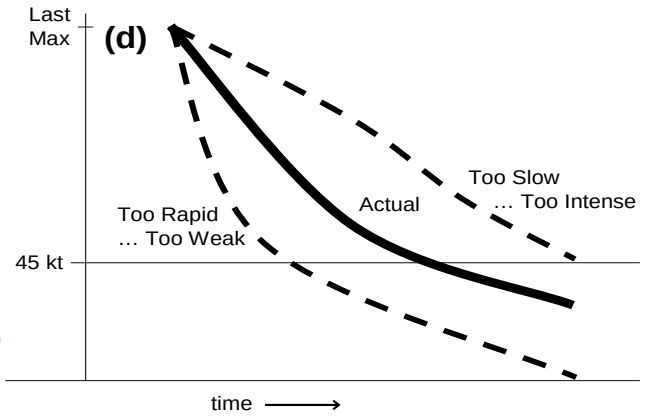




Definitions of intensity change phases during the life cycle of a tropical cyclone:

(a) Phase I—formation;
(b) Phase II—intensification;
(c) Phase IIa—decay and re-intensification cycle; and
(d) Phase III—decay

At the initial time of a 7-day forecast of landfall, the tropical cyclone may be in any of the four intensity changes



WORK PLAN FOR YEAR 1	July – December	January – June
(1.1) Completion of ending storm versions, and development of the pre-genesis/formation (defined as 35 kt) functional form describing optimum intensity		
(i) Western North Pacific (WPAC	X	
(ii) Atlantic	X	
(iii) Eastern/Central Pacific		X
(iv) Report results at 2018 IHC		X
(1.2) Couple the pre-genesis version of the weighted-analog intensity technique to the intensification version with the bifurcation option, with best-track datasets		
(i) WPAC – WAIP		X
(ii) Atlantic – WAIA		X
(iii) Eastern/Central Pacific		X(?)
(1.3) Couple the ending storm version to the coupled pre-genesis and bifurcation version to address landfall, extratropical transition with best-track data		
(i) WPAC –WAIP		X
(ii) Atlantic – WAIA		X
(iii) eastern/Central Pacific		X(?)
(1.4) Receive historical files of Marchok genesis/formation for last 6 months of 2015 (time period of TCI-15) and evaluate Time to Formation (T2F) weighted mean and spread		
(i) WPAC		X
(ii) Atlantic		x
(iii) Eastern/Central Pacific		x

- Original Work Plan began with verification study of the Marchok genesis parameter for the period of the Office of Naval Research Tropical Cyclone Intensity (TCI-15) field experiment when GEFS and ECMWF ensemble storm track forecasts were produced throughout Atlantic and North Pacific

METHODOLOGY FOR DEVELOPING AND TESTING ENDING STORM 7-DAY WAIP

- Separate WAIP versions are developed with the training datasets for ALL Sample, Ending Storms within 7 days (168 h) and Non-Ending Storms that continue at least 168 h

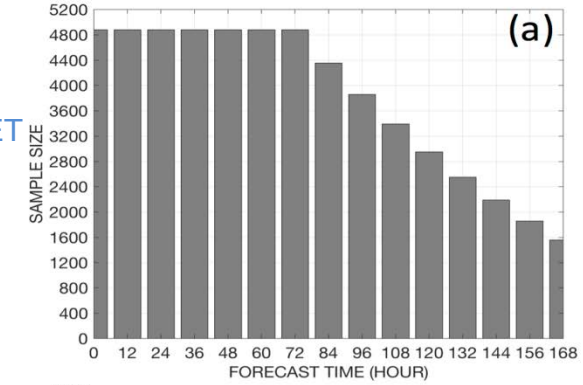
- For each training data set, 10 candidate historical analogs within ± 30 days are selected based on the average track differences between the analog storm and the target storm and on initial intensity difference that must be ≤ 20 kt

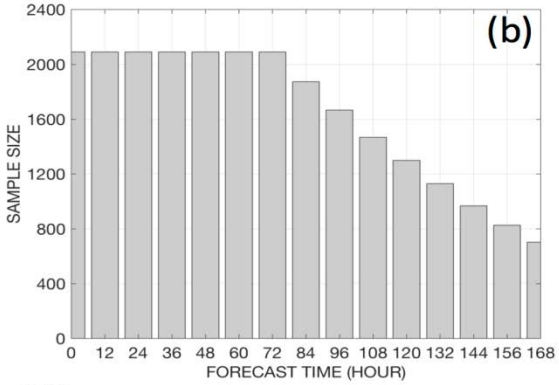
- Final ranking of the 10-best candidate analogs are weighted 0.8 for the track difference ranking and 0.2 for the initial intensity ranking

- Ending storm version of WAIP has an additional constraint in the analog selection that intensity at the last matching point with the end of the target storm track (say at LANDFALL) cannot exceed 50 kt

SAMPLE SIZES FROM 2000-2015
JOINT TYPHOON WARNING CENTER FILES

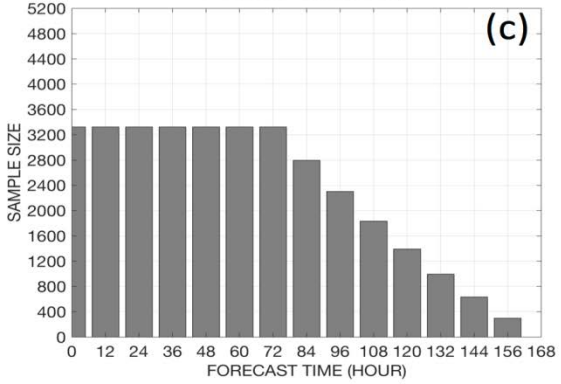
TRAINING DATASET
ALL Sample

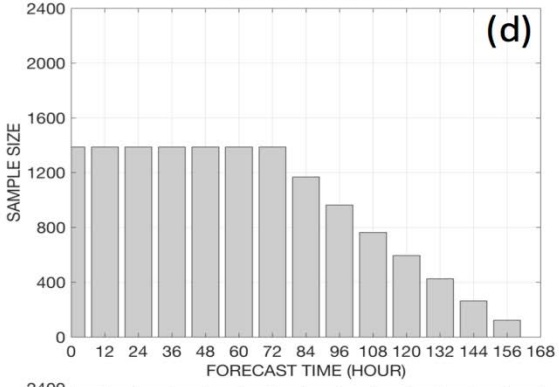




TESTING DATASET
ALL Sample

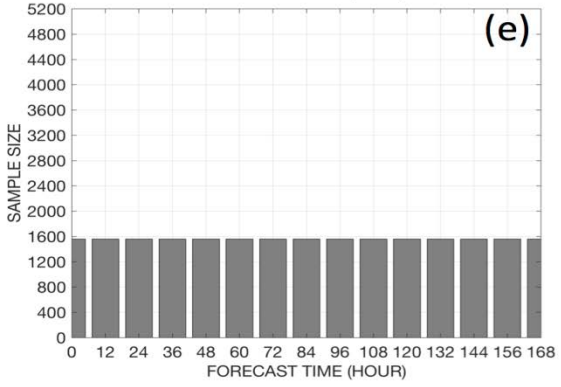
ENDING STORMS

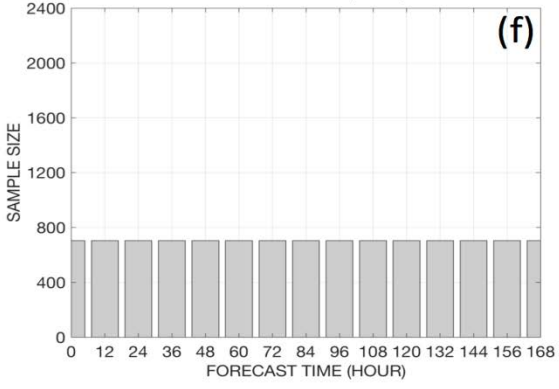




ENDING STORMS

NON-ENDING
STORMS

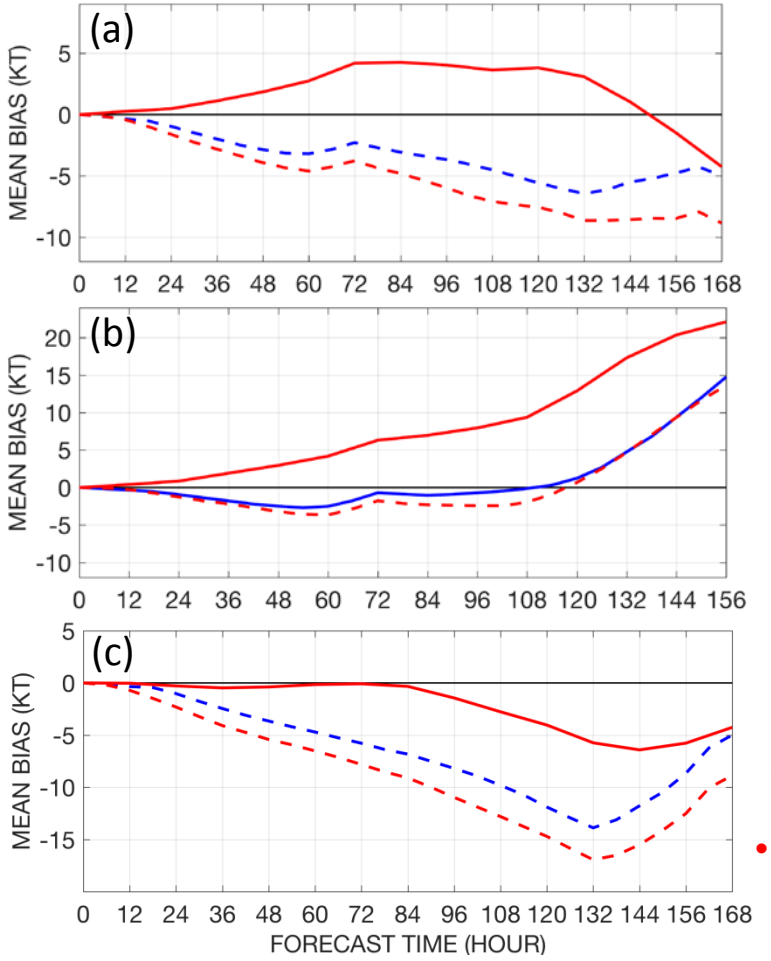




NON-ENDING
STORMS

MEAN INTENSITY BIASES APPLYING ALL SAMPLE BIAS CORRECTION

- Second step in each WAIP development is to calculate from the training dataset a bias correction that reduces to mean bias each 12 h to zero
- If the independent test sample has same intensity characteristics, applying that training sample bias correction should reduce the independent sample mean biases to near-zero



ALL SAMPLE
Dashed blue: Training set mean bias is increasingly negative
Red dashed: Independent sample mean bias before applying bias correction is even larger negative
Red line: Independent sample mean bias after applying ALL Sample bias correction is relatively successful (biases ≤5 kt)

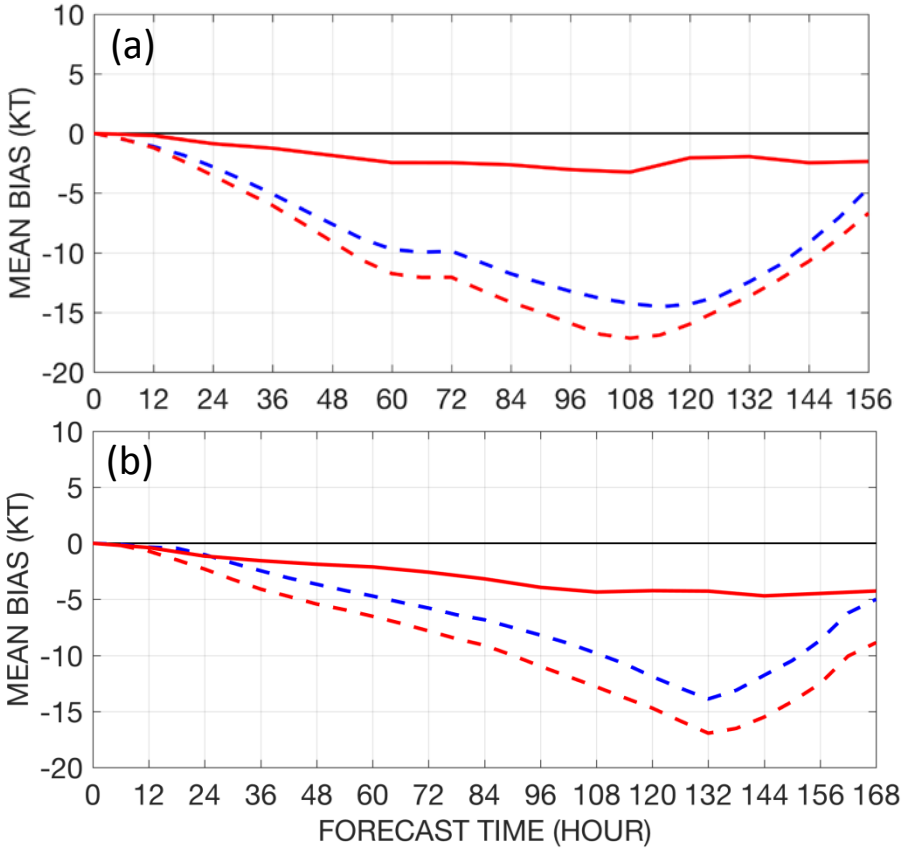
ENDING STORM SUBSAMPLE OF ALL SAMPLE
(without applying ending storm constraint)
Training and independent subsamples have very similar mean biases with increasingly positive bias (over-forecast) after 120 h because they actually end before 7 days
Applying ALL SAMPLE bias correction does not reduce independent mean bias to near-zero values (red line)

NON-ENDING SUBSAMPLE OF ALL SAMPLE
Training and independent samples have somewhat different mean biases
Applying ALL SAMPLE bias correction is successful to 84 h, but not in 120 h to 168 h forecast interval

- **Conclude that ending storms and non-ending storms require separate bias corrections (rather than ALL SAMPLE bias correction)**

MEAN INTENSITY BIASES FOR ENDING STORMS AND NON-ENDING STORMS
APPLYING SEPARATE BIAS CORRECTIONS

- Ending storm subsample now has additional constraint on analog selection that intensity at last matching point cannot exceed 50 kt, and thus this set of analogs does not have the same mean biases as in PPT 6



ENDING STORMS

Training (blue dashed) and Independent subsample (red dashed) mean biases before applying new ending storm bias correction have similar large negative biases

Independent subsample (red solid) mean biases after applying separate bias correction is very successful with mean biases ≤ 3 kt at all forecast intervals

NON-ENDING STORMS

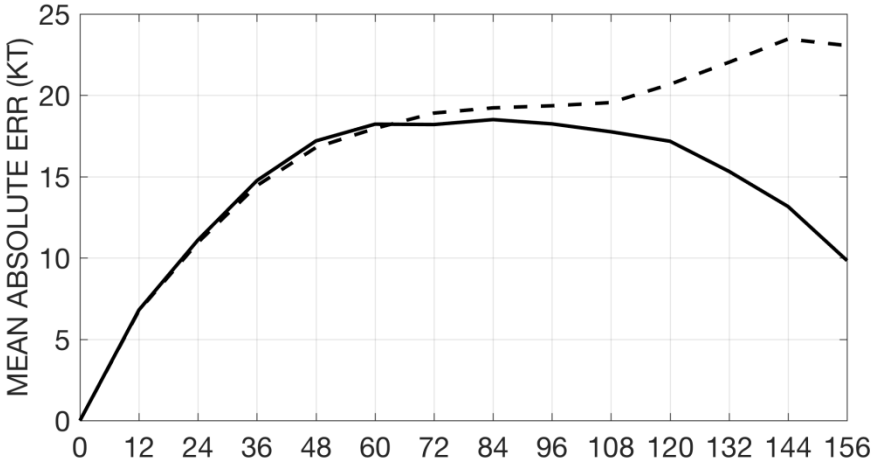
Training and Independent subsample mean biases before bias correction are similar but have somewhat different magnitudes

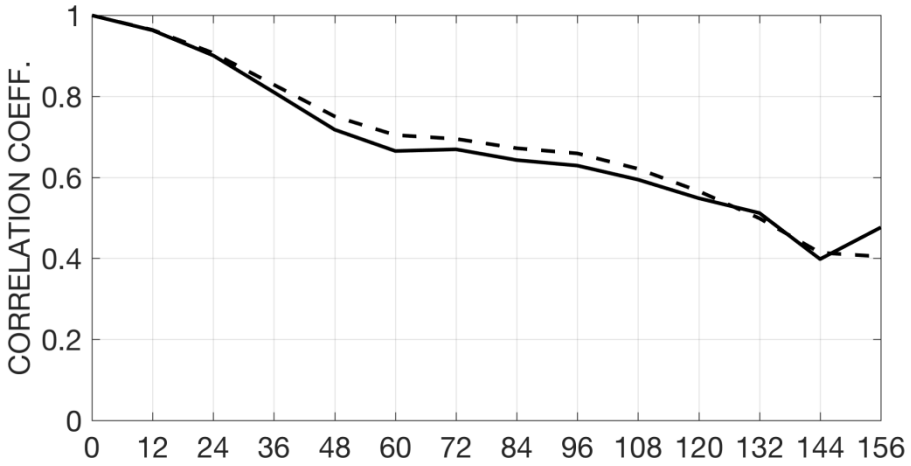
Independent subsample mean biases after applying separate bias correction are successful as magnitudes are reduced to < 5 kt

- **Conclude that separate bias corrections for the ending storms and for the non-ending storms are required, and will contribute to reduced WAIP intensity forecast errors**.

INDEPENDENT SET PERFORMANCE EVALUATION FOR ENDING STORMS

- Mean Absolute Errors (MAEs) for the independent set of ending storms when the All Sample bias correction was applied (dashed line) have increasingly larger values (especially after 108 h)
- MAEs when separate ending storm bias correction is applied (solid line) begin to decrease after 84 h and are only 10 kt at 156 h

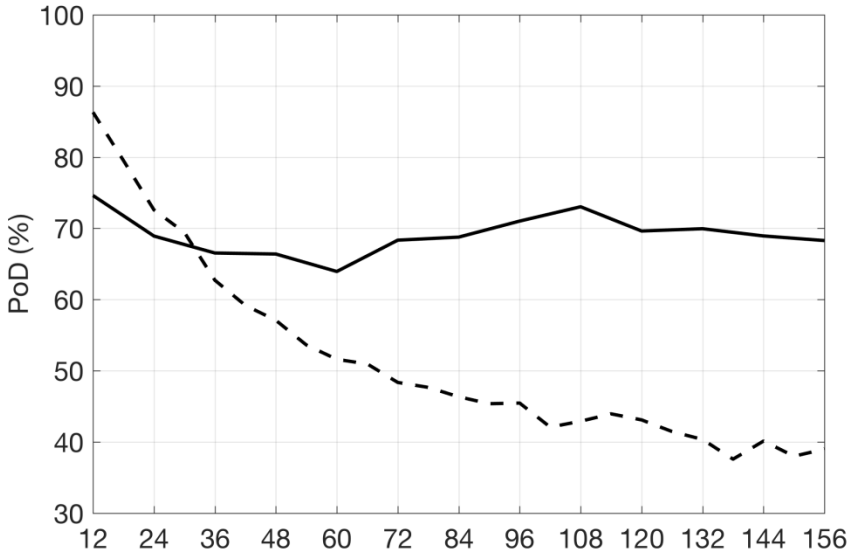


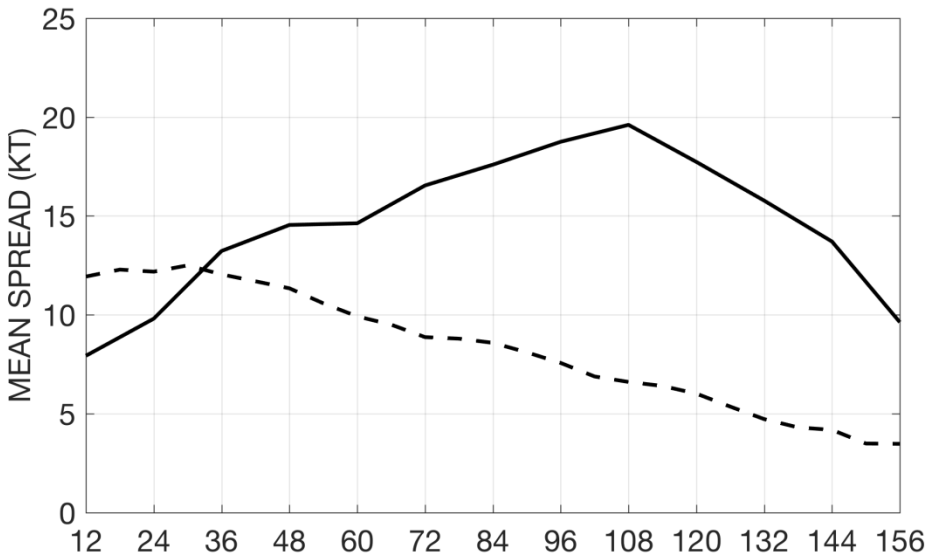


- Correlation coefficients of the WAIP intensity predictions with the verifying intensities for both the applications of the separate ending storm bias correction (solid line) and the All Sample bias correction (dashed line) are similar with decreases to < 0.6 after 108 h.
- Note that the sample sizes of the independent sample of ending storms is becoming small after 108 h and is about 100 at 156 h.

INDEPENDENT SET PERFORMANCE EVALUATION FOR ENDING STORMS

- Third step in the development of WAIP predictions is to calibrate the training set "raw intensity spreads" among the 10 analog intensities each 12 h to ensure an intensity spread that would include 68% of the verifying intensities also for the independent set
- For independent ending storm subsample, the raw intensity spreads without calibration (dashed line) would have a Probability of Detection (PoD, %) of 85% at 12 h, but would decrease to 68% by 30 h, and be < 40% after 132 h
- Calibration of the intensity spreads for the independent ending storm subsample (solid line) leads to PoD of 75% at 12 h, and very close to the desired 68% for the entire forecast intervals from 24 h to 168 h



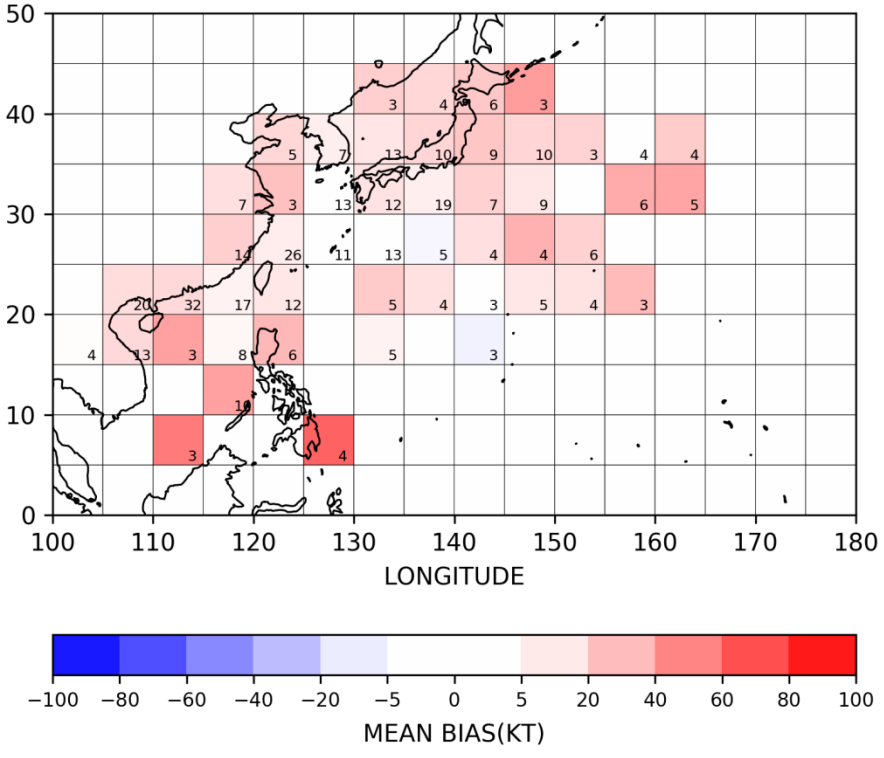


- Without calibration, the independent ending storm subsample mean intensity spreads (dashed line) decrease with forecast interval from 12 kt at 12 h to less than 5 kt at 156 h (because all of these storms must end by 168 h, and with the best-track intensities being used, the intensity spread is very small).
- After calibration to ensure a PoD of 68% for the WAIP predictions, the mean intensity spread increases from 8 kt at 12 h to 20 kt at 108 h, but then reduces to only 10 kt at 156 h (solid line).

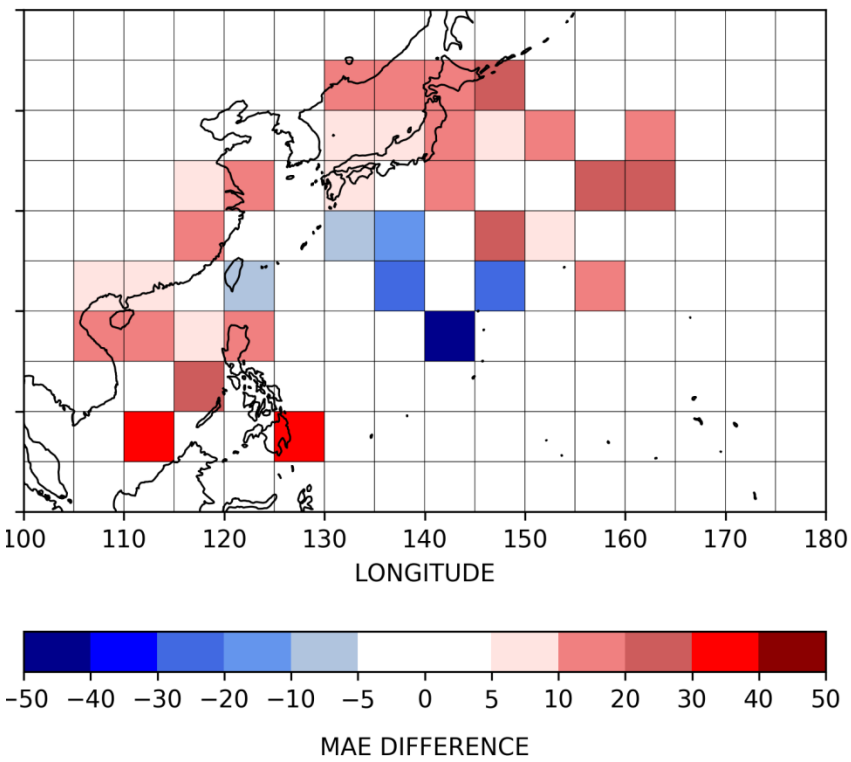
SPATIAL DISTRIBUTION OF THE REDUCED MAEs FOR ENDING-STORMS

- Mean biases of the original WAIP forecasts are positive (i.e., over-forecasting).
- Most of the reduced MAEs (i.e., improvements) are over the land and near the coast lines.

Mean Bias (Original WAIP)



Reduced MAEs



SUMMARY OF IMPROVED WAIP FOR ENDING STORMS

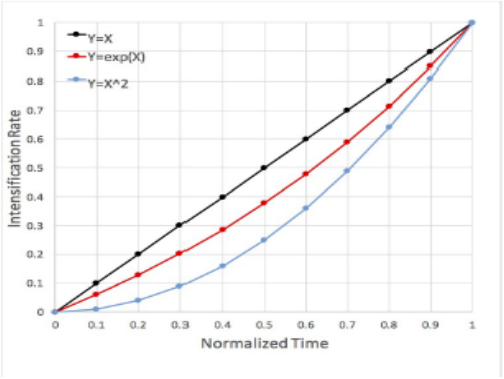
- 7-day WAIP technique has been modified to separately forecast ending storms and non-ending storms within 7 days
- Separate bias corrections for the ending storms results in improved MAEs in the 5- to 7-day forecast interval
- Calibration of intensity spread values to include 68% of verifying intensities results in smaller spreads (or higher confidence) for the ending storms
- These new ending storm (and non-ending storm) WAIP forecasts can be calculated on a desktop computer in a few minutes once the official 7-day track forecast is generated and the initial intensity is known.
- Thus, the forecaster could easily vary the landfall time to take into account likely along-track errors to see the impact on the WAIP intensity forecast.
- Another category of ending storm within 7 days is the non-developing circulation systems. Second improvement in WAIP is for pre-formation cases, or alternatively an identification of non-formation within 7 days

IMPROVING WAIP FOR PRE-FORMATION STAGE

- As suggested in PPT 2, the WAIP accuracy during the Phase II intensification is primarily a function of intensification rate, but is also affected by the timing of when 35 kt intensity is achieved, i.e. formation time.

- Same 2000-2015 dataset has been utilized to improve the WAIP accuracy during the pre-formation stage by estimating the intensity assuming one of three functional forms (linear, exponential, or square) between initial time (t=0) to formation time (t=1.0).

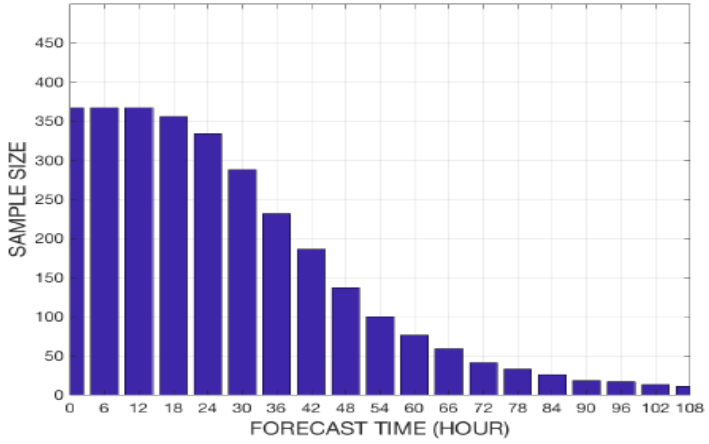
- JTWC best tracks from 2000-2015
  - Only the "developers" are used:
    - Max. Intensity could reach at least 35 kt.
- The Vmax of the first point (V0) must be at least 15 kt
- Given the formation time, the intensities between V0 and 35 kt are estimated by using the:
  - linear function
  - Exponential function
  - Square function



2

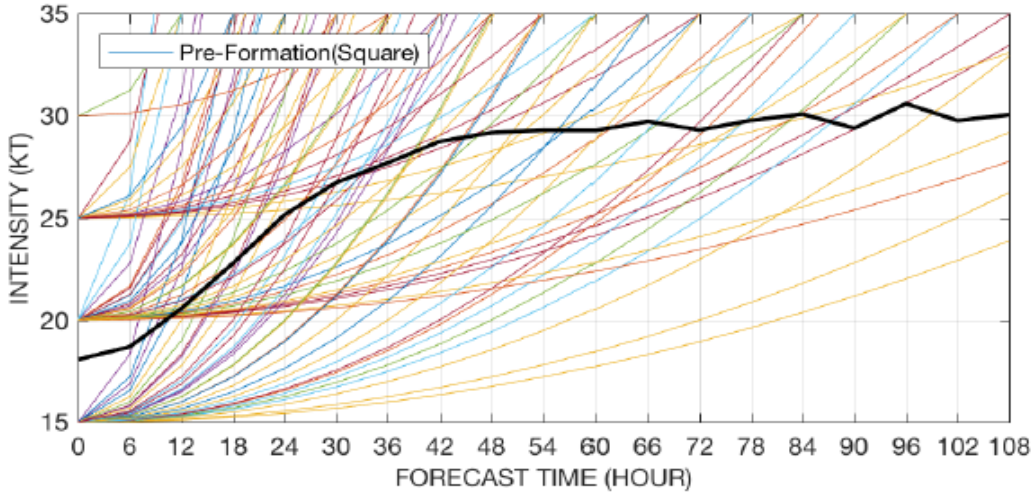
SAMPLE SIZES OF PRE-FORMATION FORECASTS DURING 2000-2015 WITH AT LEAST 10 ANALOGS FOR WAIP

- For forecast intervals of only 6, h, 12 h, or 18 h until formation, sample sizes are ~ 350.
- For forecast interval of 42 h until formation, the sample size has decreased by 50%
- It is relatively rare for a TC-like circulation system in western North Pacific to take more than 72 h to undergo formation defined as 35 kt.

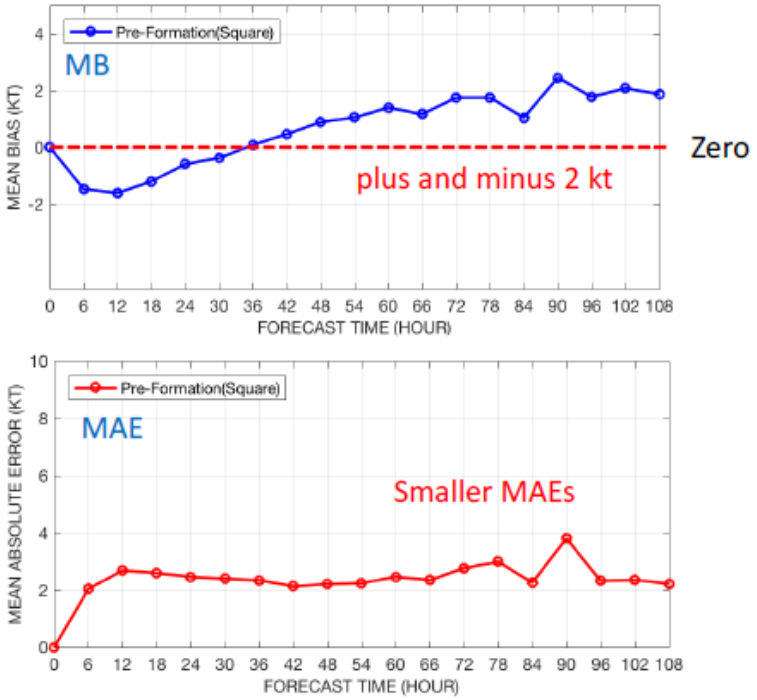


INTENSITY EVOLUTIONS ASSUMING A SQUARED FUNCTION FROM INITIAL TIME TO FORMATION TIME

- For an initial intensity of 15 kt, a few cases are already at 35 kt in 12-18 h, a large cluster intensify to 35 kt in < 42 h, but some take longer than 72 h to formation.
- For an initial intensity of 20 kt, more cases reach 35 kt in 12-18 h, and a larger fraction reach 35 kt by 72 h, but a few do not reach 35 kt until beyond 96 h.
- For an initial intensity of 25 kt, the majority reach 35 kt over a range of 24 h to 72 h, and none take longer than ~ 120 h to reach 35 kt.



MEAN BIASES AND MAES ASSUMING SQUARE FUNCTION FOR PRE-FORMATION INTENSITY EVOLUTION



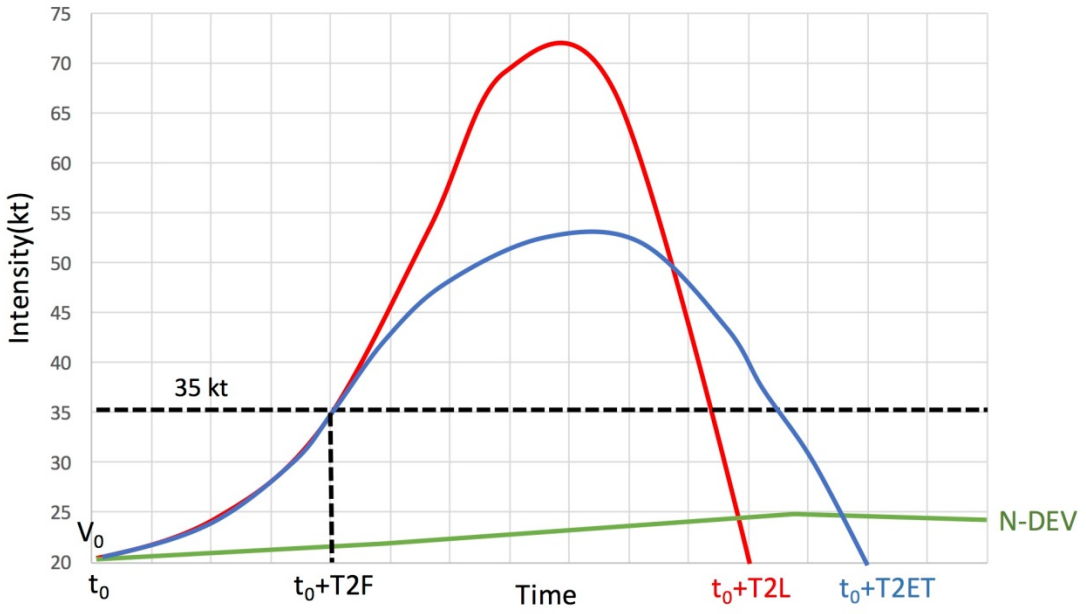
- If the Time to Formation (T2F) is known, assuming a square function intensity evolution from the initial time to the formation time will have a small mean bias (MB) and smaller mean absolute errors (MAEs) than the exponential function or the linear function.

DISCUSSION OF PRE-FORMATION STAGE WAIP

- In this study with the JTWC best-track files, the formation time (and thus the T2F) is known.
- In operations, the JTWC forecaster would have to provide the T2F, or specify that the TC-like circulation will not form within 7 days (the non-developing cases in the ending storm version of WAIP)
- JTWC has a Tropical Cyclone Formation Alert (TCFA), but only to 24 h
- For the 24 – 48 h forecast interval, perhaps the regional numerical models such as COAMPS-TC and HWRF may provide guidance as to the T2F
- In our JHT project, we will apply Tim Marchok's track genesis prediction of formation based on the NCEF GEFS ensemble storm track forecasts that are available at JTWC. To account for uncertainty in that formation time, we will test an "early formation" versus "late formation" relative to the Marchok formation time.

(Proposed) OPERATIONAL TEST OF COMBINED WAIP

PRE-FORMATION INTENSIFICATION ENDING STORM

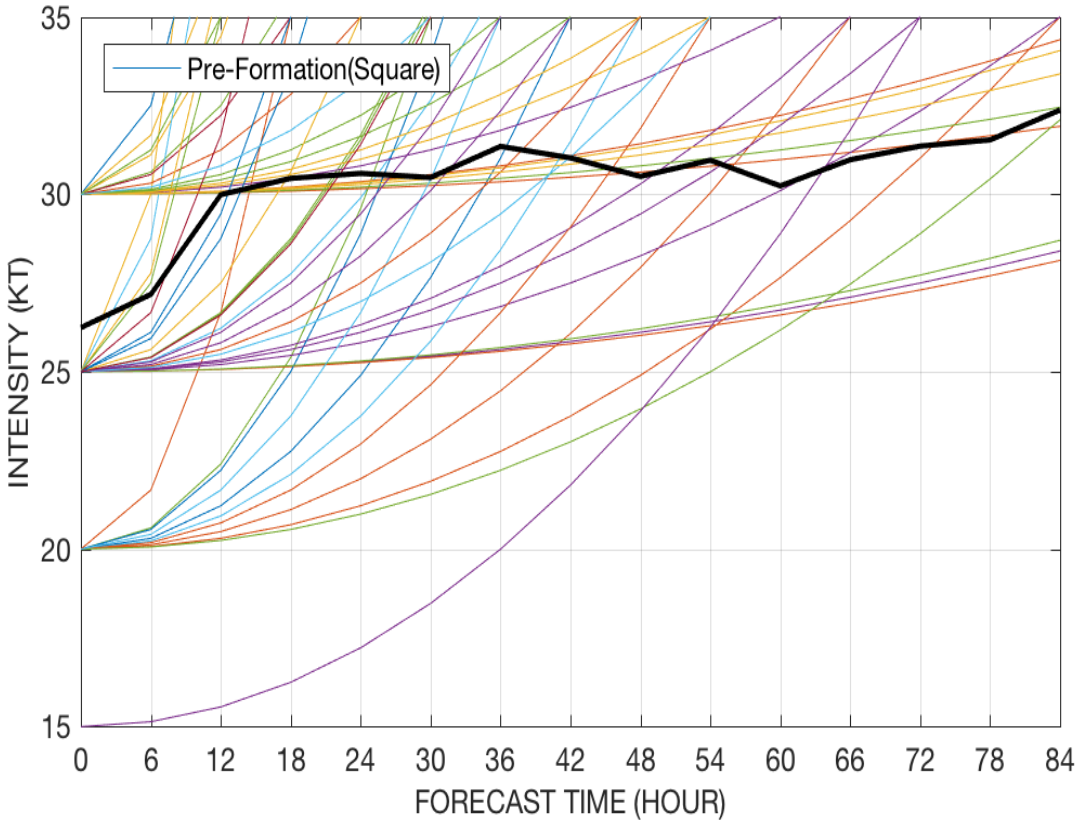


Time to Formation (T2F) provided from Marchok formation prediction
Time to Landfall (T2L) from JTWC forecast or GEFS track forecast
Time to Extratropical Transition (T2ET) from Marchok ET prediction
Non-Development (N-DEV) from Marchok non-formation prediction

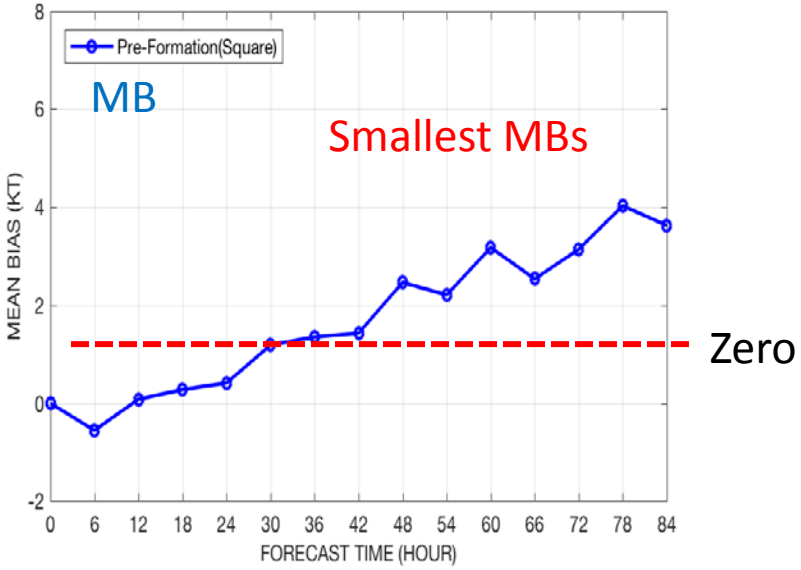
RESERVE SLIDE

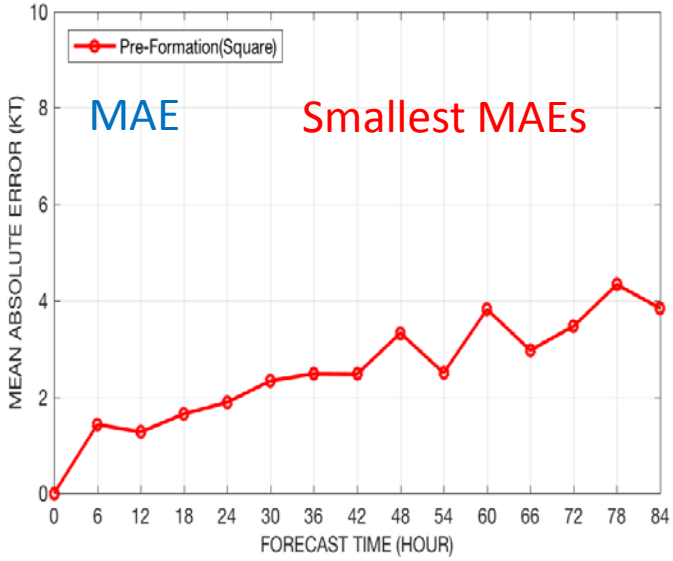
WORK PLAN FOR YEAR 2	July – December	January – June
(2.1) Publish the results of combined pre-genesis, intensification stage, and ending storm version using best-track inputs in all three basins	X	
(2.2) Evaluation of Marchok T2F forecasts in archive (i) WPAC retro test (ii) Atlantic retro test (iii) Present results at 2019 IHC	 X X	 X
(2.3) Develop an alternate ensemble storm track forecast type if the prior WMVM ensemble storm track forecast technique is not available from Marchok	X	
(2.4) Production, monitoring, and evaluation of quasi-real time intensity and intensity spread predictions with Marchok T2F and uncertainty range (i) WPAC – WAIP (ii) Atlantic – WAIP (iii) Eastern/Central Pacific	 X X	 X X X
(2.5) Publish results of quasi-real –time intensity and intensity spread forecasts for 2018, and present results at 2019 IHC		X

SQUARED FUNCTION INTENSITY EVOLUTIONS FROM INITIAL TIME TO FORMATION TIME-ATLANTIC



MEAN BIASES AND MAEs ASSUMING SQUARE FUNCTION FOR PRE-FORMATION INTENSITY EVOLUTION - ATLANTIC





FLOW CHART FOR IDENTIFICATION OF FORMATION AND NON-DEVELOPMENT OF GEFS ENSEMBLE STORMS AND BLENDING PRE-FORMATION WAIP WITH BIFURCATION INTENSIFICATION AND ENDING STORM VERSIONS