COMBINED THREE-STAGE 7-DAY WEIGHTED ANALOG INTENSITY PREDICTION TECHNIQUE FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES: DEVELOPMENT AND IMPLEMENTATION PLANS*

Russell L. Elsberry
University Colorado-Colorado Springs
and Naval Postgraduate School

Hsiao-Chung Tsai
**Tamkang University**

OUTLINE

- Add a separate pre-formation stage to the original 7-day Weighted Analog Intensity Pacific (WAIP) intensity and intensity spread prediction technique (Tsai and Elsberry 2014, 2015).

- Demonstrate optimum performance of combined, three-stage 7-day WAIP with JTWC best-track dataset for the "target track forecast," initial intensity, Time-to-Formation (T2F), defining the ending storm time, and always making the correct cluster intensity selection in bifurcation situations.

- Describe pre-operational tests with GEFS track forecasts and Warm Core Magnitude (WCM) diagrams to define initial intensity, T2F, and ending storm times as inputs to the combined three stage WAIP that will be implemented at JTWC.

ADDITION OF A SEPARATE PRE-FORMATION STAGE IN COMBINED WAIP

- The WAIP accuracy during the 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.

- 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.
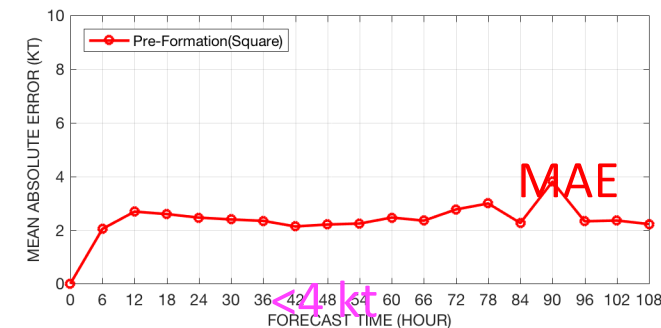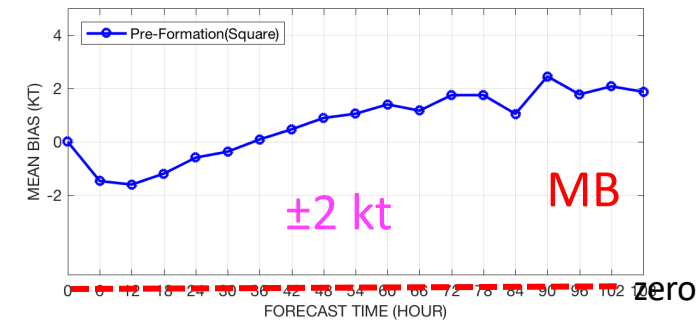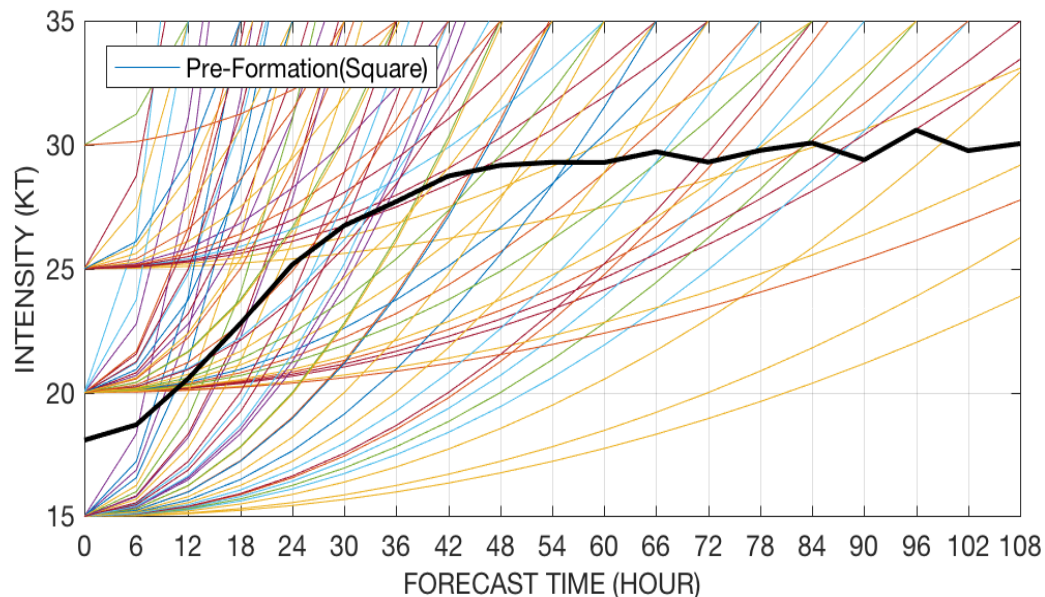
- Here T2F is from JTWC best-track; challenge in forecasting is to estimate T2F

OPTIMUM PERFORMANCE OF COMBINED VERSION OF THE 7-DAY WAIP

- **Combined 7-day WAIP**

1. **Before formation (<35 kt):**
   - Assume that time to formation T2F is known
     - For this development, JTWC best-track file provides the T2F.
   - Square function between initial intensity and 35 kt is the intensity evolution forecast.

2. **After formation:**
   - Three versions of the 7-day WAIP are combined:
     - The original 7-day WAIP (Tsai and Elsberry 2015)
     - The intensity bifurcation version (Tsai and Elsberry 2014 & 2018)
     - The ending-storm version (Tsai and Elsberry 2017)
   - Only the track forecasts starting from the formation time are used for searching the track analogs, so the pre-formation stage of the combined WAIP is separate from the after-formation WAIP

OPTIMUM PERFORMANCE SEARCH FOR THE TRACK ANALOGS

- Only tracks in the JTWC best track dataset within ±30 days of the date of the target storm are considered.

- Two metrics are considered:
  - Average track difference (d_{Track} ; unit: degrees)
  - Initial intensity difference (d_{V0}; unit: knots)

- Sorting the d_{Track} and d_{V0} in ascending order:
  - $Rank_{dTrack}$
  - $Rank_{dV0}$

- The final ranking of the analogs is according to:
  $$Rank_{Analog} = w_{Track}*(Rank_{dTrack}) + w_{V0}*(Rank_{dV0})$$
 *where the weighting factors* $w_{Track} = 0.8$ *and* $w_{V0} = 0.2$

- $Rank_{Analog}$ is then sorted in ascending order to select the 16 best analogs with corresponding intensity observations.

Key point is that this selection of analogs to the target storm track can be done on a desktop computer in 1-2 minutes.
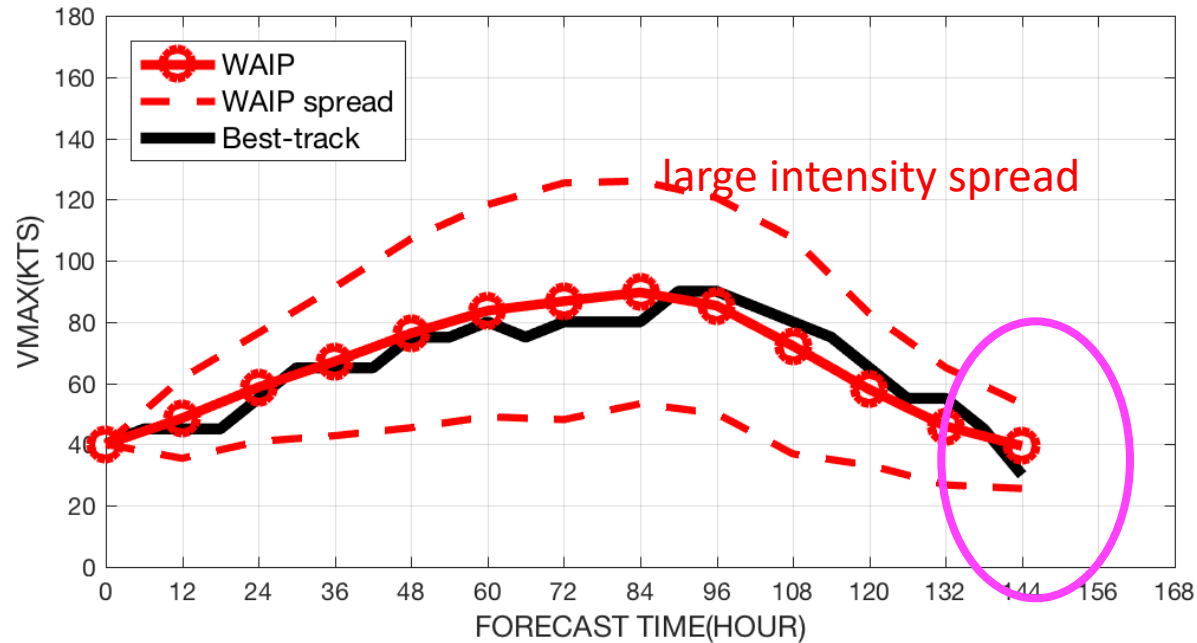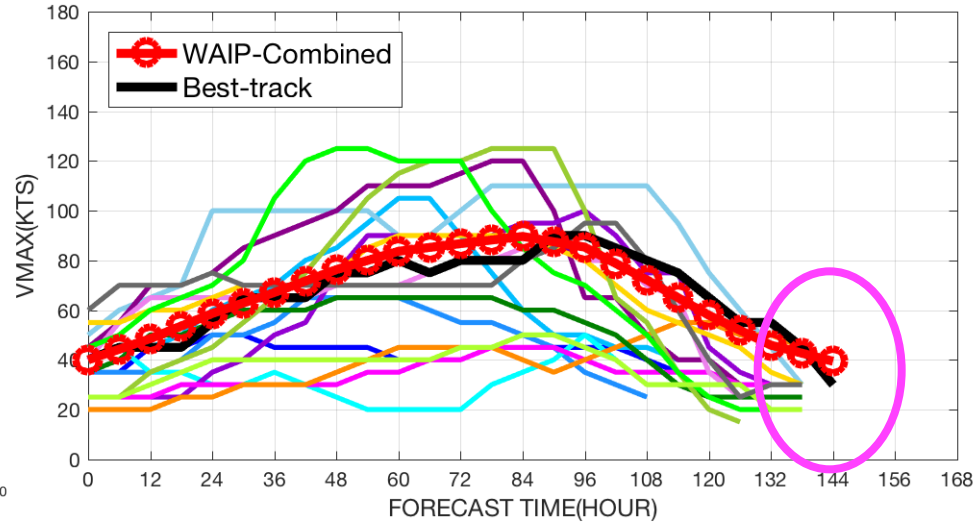
WAIP-<u>Combined</u> (with ending storm constraint)
Typhoon Matsa(09W) 1800 UTC 31 Jul 2005

Select 16 analogs ranked by track/intensity
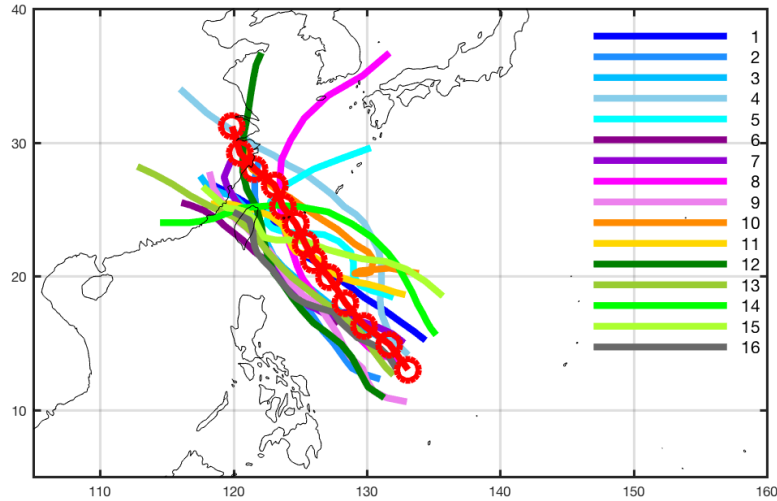
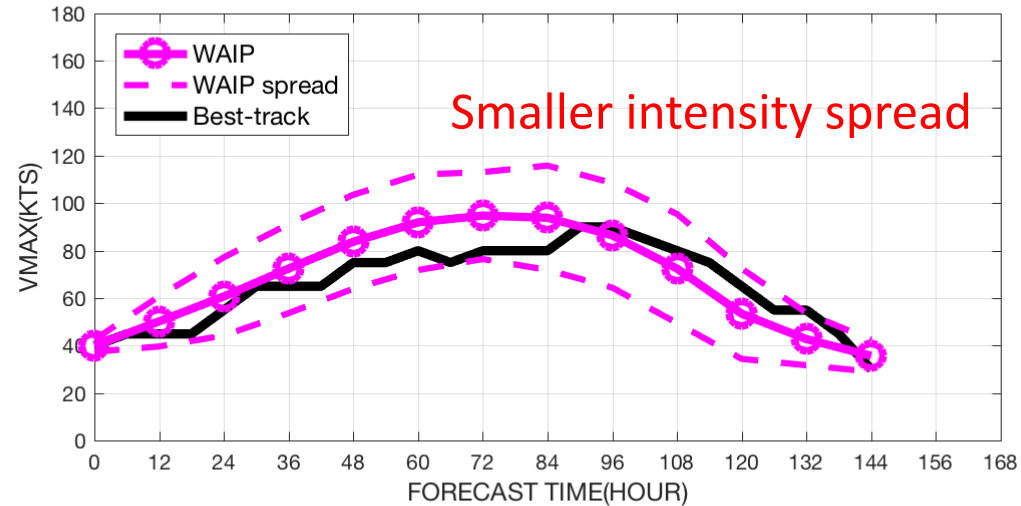Specific set of analogs all with Vmax < 50 kt at ending time

large intensity spread

ending-storm constraint is successful in reducing over-forecast intensity in Original WAIP

WAIP-Combined with Bifurcation version included
Typhoon Matsa(09W) 1800 UTC 31 Jul 2005

Large intensity spread as in PPT 5 meets the objective definition of a bifurcation (bimodal) situation (Tsai and Elsberry, 2018 *APJAS*), and two cluster intensity solution are derived with separate intensity spreads
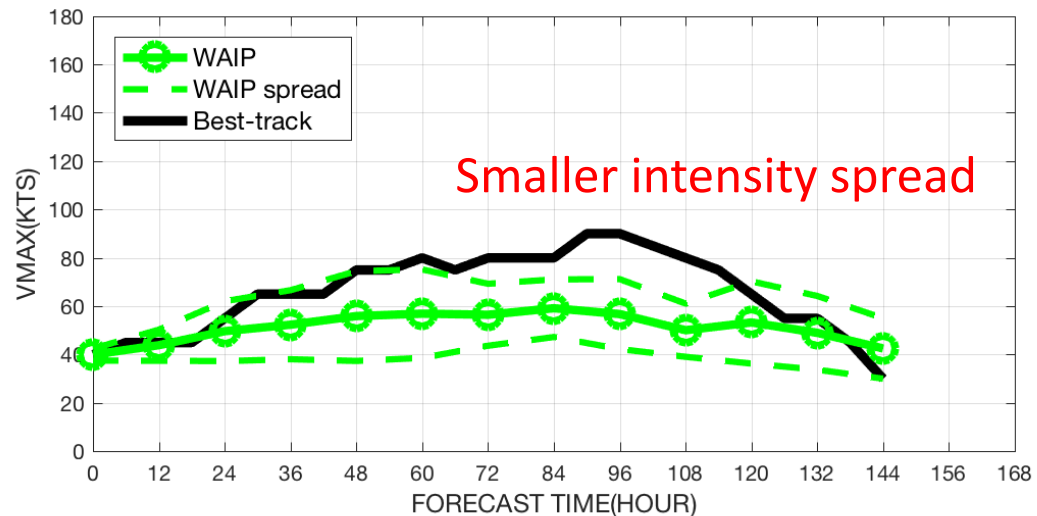
Intensity Cluster-1

Similar to the WAIP combined intensity forecast but the intensity spread is only ~50%

Smaller intensity spread

Intensity Cluster-2

Weaker intensity forecast with verifying intensity outside the spread

Smaller intensity spread

Interdepartmental Hurricane Conference, Miami, Florida, March 13, 2019

FORECAST VERIFICATION: BEFORE FORMATION
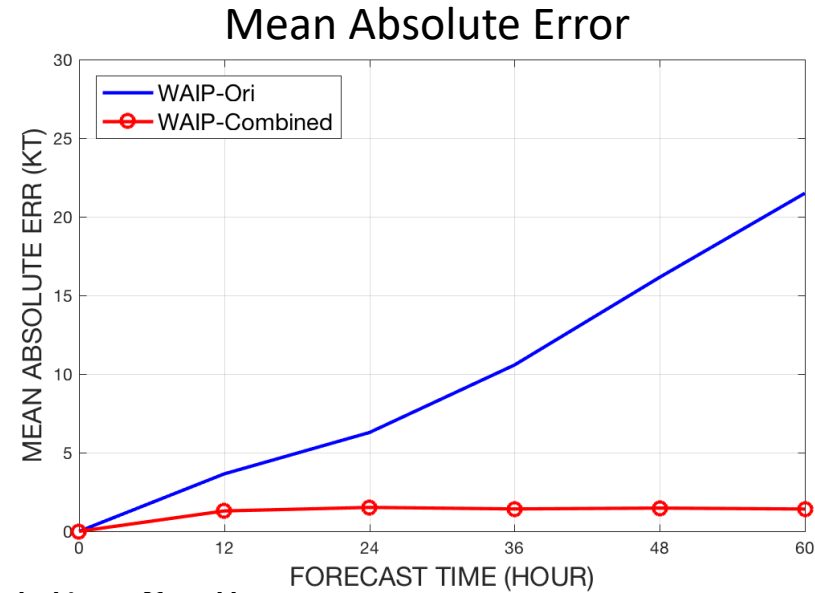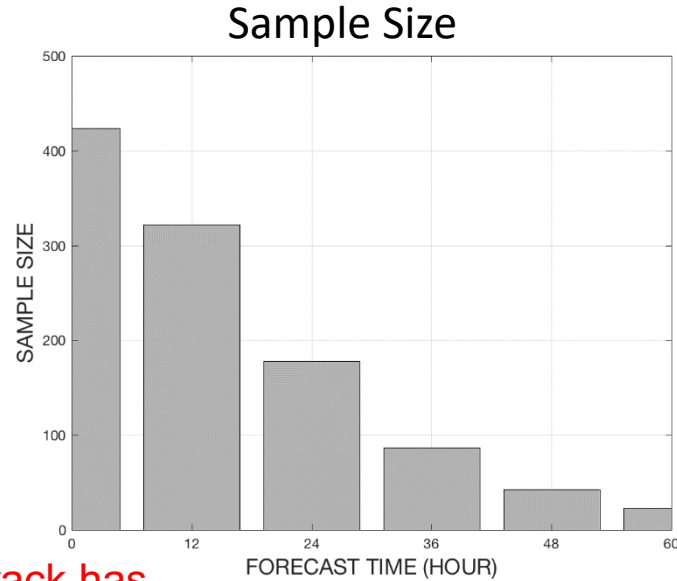
Note: JTWC best-track has only small number of pre-formation stage (15 kt and 20 kt) cases longer than 24 h, and the benefits of small MAEs during pre-formation stage of WAIPS are not realized. Furthermore, the tracks are very good if formation was only 12 h or 24 h ago. Objective now is to extend the pre-formation stage to up to 5 days.

Interdepartmental Hurricane Conference, Miami, Florida, March 13, 2019
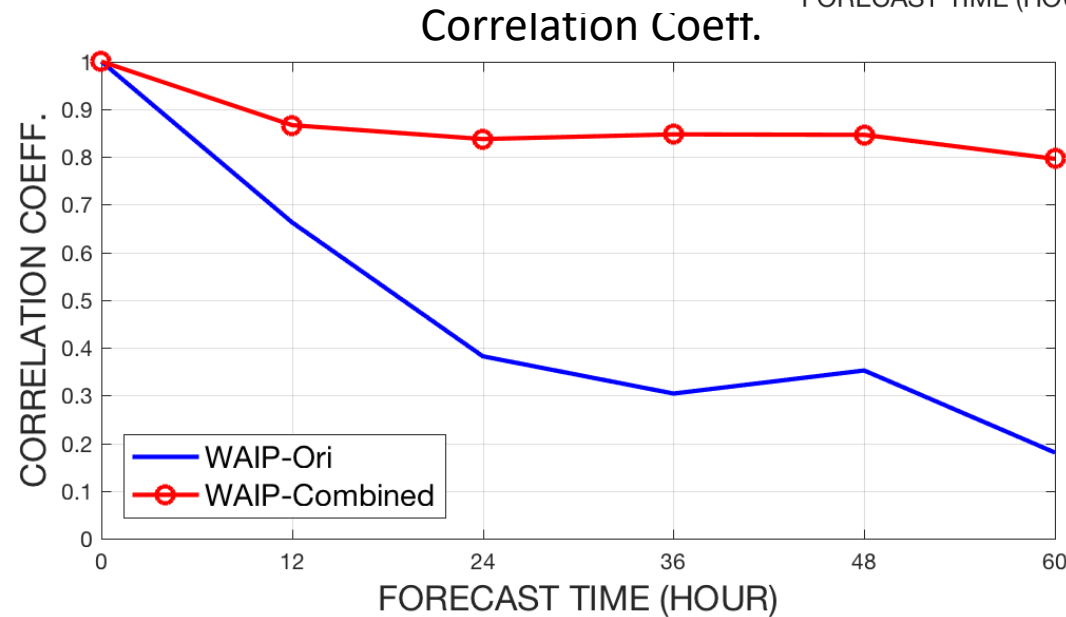
FORECAST VERIFICATION: AFTER FORMATION WITH BIFURCATION

Sample Size

Mean Absolute Error

Correlation Coeff.

Probability of Detection (%)
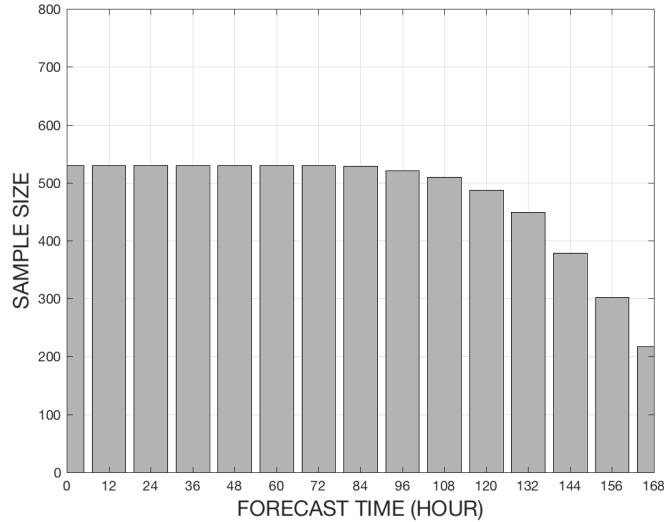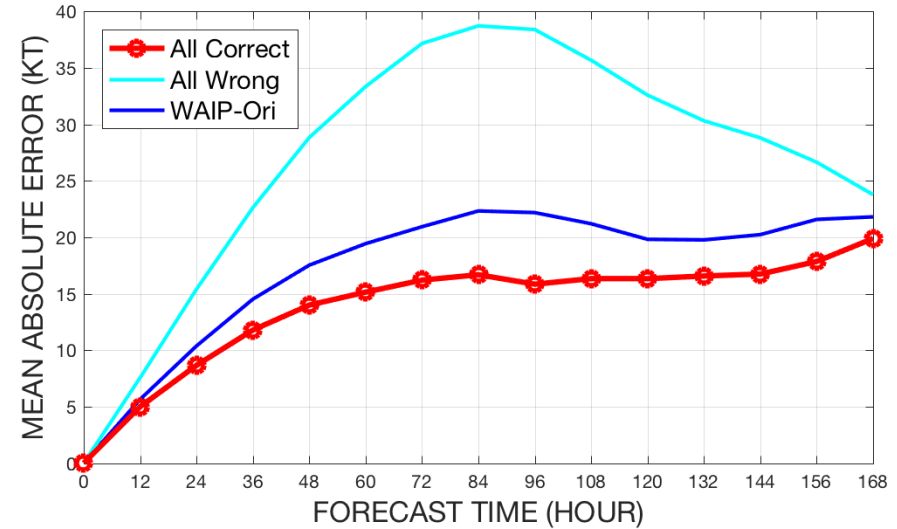
- If the forecaster always picked the Correct cluster intensity forecast in these bifurcation situations, the MAEs increase less rapidly during the first 72 h, and this improved performance continues through 144 h. Conversely, there is a large penalty MAE if forecaster always picks the Wrong cluster intensity.
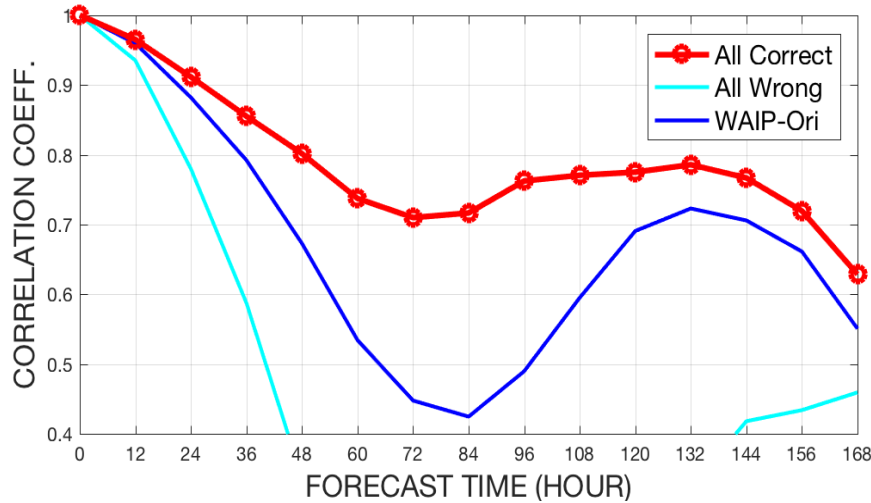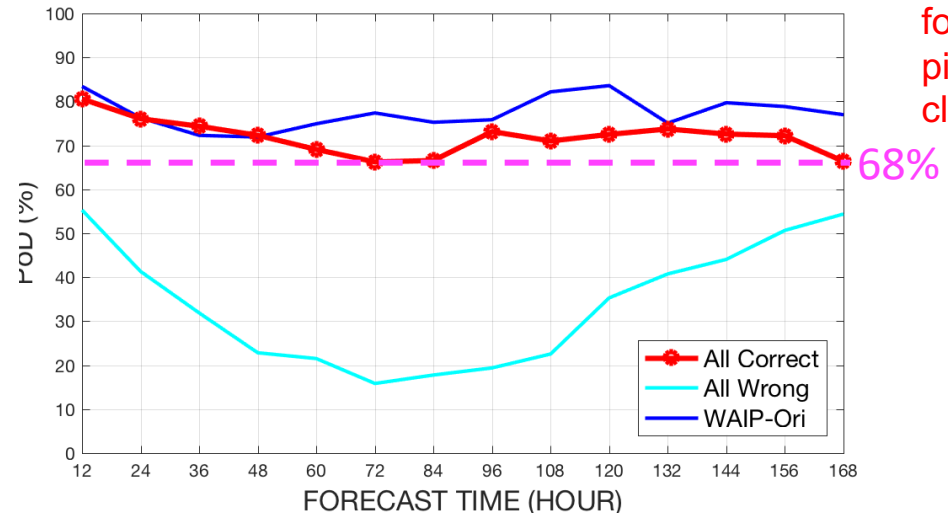
OPTIMUM PERFORMANCE SUMMARY

- Three versions of the 7-day WAIP are combined and tested with best-track files to provide improved intensity and intensity spread predictions to 7 days :

  - The original 7-day WAIP

  - The intensity bifurcation version

  - The ending-storm version

- Pre-formation stage: square function leads to small MAEs **IF** T2F is known. Recall that most of these JTWC best-track storms have T2Fwithin 24 h.

- The bifurcation version provides an opportunity to select a better intensity cluster with smaller MAE growth rate that then contributes to smaller MAEs for 72 h to 144 h

- Calibration of intensity spread values results in appropriate probability of detection to include ~68% of verifying intensities .

IMPLEMENTATION PLAN – TRACK FORECAST

- In optimum performance testing of combined WAIP of 30% randomly selected cases during the 2000-2015 WPAC seasons, JTWC best-tracks were used rather 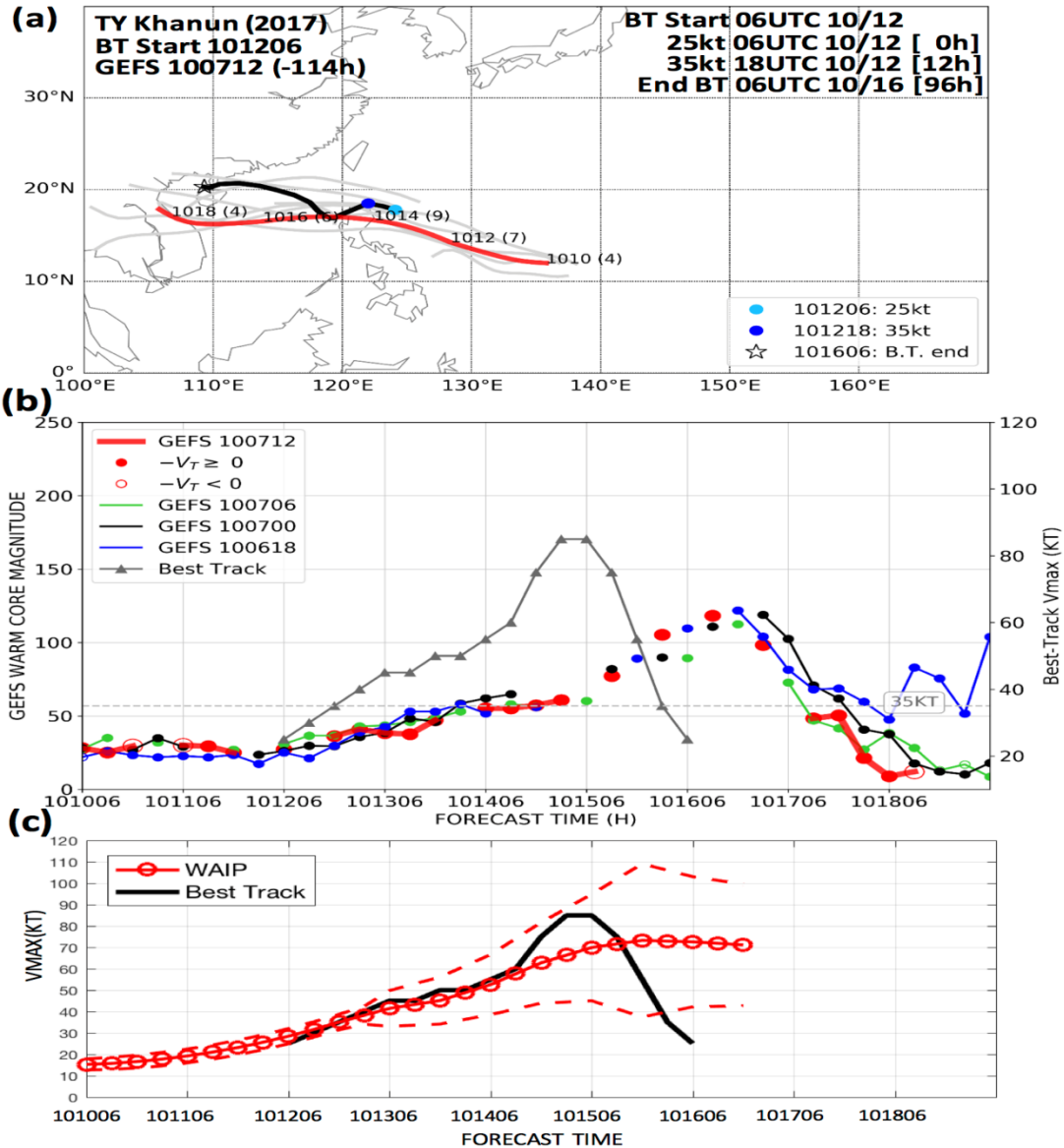than official track forecasts, best-track intensity was used for initial intensity from the warnings, the Time to Formation (T2F) and ending storm time were also from the JTWC best track. Furthermore, the correct cluster intensity selection was always made in bifurcation situations.

- To develop a combined WAIP version for implementation at JTWC, each of these variables and WAIP inputs have to be based on information available in advance to the JTWC forecaster.

- Track forecasts are from GEFS (or ECMWF ensemble) forecasts in which Weighted-Mean Vector Motion (WMVM) ensemble storm track forecasts have been created (rather than an ensemble mean track that assumes each ensemble member is equally likely)
  - Tsai and Elsberry (2011) had demonstrated that the WMVM ensemble storm tracks of the pre-formation circulations typically began 3-4 days prior to JTWC T2F as a TD (25 kt) or TS (35 kt)
  - Opportunity to search for that T2F along these WMVM ensemble storm track forecasts – but track forecast errors will lead to T2F uncertainty compared to the optimum performance testing of the combined WAIP described above

IMPLEMENTATION PLAN – ESTIMATING T2F ALONG GEFS ENSEMBLE STORM TRACK FORECAST

- Tim Marchok had defined "genesis parameters" for Atlantic storms determined from the Hart (2003) Cyclone Phase Space (CPS) parameter

- For WPAC pre-TC circulations in the GEFS, we use:
  - CPS Low-level warm core (acronym V_tL) that is positive for a TC
  - CPS Upper-Level warm core (acromym V_tU) that is positive for a TC

- Weighted-mean lower-layer (900 – 600 mb) V_tL and upper-layer (600 – 300 mb) V_tU along each of the 20 member GEFS track forecasts are calculated with the same radius-squared weighting factors as in the WMVM calculation that gives the largest weight to the ensemble member with a 12-h motion vector that most closely agrees with the past 12-h WMVM vector. That is, we want the CPS variables that best represent those along the WMVM track because we want the T2F along that WMVM track forecast

- Basic assumption is then that the GEFS forecasts of the environmental factors that determine TC formation will predict where and when along the ensemble storm track forecast that a deep warm core will be created in a pre-TC circulation, which will then be designated as the Time-to-Formation (T2F).

(a) TY Khanun (2017)
BT Start 101206
GEFS 100712 (-114h)

BT Start 06UTC 10/12
25kt 06UTC 10/12 [0h]
35kt 18UTC 10/12 [12h]
End BT 06UTC 10/16 [96h]

1018 (4) 1016 (6) 1014 (9) 1012 (7) 1010 (4)

101206: 25kt
101218: 35kt
101606: B.T. end

(b)

GEFS 100712
$-V_T \geq 0$
$-V_T < 0$
GEFS 100706
GEFS 100700
GEFS 100618
Best Track

35KT

(c)

WAIP
Best Track

# EXAMPLE OF WCM DIAGRAM AND COMBINED WAIP FOR TY KHANUN

- GEFS forecast from 12 UTC 7 October (114 h in advance of first entry in JTWC best-track) predicted a pre-TC circulation starting at 06 UTC 10 October well to east of actual formation position of Khanum

- Track forecast indicates potential threat to Luzon, maritime activities in South China Sea, and Southeast Asia

- Four consecutive GEFS-based WCM diagrams indicate potential severe tropical storm or minimal typhoon may develop

- Best track intensity (black triangles) began as tropical depression at 06 UTC 12 October and had peak intensity of 85 kt

- Excellent forecast of pre-formation stage that began with initial intensity of 15 kt at 06 UTC 10 October and extended to T2F (35 kt) at 18 UTC 12 October

- Combined WAIP intensification stage forecast was excellent until 12 UTC 14 October when it missed the rapid intensification, although V_{max} was within spread

EXAMPLE OF WCM DIAGRAM AND COMBINED WAIP FOR TS MERBOK
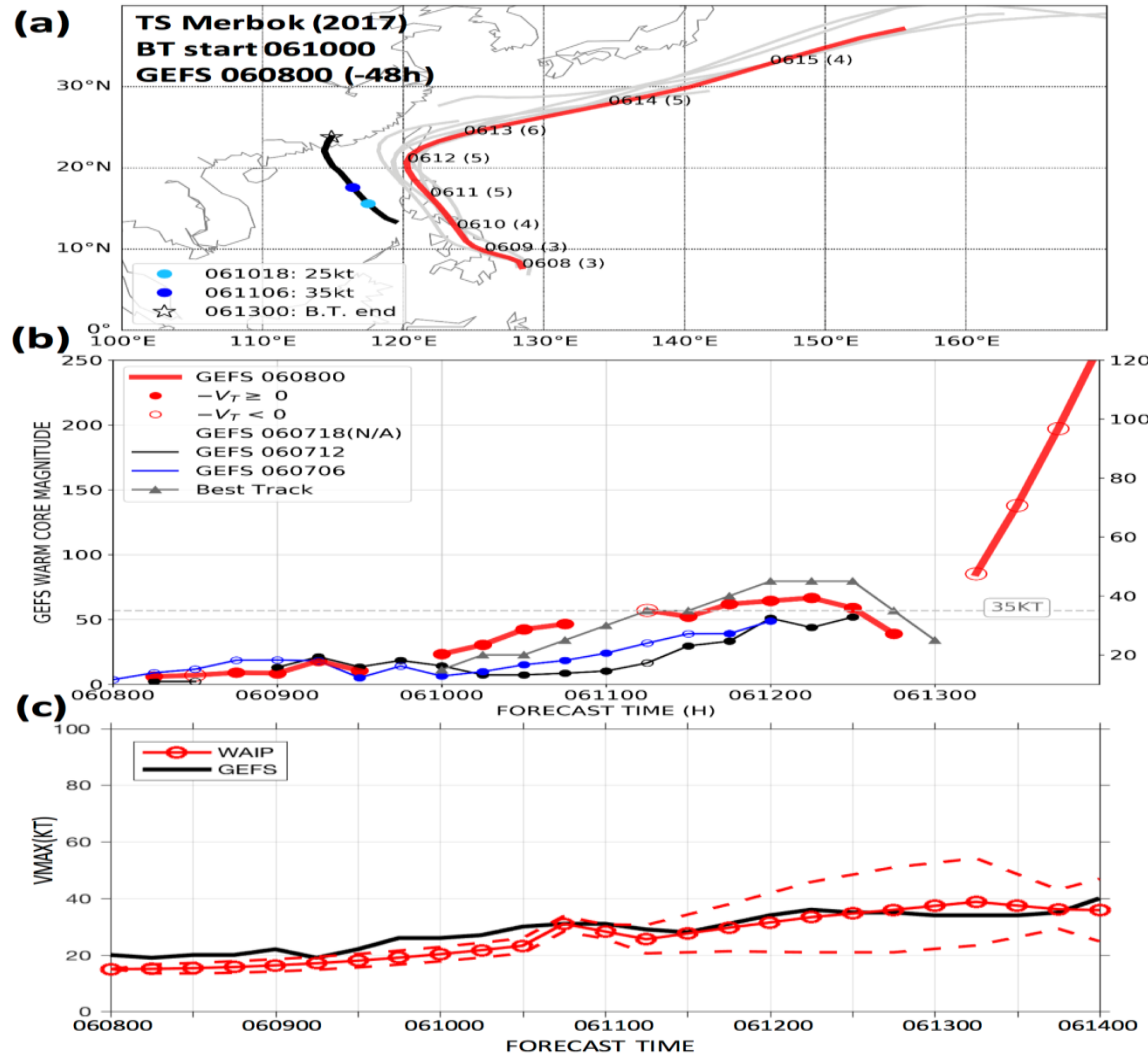
- GEFS forecast from 00 UTC 8 June (48 h in advance of first entry in JTWC best-track) predicted a pre-TC circulation starting at the initial time.

- GEFS track forecasts began far to southeast of actual formation location and had a track over the Philippines and recurved rather than make landfall.

- Three out of four consecutive WCM diagrams indicated very weak warm core development until 00 UTC 10 June when current GEFS (red dots) indicated increased WCMs, but peak at ~ 55

- Best-track intensity began at 15 kt on 00 UTC 10 June had maximum intensity of 45 kt

- Excellent WAIP forecast of development to only a tropical storm

EXAMPLE OF EARLY SEASON TROPICAL DEPRESSION TD2
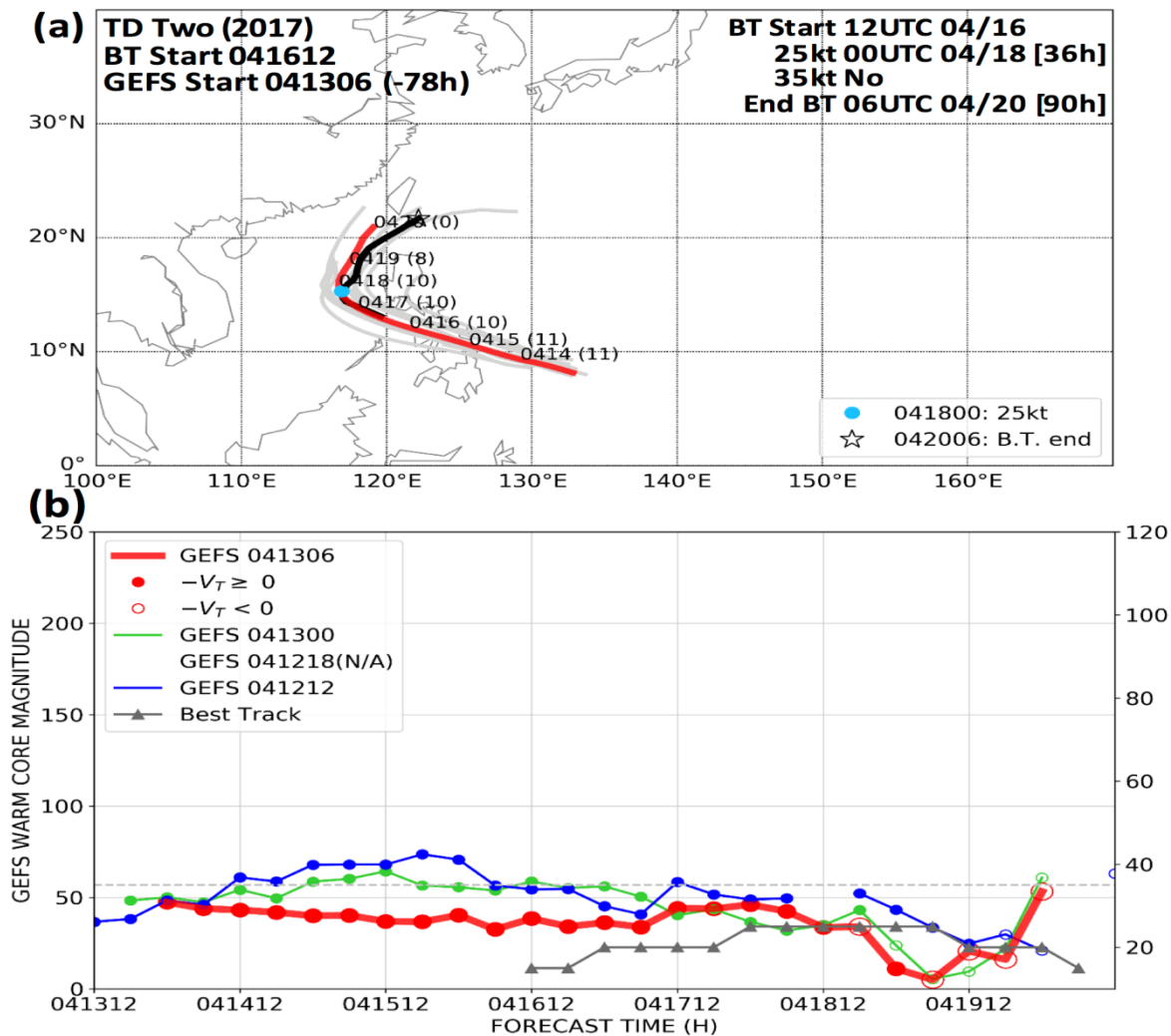
- GEFS forecast 78 h in advance of first entry in JTWC best-track predicted a pre-TC circulation starting 00 UTC 14 April, well to the southeast of TD2 that began in the South China Sea
- Track forecast indicates potential threat to Philippines and maritime operations

- GEFS forecast from 06 UTC 13 April of the WCM (red dots) decreases in time without exceeding WCM = 60
- Two previous GEFS forecasts had WCM ~ 60 but then decreased in time
- Best-track intensity (black triangles) began at 12 UTC 16 April and never exceeded 25 kt
- Expect such lack of WCM increases in time will help detect false alarm cases in GEFS

SUMMARY DIAGRAM OF WARM CORE MAGNITUDE (WCM) EVOLUTIONS

- Based on analyses of a number of WCM diagrams based on GEFS forecasts of WMVM ensemble storm tracks and two cyclone Phase Space parameters for various 2017 WPAC TCs
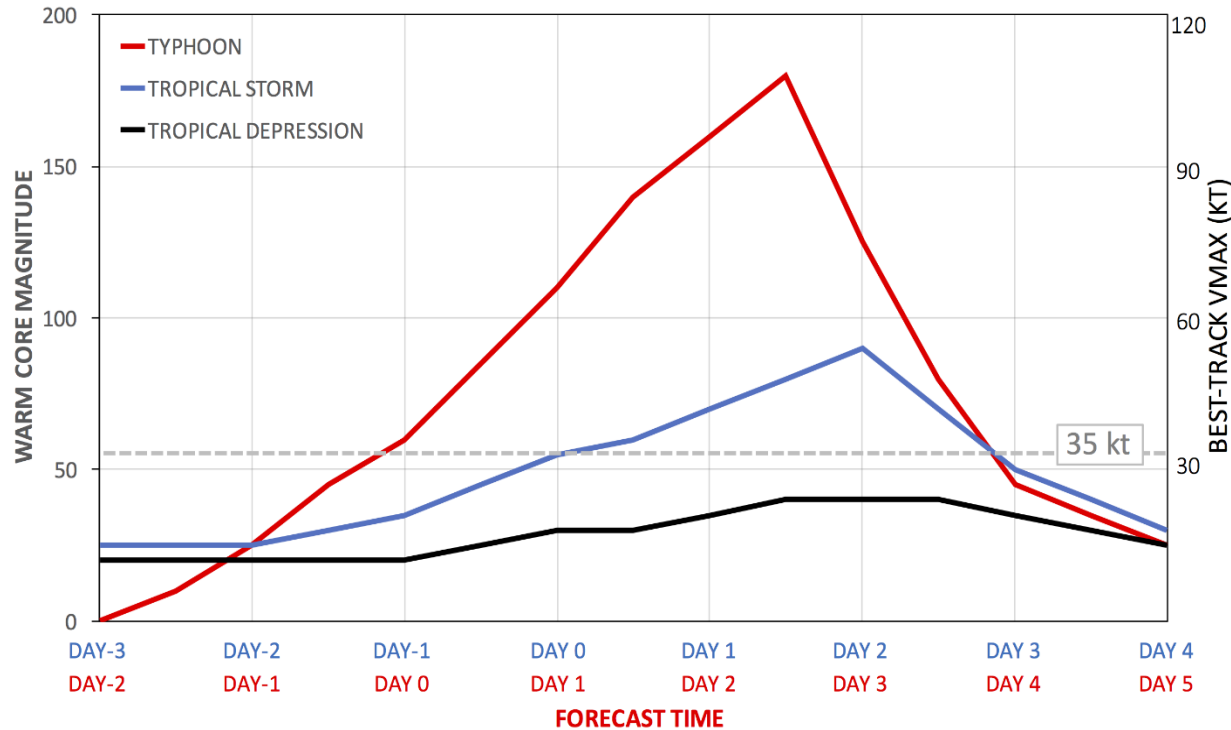
Peak Intensity	Peak WCM	Pre-formation WCM change
Typhoon	>125	Steep increase leading to T2F
Tropical Storm	60<WCM, WCM < 25	Almost flat unless steep rate increase
Tropical Depression	< 60	Almost flat without increasing to 60

Note different Time-to-Formation (T2F) for Day 0 for Typhoons (red curve and red DAY 0) versus for Tropical Storms (blue curve and blue DAY 0)

IMPROVEMENT OF JTWC POTENTIAL FORMATION AREA (PFA) PRODUCT

- Presently the JTWC forecaster subjectively identifies formation areas, timelines, and probabilities
- PFAs are issued at 00 UTC and 12 UTC, and are updated when new information is received
- GEFS-based WMVM ensemble storm track forecast plus WCM-derived T2F along that track would be a substantial improvement, and WAIP intensity and intensity spread would add useful guidance as to likelihood that the circulation will become a typhoon or at least a tropical storm

Time to formation based on first warning time estimate and graphic update time

Projected invest classification times, based on first warning time estimate (middle of formation timeframe)

Potential Formation Area P73W status
Based on 062712Z forecast
Updated 6/27/2018 at 22:19Z

TC formation probability: 50%
TC may form between 28/12Z and 30/12Z
Est. time to formation: 1.6 days (~29/12Z)

Projected classification timeline:
Invest: 24/12Z
Low: 26/12Z
Medium: 27/12Z
High: 28/12Z
First warning: 29/12Z

Corresponding invest designator: 99W

Geographic area within which TC formation may occur

PLANS FOR REMAINDER OF 2017-2019 JHT PROJECT

Western North Pacific – JTWC

- JTWC already has the WMVM ensemble storm track forecasts for GEFS and ECMWF ensemble
- Deliver in March 2019 complete package for WCM diagrams and combined three stage WAIP for operational testing

Atlantic – NHC

- Transfer existing code for WMVM ensemble storm track forecasts in Atlantic, eastern and central Pacific for GEFS and ECMWF ensemble
- Modify as necessary procedure to evaluate T2F from WCM diagrams during 2017 season
- Modify existing WAIA intensity and intensity spread to include pre-formation stage and for bifurcation situations
- Deliver complete package for WCM diagrams and combined three stage WAIA for operational testing

Combined eastern and central North Pacific – NHC

- Modify as necessary procedure to evaluate T2F from WCM diagrams during 2017 season
- Develop a combined three stage WAEC intensity and intensity spread technique for this region
- Deliver complete package for WCM diagrams and combined three stage WAEC for operational testing at NHC and CPHC, respectively