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Project Title: Ensemble-based pre-genesis watches and warnings for Atlantic and North Pacific tropical cyclones

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Reporting Timeline: Year-1 second semi-annual report of a 2-year project

1. ACCOMPLISHMENTS

The objective of this proposal is to provide guidance products for the National Hurricane Center (NHC), Central Pacific Hurricane Center, and the Joint Typhoon Warning Center (JTWC) for the production of pre-genesis watches and warnings of Atlantic and eastern North Pacific, Central North Pacific, and western North Pacific, respectively. These guidance products will be based on the NOAA Global Ensemble Forecast System (GEFS) and the European Center for Medium-range Weather Forecasts (ECMWF) ensemble forecasts and will provide the genesis time and location along the Weighted-Mean Vector Motion (WMVM) ensemble storm tracks, and also the Weighted Analog Intensity Atlantic (WAIA) or corresponding Pacific (WAIP) intensity and intensity spread forecasts to seven days.

The proposed ensemble-based guidance, which includes the deterministic model forecasts plus either 20 (for GEFS) or 50 (for ECMWF) perturbed ensemble members, has the advantage of providing uncertainty information so that a probability metric or uncertainty in genesis timing, track, and intensity are also specified. Such uncertainty information is critically important for genesis (and intensity) forecasting because the tropical cyclone genesis depends not only on the environmental forcing that is relatively well forecast – rather, the precise timing and location of tropical cyclone genesis depends on mesoscale convective systems and convective-scale systems that are not well observed or well forecast. Ensemble prediction systems that include perturbed initial conditions and physical processes such as convection are intended to represent both the environmental and convective scale uncertainty that are not represented in the corresponding deterministic model forecast that represents a single model solution. The GEFS and ECMWF ensemble have the potential to predict formation of tropical cyclones from African Easterly Waves (AEWs) or other equatorial waves as well as the monsoon depressions, hybrids, etc. that are listed in program priority JHT-4 in the Announcement.

As explained in the first semi-annual report, new Work Plans for Year 1 (Table 1) and for Year 2 (Table 2) were developed. Item 1.1 on ending storms (e.g., landfall, extratropical transition) is important because the 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) had created a Weighted Analog Intensity technique for Atlantic tropical cyclones (TCs) that had accounted for ending storm situations by constraining the analog selection to also include just ending storms. The first accomplishment was to develop and test an ending storm version of the Weighted Analog Intensity-Pacific (WAIP). An expedited contribution with a remarkably short review and publication resulted in publication schedule in December (Tsai and Elsberry 2017b).

Table 1. Revised Work Plan for Year 1 beginning on 1 July 2017. Completion of some Eastern/Central Pacific items during Year 1 is questionable as we do not have baseline intensity and intensity spread model in that basin as we have for WPAC and Atlantic.

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 Forecast (T2F) weighted mean and spread			
	(i)	WPAC		X
	(ii)	Atlantic		X
	(iii)	Eastern/Central Pacific		X

A second accomplishment has been to address the pre-formation stage for the WAIP. It was decided to first accomplish this task in WPAC because of large database of TC circulations with initial intensities of 15 kt, 20 kt, 25 kt, and 30 kt in the JTWC best-track files. However, the decision was made to define formation as ≥ 25 kt and test three functional forms (linear, exponential, and square) to represent the intensity evolution from the initial time to Time to Formation (T2F). **If the T2F is known**, assuming a square function intensity evolution from the initial time (again, from 15 kt and 20 kt values) to formation time will have a small sample mean bias (MB) and small (< 4 kt) mean absolute errors (MAEs) [Fig. 1].

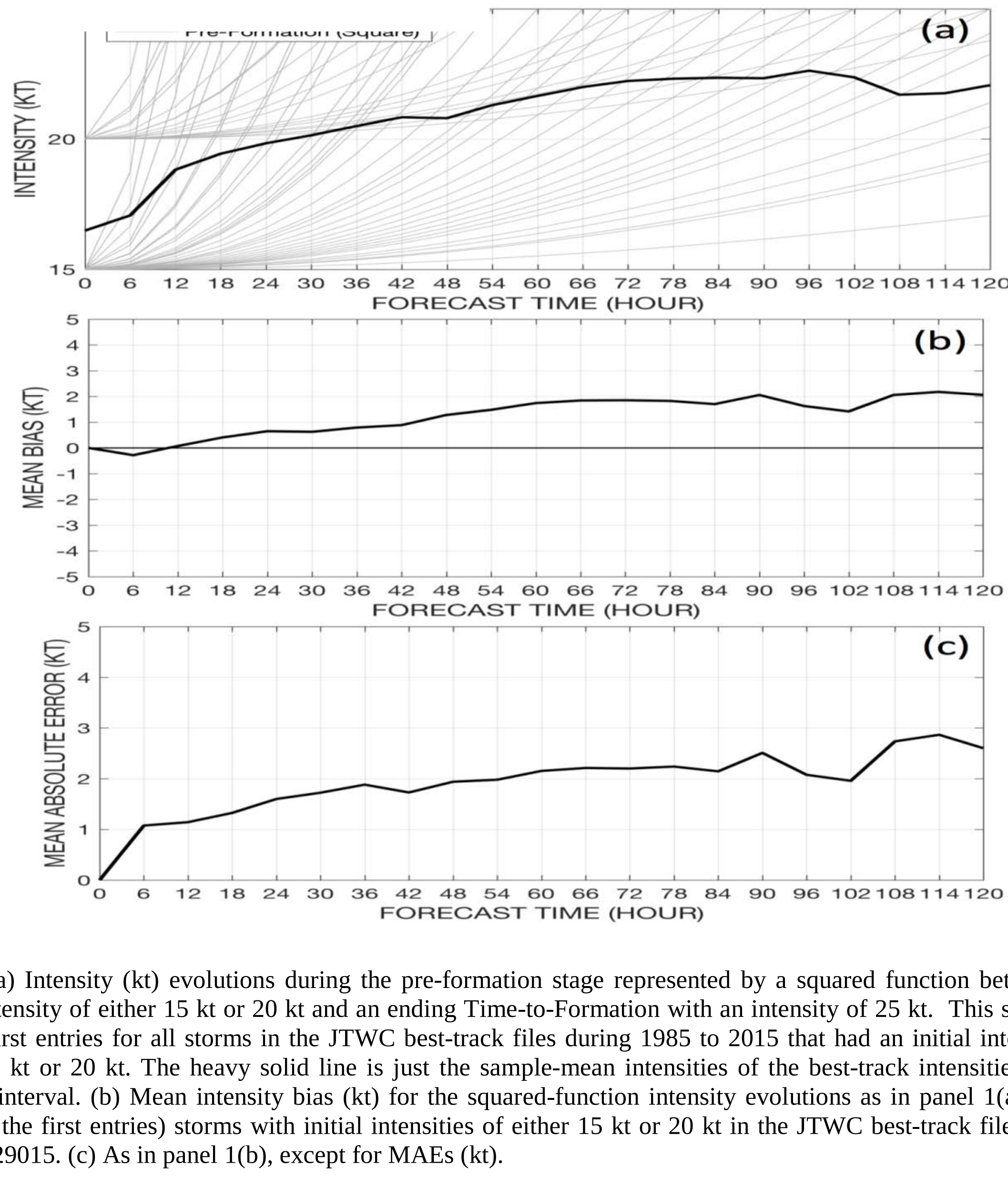

Fig. 1. (a) Intensity (kt) evolutions during the pre-formation stage represented by a squared function between an initial intensity of either 15 kt or 20 kt and an ending Time-to-Formation with an intensity of 25 kt. This sample is for the first entries for all storms in the JTWC best-track files during 1985 to 2015 that had an initial intensity of either 15 kt or 20 kt. The heavy solid line is just the sample-mean intensities of the best-track intensities at that forecast interval. (b) Mean intensity bias (kt) for the squared-function intensity evolutions as in panel 1(a) for all (not just the first entries) storms with initial intensities of either 15 kt or 20 kt in the JTWC best-track files during 1985 to 29015. (c) As in panel 1(b), except for MAEs (kt).

In this study with the JTWC best-track files, the 7-day track, the initial intensity and the 7-day intensity evolution, and the formation time (and thus the T2F) are 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, which are the non-developing cases in the ending storm version of WAIP. For the 24 h to 48 h forecast interval, perhaps the regional numerical models such as COAMPS-TC and HWRF may provide guidance as to the T2F. In this JHT project, we will apply Tim Marchok's ensemble-based track genesis prediction of formation, which is based on three genesis-related variables evaluated along ensemble storm tracks of all 21 members of the Global Ensemble Forecast System (GEFS; already 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.

Tsai and Elsberry (2018b) have developed and tested the combined pre-formation, intensification, and ending storm WAIP as shown in Fig. 2. In this schematic, the circulation system is assumed to have an initial intensity of 20 kt. Given the T2F (i.e., 35 kt) provided from the Marchok formation prediction, the time to landfall (T2L) will be from the official JTWC track forecast or the GEFS ensemble storm track forecast. The time to an ending storm due to Extratropical Transition (ET) is expected to be from Marchok's ET prediction along the ensemble storm track forecast from GEFS. Finally, the cases of non-development (N-DEV) within the 7-day forecast will also be from the Marchok genesis variables indicating this circulation system will **not** achieve > 35 kt intensity.

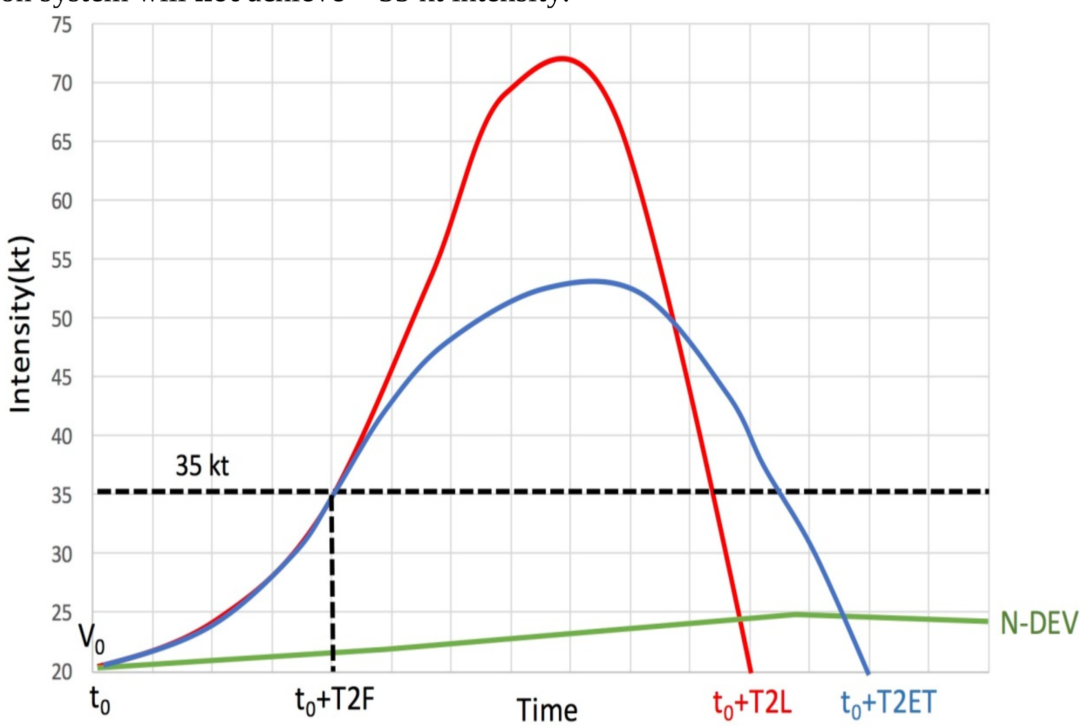

Fig. 2. Schematic of the combined WAIP version that includes the pre-formation, intensification, and ending storm stages. The descriptions of time to formation (T2F), time to landfall (T2L), time to extratropical transition (T2ET), and the non-development (N-DEV) are in the text.

The flow chart in Fig. 3 summarizes the steps in testing the performance of the combined 3-stage WAIP with JTWC best-track datasets. The original 7-day WAIP (Tsai and Elsberry 2015), the bifurcation version (Tsai and Elsberry 2018) and the ending-storm version (Tsai and Elsberry 2017) were all developed with a training set of 70% randomly selected storms of the 2000-2015 JTWC best-track files and verified with an independent set of 30% of the storms. Rather than selecting only 10 historical analogs as in the original WAIP version and the ending storm WAIP version, a total of 16 analogs will be selected as required for the bifurcation version. That is, a larger number of analogs is necessary for calculating a separate Cluster 1 WAIP intensity evolution that will have a larger maximum intensity versus Cluster 2 WAIP intensity evolution that will have a smaller maximum intensity. Indeed, the bifurcation version of the WAIP is the central feature in the combined 3-stage WAIP (Fig. 3).

This demonstration of the combined 3-stage WAIP begins with a target storm 7-day track and intensity record from the JTWC best-track file, and Test 1 is whether the initial intensity (V_{max}) is greater or less than 25 kt (Fig. 3). If the target storm is at least a TC, the WAIP bifurcation version is initiated from time T = 0, with inputs of the 7-day track and the initial V_{max}. However, Test 2 is first applied to determine whether there is an ending-storm event due to a landfall or an extratropical transition along the 7-day target storm track. If the answer is "No," the WAIP bifurcation version prediction to 168 h is the final intensity forecast and intensity spread guidance (Fig. 3, pathway on right side). If the answer is "Yes," the ending storm constraint on the historical analog selection is applied in the WAIP bifurcation versionthat the intensity at the last matching point with the target TC track cannot exceed 50 kt. Since the WAIP prediction is then constrained at T=0 by the initial Vmax and at the ending time by the 50 kt value, and by the basic requirements to have a similar track and be within ± 30 days, the selected analog intensity evolutions tend to be quite similar so that final WAIP intensity forecast tends to be more accurate and have a smaller intensity spread (Tsai and Elsberry 2017).

The more interesting and challenging pathway in Fig. 3 is when the initial intensity is less than 25 kt, i.e., target storm is in the pre-formation stage with an intensity of either 15 kt or 20 kt. The Test 1 question is then whether this pre-TC circulation will not develop to at least 25 kt, which is very rare as indicated in Fig. 1a because every storm in the JTWC best-track file attains at least 35 kt at some time during the lifecycle. When the WAIP is moved to operational testing and applied to Invests, the answer to the non-development question will more frequently be "yes" and this will end consideration of such a pre-TC circulation (Fig. 3, left side).

If development within 7 days is an option, the first step (Fig. 3, middle-left) is to apply the pre-formation squared function for the intensity evolution between the target storm initial time and the T2F, which is accurately known in this study because best-track intensities are available. The second step is then to apply the WAIP bifurcation version starting at T2F with the inputs of the 7-day track and the initial intensity at T2F. However, Test 2 is first applied to determine whether there is an ending-storm event due to a landfall or an extratropical transition along the 7-day target storm track. If no ending storm event is predicted, the combination of the pre-formation intensity evolution plus the WAIP bifurcation version intensity forecast and intensity spread guidance becomes the final forecast. If an ending storm event is predicted, the ending-storm constraint on the historical analog selection is applied in the WAIP bifurcation version that the intensity at the last matching point with the target track cannot exceed 50 kt. As

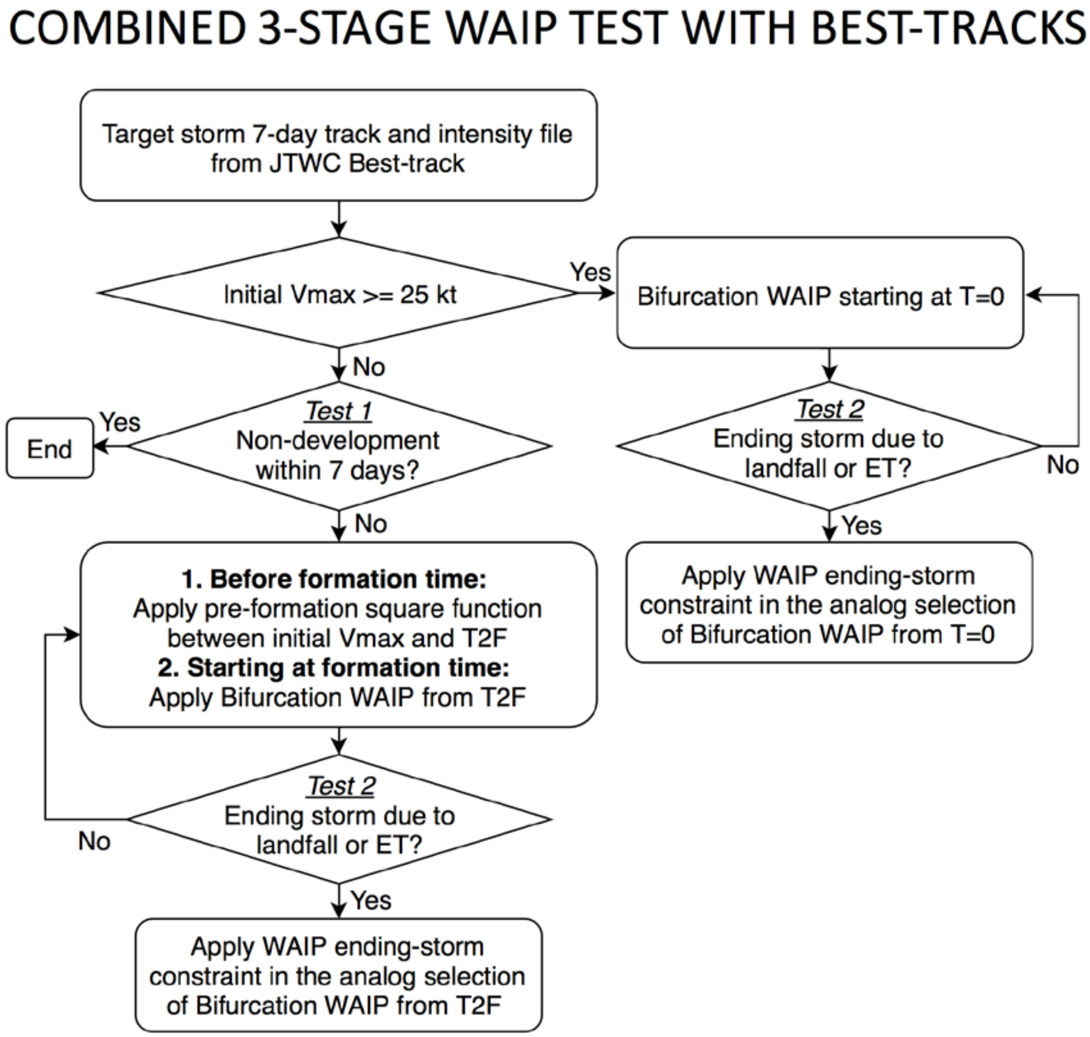

Fig. 3. Flow chart of the combined 3-stage, 7-day WAIP test with the JTWC best-track files (Tsai and Elsberry 2018b).

indicated above, the constraints at the initial and ending times leads to more accurate WAIP intensity forecasts with smaller intensity spreads (Tsai and Elsberry 2017).

As described in section 2 below, four conference presentations during February-June 2018 were made that described the development and testing of the combined 3-stage WAIP. The AOGS presentation on June 3 gave the results of the test of the combined WAIP and Tsai and Elsberry (2018b) is the submitted manuscript.

2. PRODUCTS

Four conference presentations (see list in References) were made during this second semi-annual period. A presentation by Elsberry and Tsai (2018a) entitled: "Improvement of seven-day weighted analog intensity prediction technique: Addressing pre-formation and ending storm stages" was made at the 2018 PACOM Assembly. This was an opportunity for discussions with JTWC personnel and planning for an operational test for the WPAC later this year. Discussions were also held with CPHC personnel. Another planning meeting with the JTWC personnel was held on June 4th to finalize plans for the operational test (see description in Section 5).

Another conference presentation (Elsberry and Tsai 2018b) was made at the 2018 IHC entitled: “Ensemble-based pre-genesis watches and warnings for Atlantic and North Pacific tropical cyclones.” This was an opportunity for helpful discussions with NHC personnel.

Tsai and Elsberry (2018a) AMS conference presentation was entitled:” Improved weighted-analog intensity and intensity spread predictions for western North Pacific tropical cyclones in pre-formation and ending stages.”

Finally, the Asia Oceania Geophysical Society (AOGS) conference presentation by Tsai and Elsberry (2018b) was entitled: “Improvement of weighted analog intensity prediction for different stages of the western North Pacific tropical cyclones.”

3. PARTICIPANTS

Dr. Hsiao-Chung Tsai of Tamkang University, New Taipei City, Taiwan and Tim Marchok, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey.

4. IMPACTS

Approximately 25% of the budget has been spent in a foreign country (Taiwan).

5. CHANGES/PROBLEMS

As described in the first semi-annual report, the Work Plan for Year 2 had to be revised, and the new Work Plan is presented in Table 2. One revision was a new Task 2.3, which is an alternate ensemble storm track forecast to replace our WMVM track forecasts. At that time our understanding was that NHC did not have a MATLAB license that is necessary to calculate the Naval Postgraduate School WMVM ensemble storm track forecasts. While completing the Research to Operation Transition Plan for this JHT project it was discovered that NHC did have a MATLAB capability in-house, so Task 2.3 is no longer necessary. At the invitation of Mark DeMaria of NHC, we have transferred the MATLAB code for the Weighted Analog Intensity Atlantic (WAIA) technique to NHC and Jose Salazar has successfully completed the test case on internal NHC computers. The revised Work Plan in place of Task 2.3 is for Jose Salazar to test the WAIA (which has the ending storm component, but not the bifurcation version, and it does not have the pre-genesis stage) for the 2017 season as a preliminary test to an operational test of the full WAIA technique to be delivered in the July-September period.

Table 2. Revised Work Plan for Year 2 as in Table 1

<u>Work Plan for Year 2</u>	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	X	
(ii) Atlantic retro test	X	
(iii) Present results at 2019 IHC		X
(2.3) Develop an alternate ensemble storm track forecast type if the prior NPS 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	X	
(ii) Atlantic – WAIP	X	
(iii) Eastern/Central Pacific		X
(2.5) Publish results of quasi-real-time intensity and intensity spread forecasts, and present results at 2019 IHC		X

Development of an operational test version of combined 3-stage, 7-day WAIP.

An important consideration in an operational test and implementation of the 7-day WAIP at the JTWC is that every 7-day intensity forecast in the western North Pacific (WPAC) will involve one of the three stages in the TC lifecycle: Pre-formation; intensification; or ending storm stage, which are addressed in the combined WAIP. If the TC is still in the pre-formation stage, the 7-day WAIP forecast will highly likely involve the intensification stage because the pre-formation stage is seldom longer than 72 hours in WPAC. Similarly, a TC in the intensification stage in WPAC may also be in the decay stage or make landfall within the 7-day WAIP forecast. Especially if the TC forms in the far western North Pacific (or in the South China Sea), all three stages may be involved and the 7-day WAIP will be required to forecast the entire lifecycle of such a TC.

Tsai and Elsberry (2018b) developed and tested the combined 7-day WAIP with JTWC best-track files (rather than real-time values) for the tracks and for the initial intensity. In addition, Tsai and Elsberry used the best-track file to specify the T2F (i.e., first time $\geqq$ 25 kt) and the ending storm timing due to landfall, extratropical transition (T2ET), or simply non-development within 7 days. For operational testing, the JTWC official track forecast and the warning intensity will be primary inputs to WAIP--if available. At the present time, JTWC only issues 5-day track forecasts, and their prototype 7-day track forecasts are based on a consensus average of 10 track forecasts rather than on a weighted-mean vector motion (WMVM). Furthermore, their Invest file only has those circulations that did at least achieve a Tropical Depression status. The JTWC Working Best Track (WBT) files do include other pre-TC circulations, but complete WBT files suitable for input to WAIP are only available since the 2016 season. Consequently, the GEFS and ECMWF ensemble storm track forecasts computed as WMVM tracks will be the primary input to WAIP for the pre-formation stage and to create extensions of the 5-day JTWC official tracks to 7 days.

Key inputs to the combined 7-day WAIP are the T2F and T2ET along the GEFS and ECMWF ensemble storm track forecasts, which will be estimated from the Marchok vortex tracker variables. This vortex tracker first checks each 12 h along these ensemble storm track forecasts for a cyclonic circulation and a closed Minimum Sea-Level Pressure (MSLP) contour using an interval of 1 mb, and also checks that the circulation exists at least 24 h. Then the T2F and the T2ET are determined from the Cyclone Phase Space (CPS) parameters of Hart (2003, Fig. 4, not shown): (i) CPS Parameter B that essentially characterizes whether the cyclonic vortex is vertically stacked (B < 10) as a TC or is tilted (B > 10) as an extratropical cyclone, which for this study will be an indication that the TC is undergoing extratropical transition; (ii) CPS Low-level warm core (acronym ***V***tL), which is an indication of a warm-core TC if ***V***tL is positive but is negative for a cold-core extratropical cyclone; and (iii) CPS Upper-level warm core (acronym ***V***t***U***) that again will be positive (negative) for a warm-core TC (cold-core extratropical cyclone). In these two acronyms, the ***V***t refers to an integrated thermal wind in the 900-600 mb (**L**ower) layer or the 300-600 mb (***U***pper) layer that Hart (2003) relates to either a warm (cold) core for a positive (negative) value. For example, the TC vortex has maximum wind speed in lower levels that decreases with decreasing pressures aloft because it is a deep warm-core circulation.

Tim Marchok has applied the simple combination of Parameter B < 10 and Lower-layer warm core VtL > 0 to detect TC genesis in the Atlantic and eastern North Pacific. He has subjectively associated this combination of Hart (2003) parameters from single ensemble members with pre-TC circulations to diagnose the timing of genesis along that ensemble member track forecast. At the request of the National Hurricane Center, Marchok is presently doing a systematic evaluation of his "genesis parameter."

Our JHT project will use the Marchok vortex tracker files along with the GEFS and ECMWF ensemble WMVM track forecasts and generate ensemble storm weighted-mean parameter B, weighted-mean Lower-layer warm core VtL, and weighted-mean Upper-layer warm core VtU at every 12 h. The weighting factors to be used in calculating these weighted-mean parameters are identical to the weighting factors in the WMVM calculation. That is, the CPS parameters associated with that ensemble member that has a 12-h motion vector most similar (least similar) to the past 12-h WMVM vector will provide given the largest (smallest) weighting factor. Thus, these weighted-mean Hart (2003) CPS parameters will provide more representative (compared to any single ensemble member parameter values) of the vertical vortex structure (Parameter B) and the warm-core vertical structure (VtL and VtU) because the spatial and temporal variability in these parameters will be taken into account by the weighting factors. In this case, a radius-squared dependence is assumed to ensure that the greatest weight is given to the CPS parameters of the ensemble member whose motion vector most closely is aligned with the WMVM. Conversely, the CPS parameters of an ensemble member with an outlier motion vector will contribute very little to the weighted-mean CPS parameters.

In the Hart (2003, Fig. 4, not shown) CPS diagram, the pre-TC circulation of Mitch (1998) began on 21 October in the deep tropics as a symmetric (B < 10, Hart 2003, Fig. 4a ordinate), warm-core (- VtL > 0, Fig. 4a and 4b abscissa, and –VtU > 0, Fig. 4b, ordinate) TC. In other TC examples in Hart (2003), the pre-TC circulation originated as an extratropical cyclone that transitioned to become a TC (Hart, Fig. 6 not shown) or as a subtropical cyclone that became a hurricane (Hart, Fig. 7, not shown). Regardless of the origin of a pre-TC circulation, the Hart CPS parameters provided by the Marchok vortex tracker along the GEFS and ECMWF ensemble storm WMVM track forecasts will provide the formation time (i.e., when the conditions are met with a weighted-mean Parameter B < 10 and the weighted-mean VtL and weighted-mean VtU indicate a deep warm core). However, we may also use Logistic Regression to optimize the T2F.

Note in the Hart Fig. 4 (not shown) that the Parameter B < 10 condition was satisfied from the initial time (21 October) and throughout the remaining times. However, the Lower-layer warm core (VtL, Fig. 4a and 4b abscissa) and Upper-layer warm core (VtU, Fig. 4b ordinate) values are near-zero from 21 October through 24 October. It was not until 12 UTC 24 October that the Lower-layer warm core magnitude begins to steadily increase (Figs. 4a and 4b). Similarly, the Upper-layer warm core begins to steadily increase in magnitude at 12 UTC 24 October (Fig. 4b). Thus, a deep (300 – 900 mb) layer of warming was occurring in pre-Mitch, and intensification was observed (change from small circles to progressively larger circles in Fig. 4b) as expected from the hydrostatic equation.

Our validations of the ECMWF ensemble forecasts in the Atlantic during 2012 (Elsberry et al. 2014) and in the western North Pacific during 2009 (Tsai and Elsberry 2011) revealed that WMVM track forecasts of the ensemble storm cyclonic circulations typically began 2-3 days prior to the National Hurricane Center and the JTWC, respectively, designated that corresponding circulation in nature to be a TC. Our interpretation was that a weak warm core was being predicted by the ECMWF ensemble model (relatively coarse horizontal resolution at that time), but the vortex circulation was not well organized as a compact cyclonic circulation as a TC during that early pre-TC circulation stage. It was only later that the circulation became better organized and intensification began.

Our hypothesis is that a Hart (2003) CPS diagram of the ECMWF ensemble model predictions for at least 2-3 days prior to the beginning of the intensification would resemble the 21-24 October period in Fig. 4 with Parameter B < 10 but only small values of Lower-layer and Upper-layer warm core. Rather than defining formation as a specific (i.e., sustained surface wind speed such as 25 kt or 35 kt), we will define the "formation" as the beginning in the ECMWF ensemble model of systematic and sustained increases in the Lower-layer and Upper-layer warm-core values in a Hart-type CPS diagram. That is, for the purpose of defining the time to formation (T2F) in this 7-day combined WAIP, we will specify that beginning time of sustained warm core increases predicted by the ECMWF ensemble model (and GEFS) is defined as T2F. This definition is consistent with the WAIP pre-formation concept of only a slow intensification stage prior to the typical or rapid intensification stage, which in WAIP is predicted by selecting historical analogs with a similar track and initial intensity. Retrospective studies of that appropriate initial intensity to be specified at the T2F time from the ECMWF ensemble model forecasts are in progress. We anticipate that T2F initial intensity may be different for monsoon depressions versus equatorial waves in the western North Pacific. It is noted that in WAIP the T2F is more important than the actual wind speed at T2F since the formation definition is 25 kt at JTWC.

Another benefit from the weighted-mean Hart CPS diagram of the time evolution of the vortex structure changes predicted by the ECMWF ensemble or GEFS model is to detect non-development within the 7-day period of the WAIP forecast. That is, the weighted-mean warm-core parameters should not have a substantial and/or sustained increase over the next 7 days. Finally, ending storm conditions of landfall decay time (decreasing Lower-layer warm core) and extratropical transition (B > 10) of a TC will also be displayed on the weighted-mean Hart CPS diagram. Thus, completion of the coding of the weighted-mean CPS diagram will be a crucial step in the preparation for an operational test of the 7-day WAIP at the JTWC.

Once this technique is developed and tested for the western North Pacific, it will be relatively straight-forward to adapt it for the Atlantic, and later for the combined East and Central Pacific regions.

6. SPECIAL REPORTING REQUIREMENTS

None required

7. BUDGETARY INFORMATION

The project is on budget and no changes are planned.

8. PROJECT OUTCOMES

No project outcomes this early in the project.

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Tsai, H.-C., and R. L. Elsberry, 2018b: Combined three-stage, 7-day weighted-analog intensity prediction technique for western North Pacific tropical cyclones: Combined pre-formation, bifurcation intensification, and ending storm version. *Weather and Forecasting*, Manuscript submitted.

Conference Presentations

Elsberry, R. L. and H.-C. Tsai, 2018a: Improvement of seven-day weighted analog intensity prediction technique: Addressing pre-formation and ending storm stages. 2018 PACOM Joint Tropical Cyclone Forecasting Program Assembly, Honolulu, Hawaii, 20-23 February 2018

Elsberry, R. L., H.-C. Tsai, and T. Marchok, 2018b: JHT project 7: Ensemble-based pre-genesis watches and warnings for Atlantic and North Pacific tropical cyclones. 2018 Interdepartmental Hurricane Conference, Miami, Florida, 13-15 March 2018

Tsai, H.-C., and R. L. Elsberry, 2018a: Improved weighted-analog intensity and intensity spread predictions for western North Pacific tropical cyclones in pre-formation and ending stages. Presentation 16C.6, AMS Hurricane and Tropical Meteorology Conference, Ponte Verda, Florida, 16-20 April 2018

Tsai, H.-C., and R. L. Elsberry, 2018b: Improvement of weighted analog intensity prediction for different stages of the western North Pacific tropical cyclones. Presentation AS31-028, Asia Oceanic Geophysical Society meeting, Honolulu, Hawaii, 3-8 June 2018