Appendix A

FORMAT FOR USE IN SUBMISSION OF INTERIM AND FINAL RESEARCH PERFORMANCE PROGRESS REPORTS

COVER PAGE

NOAA/JHT

Federal Grant Number Assigned by Agency: NA17OAR4590138

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

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Report Term or Frequency: semi-annual

Final Annual Report? No

1. ACCOMPLISHMENTS

Summary of the project accomplishments for the 4 main project tasks:

Tasks 1 and 2: Add a tropical cyclone (TC) wind structure based predictor or combination of predictors to Statistical Hurricane Intensity Prediction Scheme (SHIPS), the Logistic Growth Equation Model (LGEM), the multi-lead time probabilistic Rapid Intensification Index (MLTRII), and the global Rapid Intensification Index (GRII). These changes were designed to improve SHIPS, LGEM, and RIIs forecast performance based on the recent research that demonstrated that both TC intensification rate and the likelihood of undergoing Rapid Intensification (RI) are related to storm size, with smaller storms found to be more likely to intensify, and that the wind structure parameters, such as the radius of maximum winds (RMW), the average radius of gale-force winds (R34), and the objective size parameter (R5, Knaff et al, 2014) are strongly negatively correlated with the rate of change of intensity. The software for creating databases of RMW, R34, and corresponding climatological parameters was developed. The full developmental database of R34 and RMW was created for the years 1982-2017, which is the full length of the developmental database sample used for SHIPS, LGEM, and RIIs development. The software for performing dependent sample testing for SHIPS, LGEM, GRII, and MLTRII was modified to use new size-based predictors, including RMW, R34, R5, and storm latitude. Depended sample testing demonstrated that the use of a combination of data and climatology for size predictors produces results similar or better that use of data only for the cases when data are available. In addition, the option to use size-based predictors was added to the models, and retrospective model runs with the new predictors are in progress.

Tasks 3 and 4: Add a predictor or a group of predictors based on the probability of the eye existence and the code to calculate that probability to SHIPS/LGEM, MLTRII, and GRII. These changes were designed to use the automated objective eye-detection algorithm (EDA) recently developed at CIRA (Knaff and DeMaria, 2017) to improve SHIPS, LGEM, and RIIs forecast performance based on multiple studies that demonstrated that the appearance of the eye is strongly related to storm 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 currently performed manually by forecasters. The EDA allows to automate that procedure making it possible to use eye-existence based predictors for statistical intensity forecast models. Work on these tasks is scheduled to begin in May, 2018. However, some preliminary tests were run using 2017 EDA data and work has started on adapting EDA to work with GOES-16 data.

What were the major proposed **goals, objectives, and tasks** of this project, and what was accomplished this period under each task? (a table of planned vs. actuals is recommended as a function of each task identified in the funded proposal)

Note: Funding for this project arrived 1 month later than expected. All the millstones were shifted accordingly, which was approved by JHT. All milestone dates below are adjusted dates.

Goals, Objectives, Tasks	Planned: Aug 2016 – Aug 2017	Actual: Sep 2016 – Aug 2017
Create updated database of wind structure predictors	Create SHIPS developmental database of R34, RMW, and R5 predictors and corresponding climatology	The databases of R34, RMW, and R5 and corresponding climatologies were created for the years 1982 - 2017, and added to the SHIPS developmental database.
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	Perform dependent sample testing of SHIPS/LGEM, and RIIs to determine the best combination of wind structure predictors.	The preliminary dependent sample testing was completed. The testing included the use of both data and climatology (when data are not available). The improvement is similar or better compared to the preliminary testing that used a limited dataset.
Modify SHIPS and both RIIs to use wind structure predictors	Modify SHIPS and both RIIs to use wind structure predictors	SHIPS, LGEM, and RIIs were updated to use additional wind structure predictors.

Are the proposed project tasks **on schedule**? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

Task	Cumulative percent towards completion and due dates	Due Date	On schedule (yes/no)
Create updated database of wind structure predictors	100%	Nov 2017	Yes
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	90%	Jan 2018	Yes. The final combination of predictors will be determined based on the results of retrospective runs.
Modify SHIPS and both RIIs to use wind structure predictors	90%	Feb 2017	Yes. Additional adjustment might be required based on the results of retrospective and real-time runs

What were the major completed **milestones** this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

Milestone	Completed vs proposed
Create updated database of wind structure predictors	Completed as proposed
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	Completed as proposed
Modify SHIPS and both RIIs to use wind structure predictors	Completed as proposed

Detailed description of the work completed for each milestone since the last report is presented below.

Milestone: Create updated database of wind structure predictors. The updated databases of RMW, R34A, and R5 were created and added to a full SHIPS developmental database for the years 1982 - 2017. The operational SHIPS developmental database is available at http://rammb.cira.colostate.edu/research/tropical_cyclones/ships/developmental_data.asp. The R34 and RMW wind data were obtained from the extended best track (http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/, Demuth et al, 2006) and from the ATCF a- and b-deck for data after 1990 for RMW (after 2002 for R34). Updated readers for the ATCF data were developed to complete these tasks. The statistical models require input at all synoptic times, however, data are not available at all times. For example, RMW is not available prior to 1987 for the Atlantic (prior to 2000 for east Pacific), and R34 data are not available prior to 1988 for the Atlantic (prior to 2001 for eat Pacific). Thus, a climatology is required for running the models. The climatology of RMW as a function of maximum wind speed and latitude was created following Willougby and Rahn (2004), who found that RMW can be approximated as

$$RMW = 51.6 \exp(-0.0223Vmax + 0.0.281\ \varphi),$$

where Vmax is the maximum intensity and φ is the latitude. The climatology for the R34 was derived based on Knaff et all (2007) using the modified Rankine vortex, assuming there are no asymmetries:

$$V(r) = Vmax\left(\frac{r^m}{r}\right)^x,$$

where Vmax is the maximum wind speed and m and x can be determined as function of Vmax and latitude as described in Knaff et al (2007). The R5, the normalized R5, and the corresponding climatological values were determined as described in Knaff et al 2015.

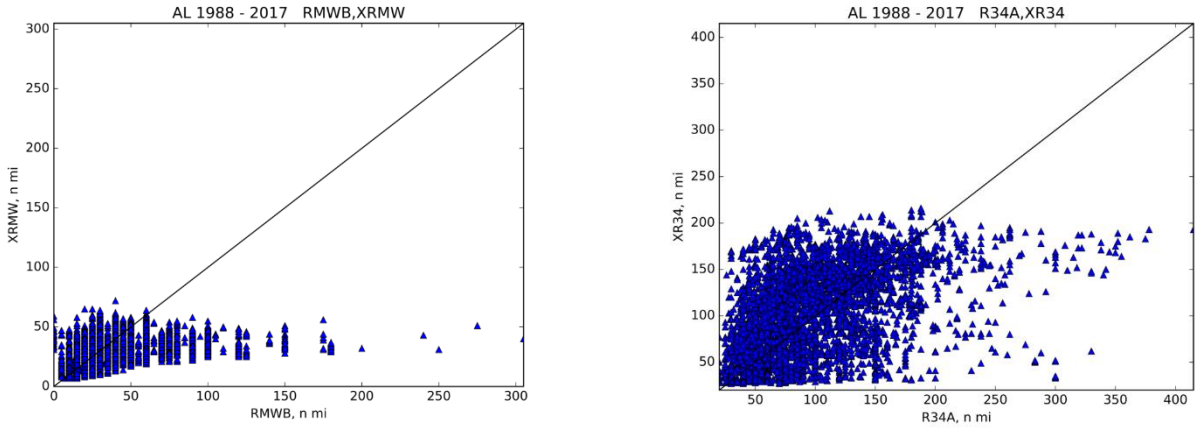

Figure 1. Left: scatter plot of climatological RMW (XRMW) vs RMW from ATCF and extended best track. Right: the same for R34.

Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors.

The software for performing dependent sample testing for SHIPS, LGEM, GRII, and MLTRII was modified to use new size-based predictors, including RMW, R34, R5, and storm latitude. Depended sample testing demonstrated that the use of a combination of data and climatology for size predictors produces results similar or better that use of data only for the cases when data are available. Figure 2 shows the dependent sample testing results for SHIPS for the Atlantic. For these test a full data sample for the years 1982 - 2017 was used, and climatological values were used for the cases when data are not available. The test results show almost one percent improvement in forecast for the forecast lead time of 18 hours. That is a significant improvement compared to preliminary tests that were performed using a limited subset of cases. The most improvement is observed when using a combination of R34, R5, and storm latitude as new predictors. The final combination of new predictors will be determined based on the results of retrospective runs.

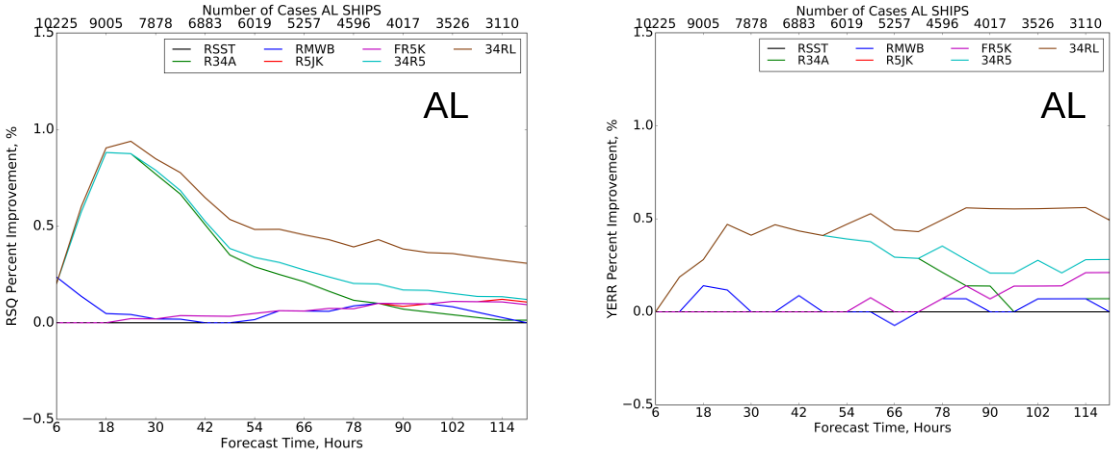

Figure 2. Results of SHIPS dependent sample testing with using size predictors. Left: percent improvement in R^2. Right: percent improvement in Yerr. Predictors shown: RSST - baseline using operation model; R34A - non-zero averaged R34; RMWB - RMW from ATCF best track; R5JK - objective TC size parameter R5l FR5K - normalized objective TC size parameter FR5; 34R5 - both R35 and R5 added; 35RL - 3 predcitors added, R34, R5, and storm latitude. All predictors use climatological values when data are not available.

Milestone: Modify SHIPS and both RIIs to use wind structure predictors. The option to use size-based predictors was added to the models. Additional adjustment to the code might be required based on the results of retrospective runs.

Milestone: Derive updated regression coefficients and complete retrospective SHIPS and RII runs with new structure predictors. Updated regression coefficients were derived for SHIPS and LGEM, and the retrospective model runs are currently in progress. This Milestone is scheduled to be completed in March, 2018.

Milestone: Develop operational version of the CIRA's EDA and incorporate it into SHIPS processing. In addition, the work to adapt the EDA to work with GOES-16 data has begun ahead of time.

What opportunities for training and professional development has the project provided?

People working on the project obtained increased knowledge and skills in the development of statistical models. Also, collaboration between CIRA and AOML on this project provides opportunities for professional development for people working on the project

How were the results disseminated to communities of interest?

1) The project results will be presented at the IHC in March 2018. Also, John Kaplan visited CIRA in September, 2017, and presented a talk "Statistical rapid intensity prediction: Implications of recent Model Results 2016 and 2017" at a CIRA seminar. The talk included some of preliminary results and future plans for this project. Additional details about the project were communicated to JHT points of contact, Dan Brown (NHC), Mark DeMaria (NHC), Robert Ballard (CPHC), Brian Strahl (JTWC) and Chris Landsea (NHC).

2) The project was discussed with JTWC POC, Brian Strahl by Kate Musgrave (CIRA) during her visit to JTWC in October, 2017

2) At later stages of the project updated software and databases will be provided to NHC, and test results will be provided to NHC, CPHC, and JTWC POCs.

What do you plan to do during the next reporting period to accomplish the goals and objectives?

During the next reporting period we plan to conduct retrospective runs of the experimental version of the SHIPS/LGEM and RIIs with size predictors. In addition, final adjustments and modifications to the code will be implemented based on the results of the retrospective runs. We will further work with JHT and NHC TSB staff to implement experimental versions of SHIPS/LGEM and RIIs on quasi-production on WCOSS for the 2018 season and/or will implement parallel runs at CIRA. In addition the EDA will be adapted to work with GOES-16 data and converted to Fortran.

2. PRODUCTS

What were the major completed **products or deliverables** this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Product/Deliverable	Actual
Updated database of size predictors and corresponding climatological values for the years 1982 - 2017.	Developed as planned. The updated 2018 version will be provided to NHC.

What has the project produced?
-publications, conference papers, and presentations*;

-technologies or techniques;

None

-inventions, patent applications, and/or licenses; and

None

-other products, such as data or databases, physical collections, audio or video products, software, models, educational aids or curricula, instruments or equipment, research material, interventions (e.g., clinical or educational), or new business creation.

- Database of TC-size predictors converted to SHIPS input format. The database includes both available data and climatology.
- Updated climatology of RMW, R34, and R5

*For **publications**, please include a full reference and digital object identifier (DOI; http://www.apastyle.org/learn/faqs/what-is-doi.aspx) and attach all publications and presentations on this project from this reporting period to the progress report, or include web links to on-line versions. Within your publications and presentations, please include language crediting the appropriate NOAA/OAR organization and program (e.g., NOAA/OAR/OWAQ and the U.S. Weather Research Program; or NOAA/OAR/NSSL and the VORTEX-SE program) for financially supporting your project. Suggested language is as follows:
"This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under Grant No. XXXXXXX."

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

Galina Chirokova, John Knaff, John Kaplan

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

NHC points of contact have been involved. Also work for this project has been coordinated with NHC TSB branch.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

The project directly address the program priorities JHT-3 and JHT-1. Specifically, improved SHIPS and RIIs will provide a better guidance for TC intensity change including the onset, duration, and magnitude of RI events, and over-water weakening events (JHT-3). These intensity guidance techniques are routinely used operationally at NHC, CPHC, and JTWC to forecast TC intensity. In addition, the use of the EDA output as predictor in SHIPS and RIIs will provide improved capability to observe the TC and its environment to support forecaster analysis and model initialization (JHT-1). This work also addresses the NOAA goal for a Weather-Ready Nation. NOAA's Weather-Ready Nation is about *"building community resilience in the face of increasing vulnerability to extreme weather and water events. Record-breaking snowfall, cold temperatures, extended drought, high heat, severe flooding, violent tornadoes, and massive hurricanes have all combined to reach the greatest number of multi-billion-dollar weather disasters in the nation's history. The devastating impacts of extreme events can be reduced through improved readiness."*

What was the impact on other disciplines?
The results of this project should allow for improved operational TC intensity and structure forecasts that are important for other agencies and general public. Improvements in these capabilities may also lead to other high priority forecasts (e.g., storm surge watch/warnings, wave forecasts) and decisions (e.g., evacuations, ship routing).

What was the impact on the development of human resources?
Nothing to report

What was the impact on teaching and educational experiences?
Nothing to report

What was the impact on physical, institutional, and information resources that form infrastructure?
Nothing to report

What was the impact on technology transfer?
Methods developed at CIRA, if approved by the JHT, will transition to NHC, CPHC, and JTWC operations. Examples include the automated objective EDA.

What was the impact on society beyond science and technology?
The results of this project should allow for improved operational TC intensity forecasts that are important for other governmental agencies, industry, and general public. These efforts significantly contribute to NOAA's goal of a *Weather-Ready Nation*.

What percentage of the award's budget was spent in a foreign country(ies)?
None

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.
None
-Actual or anticipated problems or delays and actions or plans to resolve them.
None
-Changes that had a significant impact on expenditures.
None
-Change of primary performance site location from that originally proposed.
None

6. SPECIAL REPORTING REQUIREMENTS

Report on any special reporting requirements here (see previous instruction #3). If there are none, state so.

- Your assessment of the project's Readiness Level (current and at the start of project; see definitions in Appendix B)

Start of the project: RL3

Current: RL3-4

-If not already reported on in Section 1, please discuss:
-- Transition to operations activities

The transition to operations for this project is scheduled after the end of Year 2, in 2019, if accepted by NHC. The timing of the final transition will depend on the availability of NHC Technology and Science Branch (TSB) resources.

-- Summary of testbed-related collaborations, activities, and outcomes (if it's a testbed project)

1) Result and verification of the retrospective and real-time runs will be made available to JHT POCs when these are produced.

2) Updated software and databases will be provided to NHC toward the end of the Year 2 of the project.

3) The possibility of implementing real-time EDA processing in quasi-production on WCOSS for 2018 season has been discussed with NHC POCs and NHC TSB staff. The implementation of EDA in the quasi-production for 2018 season will depend on the availability of NHC TSB resources.

-- Has the project been approved for testbed testing yet (if it's a testbed project)?

Testing of the EDA in quasi-production at NHC might be implemented for 2018 season based on the availability of NHC TSB resources. Real-time runs of the updated models with size predictors will be tested at CIRA for the 2018 season. Additional details are provide in Testing Plan.

-- What was transitioned to NOAA?

The transition activities for this project are planned at the end of the Year 2 of the project, as described in Research to Operations Transition Plan.

Test Plans for USWRP-supported Testbed Projects. Test plan for this project is submitted as a separate document.

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

The project is on budget

8. PROJECT OUTCOMES

What are the outcomes of the award?

The improved versions of the operational statistical-dynamical models for forecasting TC intensity are being developed.

Are performance measures defined in the proposal being achieved and to what extent?

The performance measures defined in the proposal (the milestones) are being achieved as planned.

9. REFERENCES

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Test Plan for NOAA/OAR/OWAQ Testbed Projects

*I. What major **concepts/techniques** will be tested? What is the scope of testing (what will be tested, what won't be tested)?*

The following models will be tested:
- the Statistical Hurricane Intensity Prediction Scheme (SHIPS)
- the Logistic Growth Equation Model (LGEM)
- the multi-lead time probabilistic Rapid Intensification Index (MLTRII)
- the global Rapid Intensification Index (GRII)

The above models will be tested with the best combination of added size-based and eye-formation based predictors, as determined by dependent sample testing and retrospective runs.

*II. **How** will they be tested? What **tasks** (processes and procedures) and activities will be performed, what preparatory work has to happen to make it ready for NOAA testing, and what will occur during the experimental testing in the testbed?*

1) Tasks that will be performed during testing at CIRA:
- run scripts to receive operational SHIPS diagnostic files in real-time
- run scripts to add new size-based and eye-formation based predictors and corresponding climatology to the operational diagnostic files
- run the models
- save the model output, including ATCF A- and E-deck format, for deterministic and probabilistic forecasts, respectively, and make it available to NHC and JTWC via ftp

2) Preparatory work:
- complete retrospective runs using 2017 or 2018 version of SHIPS/LGEM and RIIs
- derive updated coefficients for test versions of SHIPS, LGEM, and RIIs

3) During the testing:
- monitor model performance
- conduct post-season verification

*III. **When** will it be tested in coordination with the NOAA testbed? What are **schedules and milestones** for all tasks described in section II that need to occur leading up to testing, during testing, and after testing?*

Year 1:

Aug 2017 -	Funding arrives and work begins
Sep 2017 -	Create updated database of wind structure predictors
Dec 2017 -	Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors
Jan 2018-	Modify SHIPS and both RIIs to use wind structure predictors

Feb 2018 - Derive updated regression coefficients and complete retrospective SHIPS and RII runs with new structure predictors

Feb 2018 - Year 1 semi-annual report

Mar 2018 - Present year 1 results at IHC and gather feedback from JHT staff

May 2018- Conduct algorithm changes based on feedback and validation results

Jun 2018 - Develop operational version of the CIRA's EDA and incorporate it into SHIPS processing

Jul 2018 - Prepare final updated version of the modified SHIPS and RII code for parallel runs during the 2018 season (to include use of new structure predictors) for AL and EP basins

Aug 2018 - Submit Year 1 final report

Year 2:

July 2018 - Coordinate with JHT and TSB staff to implement updated SHIPS and RII code to run in parallel on NCEP supercomputer or implement code at CIRA and implement EDA code at CIRA

Aug 2018 - Begin parallel runs during 2018 season and monitor results during the season

Dec 2018 - Create database of the eye predictors and complete SHIPS dependent testing and RII s statistical testing to determine the best combination of eye predictors

Dec 2018- Modify SHIPS and RII to include the eye predictors

Jan 2019 - Complete retrospective runs of the models with eye predictors

Feb 2019 - Extend SHIPS modifications to the global version

Mar 2019 - Evaluate parallel runs from 2018 season and make any necessary adjustments to the modified SHIPS and RII

Feb 2019 - Year 2 semi-annual report

Mar 2019 - Present year 2 results at IHC and compile feedback from JHT staff

Jun 2019 - Complete retrospective runs of modified SHIPS and RII with all improvements and additions included, adjust new combined predictors for best performance, and derive new regression coefficients

Jul 2019 - Complete SHIPS and RII verification by comparing the intensity forecasts against the final NHC best track

Jul 2019 - Finalize updated SHIPS and RII code for product enhancements/additions; coordinate with JHT and TSB staff to implement model upgrades approved for operational implementation

IV. ***Where*** *will it be tested? Will it be done at the PI location or at a NOAA testbed location?*

1) If possible, the updated models will be tested on quasi-production on WCOSS, depending on the availability of TSB resources.
2) If parallel runs of experimental SHIPS/LGEM and RIIs cannot be implemented on quasi-production, they will be implemented at CIRA.

*V. Who are the key **stakeholders** involved in testbed testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their **roles and responsibilities**?*

Stakeholders and Roles:
- PIs: prepare model: provide code and data to NHC, conduct parallel runs at CIRA if needed
- TSB staff and JHT support staff: if possible, implement updated models on quasi-production on WCOSS. Evaluate the new products and provide feedback.
- JHT POCs: monitor the model performance and provide feedback to PIs

*VI. What **testing resources** will be needed from each of the above participants (hardware, software, data flow, internet connectivity, office space, video teleconferencing, etc.), and who will provide them?*

The updates models require resources similar to the operational versions. Existing hardware and software will be used for testing on quasi-production on WCOSS and/or at CIRA.

*VII. What are the **test goals, performance measures, and success criteria** that will need to be achieved at the end of testing to measure and demonstrate success to advance to higher Readiness Levels and to proceed to full transition to NOAA operations (Readiness Level 8)?*

1) Test goals:
- Evaluate the performance of the updated models
- Compare experimental parallel runs with operational runs
- Provide testing results to NHC and JTWC and respond to feedback

2) Performance measures:
- Model verification with the algorithms that are used to evaluate the performance of the operational models. These include mean absolute error and bias for deterministic models and Brier skill score and optimal threat score for probabilistic models. These measures can be generated using NHC's verification code, given the A- and E-deck files from the experimental runs.

3) Success criteria:
- Performance of the experimental models exceeds that of the operational models

*VIII. How will testing **results** be documented? Describe what information will be included in the **test results final report**.*

Test results will be provided to NHC, JTWC, and JHT in the final project report and test results final report.
1) The documentation of the test results will include:
- the results of retrospective model verification
- the results of the post season verification of real-time runs.

2) The test results final report will include the result of the retrospective model verification. The post season verification for the 2nd year of the project cannot be completed until the end of the hurricane season, therefore these results might not be available in time to be included in the test results final report.