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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Award Period: 8/1/17-7/31/19

Reporting Period End Date: 1/31/19

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 are 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 for the developmental database, reruns, and real-time runs was developed. The developmental database of R34 and RMW was created for the full length of the developmental database sample used for SHIPS, LGEM, and RIIs, 1982 – 2017. The 2018 versions of SHIPS, LGEM, GRII, and MLTRII were modified to use new structure-based predictors, including RMW, R34, R5, FR5, and time-averaged storm latitude (TLAT). Depended sample testing for 2017 and 2018 versions of the models was completed, and demonstrated that the addition of three new predictors, including two TC-size parameters and time-averaged latitude results in most forecast improvements for all models for both Atlantic and east/central Pacific basins. New predictors, including R34, R5, and TLAT were added to the 2018 versions of SHIPS, LGEM, and GRII; and RMW, FR5, and TLAT to MLTRII. Retrospective model runs revealed issues with databases related to the incorrect formatting of some of NHC's best track files. The best track formatting was corrected where needed, the databases of structure parameters were updated using NRL ATCF reader, and retrospective model runs and verification 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 are designed to use the automated objective infrared (IR) Satellite Eye-Detection Routine (SEDR) 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. SEDR allows to automate that procedure making it possible to use eye-existence based predictors for statistical intensity forecast models. Several versions of SEDR were used to reprocess all available IR data for 1982 – 2017, Fortran90 code was developed to add SEDR predictors to SHIPS diagnostic files, development of the Fortran90 version of SEDR continues, and dependent sample tests were completed for SHIPS with SEDR predictors.

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 include adjusted dates.

Goals, Objectives, Tasks	Planned: Aug 2018 – Feb 2019	Actual: Aug 2018 – Feb 2019
Develop database of structure predictors	None	Database was updated using NRL ATCF reader to correct issues caused by incorrect formatting of some of NHC's best track files.
Develop database of SEDR predictors	Develop database of SEDR predictors	SEDR was reprocessed for 1982 – 2017 and the SHIPS database of SEDR predictors was developed. In addition, the climatological version of SEDR was reprocessed and the database of climatological SEDR was created.
Develop version of SHIPS/LGEM with structure predictors	None	Depended sample tests were completed using the updated database of structure predictors and the updated version of developmental code with a few bugs fixed.
Develop version of SHIPS/LGEM with SEDR predictors	Begin developing of SHIPS/LGEM with SEDR predictors	The developmental code was modified to include SEDR predictors, and dependent sampling test were completed for SHIPS
Develop version of RII with structure predictors	None	None
Develop version of RII with SEDR predictors	Begin developing RII with SEDR predictors	Task is delayed due to lapse in appropriations in January, 2019
Develop final improved version of SHIPS/LGEM with new predictors	None	None
Develop final improved version of RII with new predictors	None	None
Complete final verification of the new models	None	None

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)
Develop database of structure predictors	100%	Nov 2017	Yes
Develop database of SEDR predictors	95%	Nov 2018	Yes
Develop version of SHIPS/LGEM with structure predictors	90%	Jun 2018	Final version was developed. Testing revealed issues with the structure predictors database related to incorrect formatting of some of NHC's best track files. Additional reruns and verification are in progress.
Develop version of SHIPS/LGEM with SEDR predictors	70%	Mar 2019	Yes
Develop version of RII with structure predictors	70%	Jun 2018	Reruns of new structurally-based RII models using updated database of structure predictors are in progress
Develop version of RII with SEDR predictors	0%	Mar 2019	Task is delayed due to lapse in appropriations in January, 2019
Develop final improved version of SHIPS/LGEM with new predictors	0%	Jul 2019	Yes
Develop final improved version of RII with new predictors	0%	Jul 2019	Yes
Complete final verification of the new models	0%	Jul 2019	Yes

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

Several milestones were added which were not reflected in the original schedule. These milestones are related to developing and verifying the database of structure and SEDR predictors. All these additional milestones were successfully completed.

Milestone	Completed vs proposed
Added Milestones	
Create updated database of wind structure predictors	Completed. The formatting of NHC's best track files that caused issues with the earlier version of the database were corrected, and the global databased of structure predictors was updated using NRL's ATCF reader.
Reprocess SEDR for all global basin for 1982 - 2017	Completed
Develop climatology for SEDR predictors	Completed

Develop software for adding SEDR predictors to diagnostic files	Completed
Add SEDR predictors to SHIPS diagnostic files and complete database verification	Completed. SEDR predictors were added to the 1982-2017 developmental database.
Original Milestones	
Conduct parallel runs of models with structure predictors	Parallel runs were delayed and replaced by retrospective runs due to the late delivery of the 2018 version of NHC guidance by TSB, which is the starting point for the modified version. Retrospective runs revealed issues with database of RMW and R34 related to incorrect formatting of some of NHC's best track files. The best track formatting was corrected, and reprocessing is in progress.
Modify SHIPS and RII to include SEDR predictors	Developmental code was modified to include SEDR predictors
Complete retrospective runs of models with SEDR predictors	Dependent sample testing was completed with SEDR predictors, reruns are in progress
Develop Fortran 90 version of SEDR	The Fortran 90 code is about 70% completed and will be finalized after we determine which version of SEDR is best to use.
Extend SHIPS modifications to global version	Code was developed for adding structure and SEDR predictors to global developmental diagnostic files

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

Milestone: Create updated database of wind structure predictors. The version of 2018 SHIPS/LGEM and RII was developed and tested with structure predictors. Testing revealed a number of issues with the database of structure predictors. It was found that the formatting of some of NHC's best tracks is incorrect which caused data reading errors in some cases. The best track formatting was corrected where needed, which allowed to use NRL's native ATCF reader to create the updated database of structure predictors. It was not possible to use NRL reader until the best track formatting was corrected. NHC is using NRL ATCF reader in operations and use of the same reader should simplify transitioning of the current project to operations if such transition is approved.

Milestone: Reprocess SEDR for all global basins from 1982 – 2017. SEDR data were reprocessed for the whole developmental database, 1982 – 2017, for both linear and quadratic discriminant analysis (LDA and QDA) versions. Previously available SEDR data only included data for 2005 – 2016.

Milestone: Develop climatology for SEDR predictors. SHIPS/LGEM and RII must be able to run on all cases, including cases when IR data are not available. Thus, for each predictor a climatology is required that can be used when real data is not available. The climatological version of SEDR was developed few years ago, but it was never used. That code was restored to working condition, and climatological data for SEDR were reprocessed for the whole developmental database, 1982 – 2017, for both LDA and QDA versions. The climatological version of SEDR used discriminant analysis to determine probability of the eye existence based on four parameters from ATCF, including maximum sustained wind, two components of the storm motion vector, and storm latitude.

Milestone: Develop software for adding SEDR predictors to diagnostic files. Fortran 90 code was developed for adding SEDR predictors to SHIPS diagnostic files. The updated SEDR database includes satellite IR data from 1982 to 2017. Since the satellite scan schedule changed during that time, the SEDR data are available at different time intervals relative to synoptic time. The times at which SEDR predictors are available are changing between 1982 – 2017. For example, sometimes the IR images is available 30 minutes before the synoptic time, or 15 minutes before the synoptic time, or 1 minute after synoptic time. In order to create consistent SEDR predictors for the whole database, code was developed to extract from the SEDR database data binned into seven 15-minutes time intervals near each synoptic time. The 15-minutes time bins start 90 minutes prior to synoptic time and go 15 minutes past the synoptic time. In real-time the intensity guidance is run about 30 minutes after the synoptic time, thus the data that are about 15 minutes after synoptic time can be still used.

Milestone: Add SEDR predictors to SHIPS diagnostic files and complete database verification. The new Fortran 90 code was used to add SEDR predictors from reprocessed 1982 – 2017 SEDR database to 1982 - 2017 SHIPS diagnostic files for both Atlantic and east/central Pacific basins. For each synoptic time SEDR data were added for t = 0 h, t = -6 h, t = -12 h, t = -18 h, and t = -24 h, where t = -24 h corresponds to SEDR probability of eye existence 24 hours before the synoptic time. The climatology version of SEDR is estimated using data available form best track, thus these estimates are available at synoptic times. Climatology SEDR data for t = 0h, t = -6 h, t = -12h, t = -18h, and t = -24h were also added to the developmental diagnostic files. Figure 1 shows the scatter plots of SEDR data from the developmental database. It could be seen on Figure 1 that QDA and LDA versions of climatology SEDR are well correlated. The SEDR data (lower panels on Figure 1) are much noisier, especially when the probability of eye existence is around 50%.

Milestone: Conduct parallel runs of models with structure predictors. The parallel runs were delayed due to the late delivery of the 2018 version of NHC guidance by TSB, which is the starting point for the modified version. Retrospective runs were conducted with the updated 2018 version of SHIPS with added structure predictors and revealed issues with database of RMW and R34 related to the incorrect formatting of some of NHC’s best track files. Best track formatting was corrected where needed, and the updated database of structure predictors was developed. Reprocessing of SHIPS reruns with structure predictors for 1982 – 2017 and 2018 is in progress.

Milestone: Modify SHIPS and RII to include SEDR predictors. Developmental code was modified to include SEDR predictors. In addition, the 2018 version of SHIPS was cleaned up which included fixing some minor bugs. Work is in progress on adding SEDR predictors to the updated 2018 version of SHIPS.

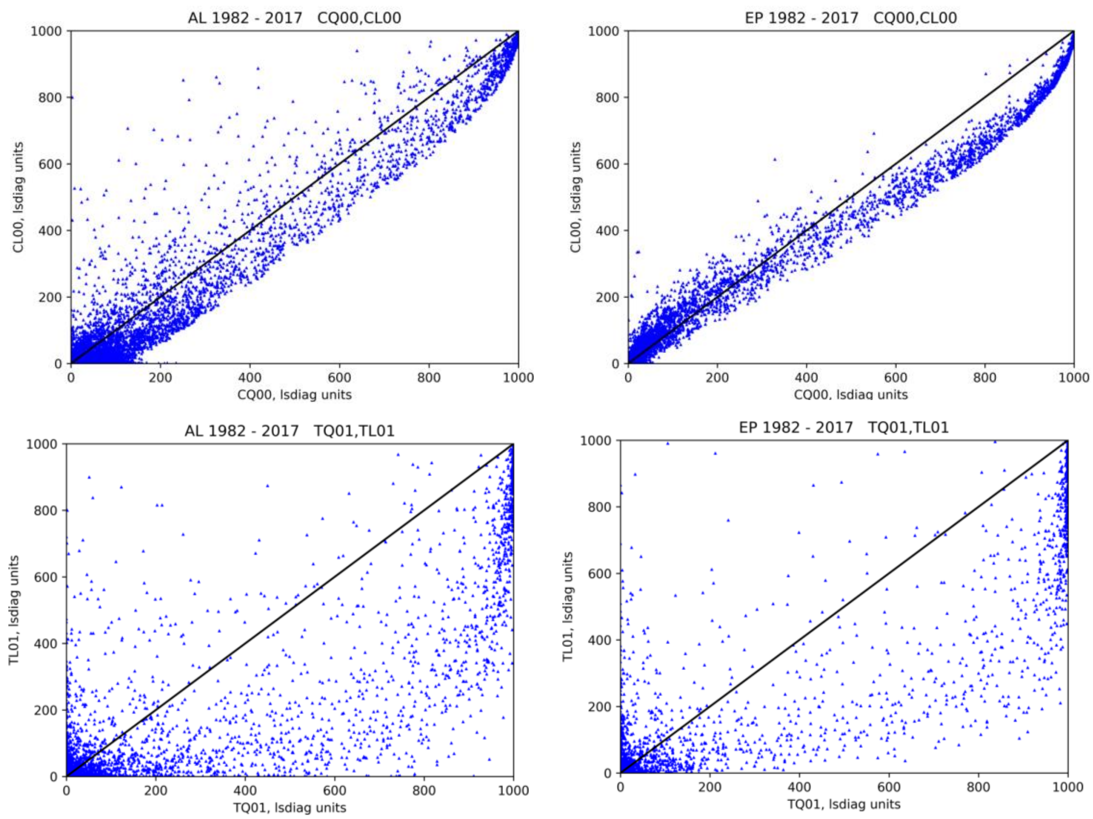

Figure 1. Scatter plots of SEDR probability of eye existence from 1982 – 2017 SHIPS diagnostic files. Upper left: Climatology SEDR LDA (CL00) vs QDA (CQ00) at t = 0 h for the Atlantic basin. Upper right: same for the east/central Pacific basin. Lower left: SEDR LDA (TL01) at t = 0 h vs QDA (TQ01, t = 0 h) for the Atlantic basin. Lower right: same for the east/central Pacific.

Milestone: Complete retrospective runs of models with SEDR predictors. SHIPS dependent sample testing was completed with SEDR predictors. Work on SHIPS and LGEM reruns with SEDR predictors is in progress. Dependent sample tests found that SHIPS forecast improvement with SEDR predictors is consistent with the preliminary results that were obtained using 2005 – 2016 SEDR data. The best results were found with using LDA version of SEDR and adding as predictors probability of eye existence at t = 0 h, t = -6 h, and t = -12h. Based on dependent tests, adding SEDR predictors produces the most significant forecast improvement at short forecast lead times (FLT), 6 – 30 h. For the 1989 – 2017 sample, the R^2 forecast improvement is up to 3.9 % at 12 h FLT for the Atlantic basin, and up to 1.4 % at 12 h for the east/central Pacific basin. In both cases three new predictors, corresponding to SEDR probability of eye existence at t = 0 h, t = -6 h, and t = -12 h were added to the model. Also, data from the climatological version of SEDR were used for the cases when data are not available. It was found that forecast improvement is much more significant for the recent cases. Adding 1982 – 1989 cases to the sample reduces forecast improvement to about 1 % for the Atlantic. That is probably related to changes in the IR data in 1995 – 1997. Until 1997/1998 the resolution of IR data was 8 km, and until 1996 only one centrally located geostationary satellite was available. SEDR was trained on 4-km data and might need to be re-trained to work well with 8 km data. Further testing will be performed to determine what are the best data to use for 1982 – 1996 to derive SHIPS/LGEM model coefficients with SEDR predictors.

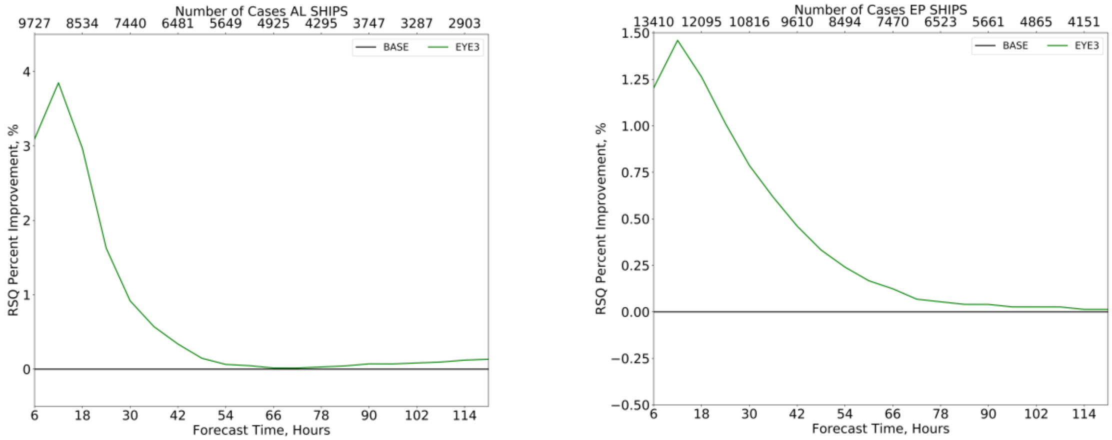

Figure 2. SHIPS dependent sample tests with LDA SEDR predictors for 1989 - 2017. R^2 is shown for SEDR runs relative to the baseline 2018 SHIPS version. 2018 SHIPS version with area-averaged daily Reynolds SST (DSTA) is used as a bassline. The SEDR version includes 3 additional predictors, SEDR probability of eye existence at t = 0 h, -6 h, and -12 h. Each SEDR probability is calculated as average of SEDR probabilities available from 45 minutes before the synoptic time to 15 minutes after the synoptic time. Left: R^2 percent improvement in SHIPS forecast after adding SEDR predictors for the Atlantic basin. Right: same for the east/central Pacific.

Milestone: Develop Fortran 90 version of SEDR. The development of Fortran version of SEDR is approximately 70% completed. Currently we have available six different versions SEDR, including LDA and QDA versions for each of the two IR data versions and LDA and QDA climatology versions. It is much easier to do reprocessing and testing using the existing python version of the code. Thus, we will complete the development of a Fortran 90 version after we complete model testing and determine which version of SEDR is best to use for real-time runs.

Milestone: Extend SHIPS modifications to global version. Fortran 90 code was developed for adding both structure and SEDR predictors to the global developmental diagnostic files, and SEDR data were reprocessed for global basins. Dependent sample testing of SHIPS/LGEM with added structure and SEDR predictors for the global basins will be conducted after the updated database of SHIPS diagnostic files becomes available. That database is currently being updated as part of a separate CIRA project.

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 were presented at the IHC in March 2018. The presentation is available online at https://www.nhc.noaa.gov/jht/17-19_proj.php . 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.

3) The project work is coordinated with NHC POC Mark DeMaria. The project was also discussed with JTWC POC, Brian Strahl, and NHC POC, Dan Brown, at IHC.

4) 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 complete retrospective runs of the SHIPS/LGEM and RIIs with structure and SEDR predictors, complete verification of retrospective runs and develop final version of SHIPS. LGEM, and RII models with the best combination of structure and SEDR predictors. Further, verification of the final version of the models will be completed.

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 structure predictors and corresponding climatological values for the years 1982 - 2017.	Developed as planned. The updated 2018 version will be made available to NHC and JTWC at the end of the project.
Fortran90 software for adding SEDR QDA and LDA predictors, and SEDR climatology predictors to global SHIPS diagnostic files	Developed as planned. Software will be provided to NHC and JTWC at the end of the project.
Global database of SEDR predictors, including LDA, QDA, and climatological versions.	Developed as planned. Updated database will be made available to NHC and JTWC at the end of the project.

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

Knaff, J. A., and R. T. DeMaria, 2017: Forecasting tropical cyclone eye formation and dissipation in infrared imagery. *Wea. Forecasting*, **32**(6), 2103-2116, doi: 10.1175/WAF-D-17-0037.1.

Chirokova, G, J. Kaplan, and J. Knaff, 2018: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors. *2018 TCORF, 14 March 2018, Miami, FL.*

-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.

- Global database of TC-structure predictors converted to SHIPS input format. The database includes both available data and climatology.
- Updated climatology of RMW, R34, and R5
- Fortran90 software for adding R34, RMW, and corresponding climatologies to SHIPS diagnostic files
- Global database of SEDR predictors converted to SHIPS input format. The database includes both available data and climatology.
- Fortran90 software for adding SEDR predictors and corresponding climatologies to SHIPS diagnostic files

*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 addresses 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 detection of probability of TC eye-existence using SEDR.

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.

The verification of retrospective runs of the 2018 models and the setup of the parallel runs of the modified versions of SHIPS, LGEM, and RIIs at CIRA were delayed relative to the original schedule. This delay was due to the very late delivery of the final version of the NHC guidance suite by TSB, which is the starting point for the modified version. Verification of retrospective runs for 2007 - 2017 revealed issues with the original version of the database of structure predictors related to the incorrect formatting of some of the NHC's best track files. The best track formatting was corrected where needed, the updated version of structure predictors was developed, and reruns with the structure predictors from the updated database are in progress. In addition, development of the RII model with new predictors was delayed due to the lapse in appropriation in January 2019. Overall the project is on schedule and the development of the final versions of the models is expected to be completed in Summer 2019, as originally planned.

-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: RL4

-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 and JTWC at the end of the project.

3) The possibility of implementing real-time SEDR processing and experimental versions of SHIPS, LGEM and RIIs with added structure and SEDR predictors in quasi-production on WCOSS for 2019 season has been discussed with NHC POCs and NHC TSB staff and will depend on the availability of NHC TSB resources. As an alternative, parallel runs for the 2019 season could be setup at CIRA.

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

The Testing Plan for this project was submitted in March, 2018. The revised version of the Testing Plan was submitted in May, 2018.

-- 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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Appendix B

NOAA READINESS LEVELS (RLs)

There are nine readiness levels defined in NOAA Administrative Order 216-105A as follows:

A. Research

RL 1: Basic research: experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications;

RL 2: Applied research: original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research or to determine new methods or ways of achieving specific and predetermined objectives.

B. Development

RL 3: Proof-of-concept for system, process, product, service or tool; this can be considered an early phase of experimental development; feasibility studies may be included;

RL 4: Successful evaluation of system, subsystem, process, product, service or tool in laboratory or other experimental environment; this can be considered an intermediate phase of development;

RL 5: Successful evaluation of system, subsystem process, product, service or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins;

C. Demonstration

RL 6: Demonstration of prototype system, subsystem, process, product, service or tool in relevant or test environment (potential demonstrated);

RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system);

RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given;

D. Deployment

RL 9: System, process, product, service or tool deployed and used routinely.