

National Oceanic and Atmospheric Administration Joint Hurricane Testbed Program

NOAA Award No. NA17OAR4590140

Title – Transition of Machine Learning Based Rapid Intensification Forecasts to Operations

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Recipient Organization (Name and Address)

Project/Grant Period (July 1, 2017 – June 30, 2019)

Valid for Period ending June 30, 2018

Report Term or Frequency (semi-annual)

Final Annual Report? No

## 1. ACCOMPLISHMENTS

*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)*

Table 1 below shows our objectives and scheduled goals. We have summarized the planned goals, our actual accomplishments, and have added some tasks in boldface based on feedback at the Tropical Cyclone Operations and Research Forum (TCORF) meeting in March.

<u>Proposed Outcome</u>	<u>Anticipated Completion Date</u>	<u>Actual Outcome</u>
Develop Training Codes to allow AIs to be updated prior to each Hurricane Season	31-Jan-18	Updated training codes are complete and have been used in 2018 Joint Hurricane Testbed; being ported to Python for eventual transition to operations
Attend Interdepartmental Hurricane Forum	15-March-18	Attended and presented at the meeting; obtained important information for updating our AI ensembles
Create website for dissemination of AI-based forecasts to forecasters	31-May-18	Website is complete and available to forecasters presently, available at <a href="http://arashi.geosci.msstate.edu/jht">http://arashi.geosci.msstate.edu/jht</a>
Disseminate results at the AMS Tropical Cyclone Meeting and Interdepartmental Hurricane Forum	30-April-18	Completed on time; all investigators attended the Interdepartmental Hurricane Forum; co-PI and grad student attended AMS Tropical Cyclone meeting

As evidenced by the table above, expected completion dates for the second reporting period's tasks are in line with current project progress.

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

Table 2: Proposed tasks from JHT proposal document with associated completion dates

<u>Proposed Task</u>	<u>Anticipated Completion Date</u>	<u>Percentage Completed</u>
Port R-based AI codes to Python scripts	28-Feb-18	This task was delayed due to feedback from the Interdepartmental Hurricane Forum (50%)
Begin Participation in 2018 Joint Hurricane Testbed	30 Nov-18	We are actively disseminating operational RI forecasts via the above mentioned website as part of the testbed, will be complete when hurricane season ends (100%)
Conduct AI-based model verification at conclusion of the Testbed, compare with NHC performance	30 Nov-18	This task is being done in real-time with the forecasts, but a full verification will not be possible until the end of the testbed (25%)
Publish results	30 Jun-19	We have already submitted one manuscript for publication and intend on submitting another (50%)

We feel the work is on track for an on-time completion, despite some delays in the Python code porting. Once FNL fields are fully implemented in the final product, the Python conversion will be completed. Otherwise, the work has progressed well into the next phase.

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

- The testbed AI ensemble currently uses seven predictors to make RI forecasts derived from operational best track and SHIPS diagnostic files: (1) Percent coverage of IR temperature below -30°C (IR00/IRXX); (2) 200 hPa zonal wind (U200); (3) MPI (VMPI); (4) 6-hour persistence; (5) 850-200 hPa generalized shear (SHRD); (6) Ocean heat content (RHCN/PHCN); and (7) 24-hour persistence.
- AI ensemble forecasts are generated in real time, automatically triggered by ATCF output every 6 hours.
- Forecasts are made available on a Mississippi State University server in ATCF e-deck format. Example: [http://arashi.geosci.msstate.edu/jht/eck\\_AL032018.dat](http://arashi.geosci.msstate.edu/jht/eck_AL032018.dat).
- Descriptor files are also made available for each forecast. Example: [http://arashi.geosci.msstate.edu/jht/18071118AL0318\\_RIAI.txt](http://arashi.geosci.msstate.edu/jht/18071118AL0318_RIAI.txt).

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

- The co-PI and Ph.D. student attended the 33<sup>rd</sup> Conference on Hurricanes and Tropical Meteorology in April 2018, where they expanded their professional network and discussed possible approaches to further improvements of the AI ensemble.
- All investigators attended the TCORF in March 2018 and obtained valuable feedback from the operational community regarding the AI ensemble. Many of the ideas discussed during that meeting are being added or adjusted within the AI ensemble as of this report.

*How were the results disseminated to communities of interest?*

- The Ph.D. student presented the AI ensemble and results from the 2017 Atlantic hurricane season at the 33<sup>rd</sup> Conference on Hurricanes and Tropical Meteorology in April 2018.

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

- Evaluate performance of current AI ensemble for the 2018 Atlantic Hurricane season. Using feedback from the Testbed experiment and forecaster input, we plan to begin updating our AI ensemble to hopefully make it ready for transition to operations.
- We will finalize adding FNL-based predictors to the AI ensemble, which will require retraining and a new set of AI ensemble members. The FNL data are being added based on feedback from the March TCORF meeting.

## 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)*

At this stage, there was only one proposed deliverable, an e-deck formatted AI output for use in the Joint Hurricane Testbed. We have successfully completed this deliverable and it is being implemented in real-time as part of the Testbed experiment. In the next phase we will require verification statistics to help demonstrate improvement (or lack thereof) from our AI ensemble over the NHC forecasts, thereby demonstrating benefit. We require the full season's results to obtain these, but are on track to do so.

*What has the project produced?*

- Presentation at IHC (March 2018)

Mercer, A. K. Wood, and A. Grimes, 2018: Transition of Machine-Learning Based Rapid Intensification Forecasts to Operations. *Trop. Cyclone Res. And Operations Forum*, Miami, FL.

- Presentation at 33<sup>rd</sup> Conference on Hurricanes and Tropical Cyclones (April 2018)

Grimes, A., A. Mercer, and K. Wood, 2018: Evaluation of Machine-Learning Based Rapid Intensification Forecast Performance During the 2017 Atlantic Hurricane Season. *AMS 33rd Conference on Hurricanes and Tropical Meteorology*, Ponte Vedra, FL.

- Real-time forecasts of RI likelihood provided on local Mississippi State server as part of the 2018 Joint Hurricane Testbed
- Descriptor files to provide supplemental information on real-time forecasts
- Submission of a manuscript to the Complex Adaptive Systems conference, specifically analyzing synoptic-scale pattern differences in false alarm RI events and correctly forecast RIs, in an effort to reduce the false alarm problems plaguing RI forecasts.

Mercer, A., A. Grimes, and K. Wood, 2018: Multidimensional Kernel Principal Component Analysis of False Alarms of Rapidly Intensifying Atlantic Tropical Cyclones. *Procedia Comp. Sci.*, in review.

### 3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

*What individuals have worked on this project?*

Andrew Mercer – Principal Investigator

Kimberly Wood – co-Principal Investigator

Alexandria Grimes – Ph.D. candidate

We have also had NOAA points of contact that we have interacted with:

Chris Landsea – lead point of contact, research to operations point of contact

Erik Blake – testbed point of contact

Stacy Stewart – testbed point of contact

Jose Salazar – testbed technological point of contact

Other than learning the official NOAA points of contact, during this reporting period there have been no changes to personnel.

### 4. IMPACT

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

The primary impacts have been in the area of machine learning and feature selection procedures, as a variety of different techniques have been implemented to identify the optimal features within the AI ensemble. Further, the probabilistic decision tree-type approach for the global ensemble output is somewhat new in the area of machine learning and has not been implemented in an operational product like ours to our knowledge.

In addition to this work, we have submitted a manuscript for publication at the Complex Adaptive Systems annual conference. This work analyzed synoptic-scale patterns within Atlantic TCs which were deemed false alarms by our AI ensemble, comparing those patterns with TCs

which were correctly forecast. In that analysis, we discovered that our AI ensemble was falsely identifying RI cases in the presence of relatively strong low-level horizontal equivalent potential temperature gradients. Further, upper-level stretching deformation fields seemed to be associated with false alarm cases as well. Further details on these differences are being analyzed presently, but it suggests the synoptic-scale low-level thermodynamics and upper-level winds contain the greatest potential for improving the AI ensemble and eventually reducing false alarms within Atlantic RI forecasts.

*What was the impact on other disciplines?*

There has been no direct impact on other disciplines as we are in the experimental stage of the project right now.

*What was the impact on the development of human resources?*

There has been no impact on the development of human resources.

*What was the impact on teaching and educational experiences?*

This project has been funding and training one Ph.D. candidate. Additionally, the project has garnered interest from outside faculty at Mississippi State who have used its content to help increase their knowledge of the machine learning field.

*What was the impact on physical, institutional, and information resources that form infrastructure?*

There has been no notable impact as of this progress report. The closest to impact has been the implementation of our AI ensemble in the testbed, which is being formally utilized by the NHC during the 2018 Hurricane Season.

*What was the impact on technology transfer?*

There was no impact on technology transfer at this stage in the project.

*What was the impact on society beyond science and technology?*

Once finished, the potential improved predictability of RI within tropical cyclones will assist infrastructure preparations prior to hurricane landfall and provide forecasters much needed intensification guidance for tropical cyclones. The results could potentially save lives by facilitating earlier evacuations (as needed) and enabling earlier preparations for landfalling major hurricanes.

*What percentage of the award's budget was spent in a foreign country(ies)?*

No funds were spent in foreign countries.

## 5. CHANGES/PROBLEMS

After some important feedback from NOAA personnel at the Hurricane Research Forum in March, we decided it would be wise to revisit the predictors and methods used in our AI ensemble. We have since developed an updated AI ensemble that, as of this progress report, only utilizes SHIPS-RII predictors along with operational track information (such as peak wind speed, intensity change, etc.). With these new predictors, we retrained the models and obtained a new 24-member AI ensemble. We also developed an AI that combines the 24 members into a single probabilistic output (with some basic decision trees incorporated as well). This probabilistic output showed significant growth in the 2017 season's forecasts when compared against our old model, and these changes have been implemented in the newest version which is being provided to NOAA presently during the testbed. We await further feedback from NOAA for improving the AI ensemble. Also, based on their feedback, we have begun incorporating FNL data into the ensemble, though the feature selection processes have taken some time and this is not fully implemented as of this progress report. We expect the FNL data to be incorporated fully at the end of the next reporting period.

## 6. SPECIAL REPORTING REQUIREMENTS

As this is a Joint Hurricane Testbed project, there are a few special reporting requirements. Outcomes for those requirements are provided after their questions below.

*What is your assessment of the project's Readiness Level?*

We feel the project remains at a readiness level of 5 as the Testbed has just begun. At the end of the next reporting period (at the conclusion of the Testbed), we hope the product will have progressed to a readiness level of 6.

*Project Test Plan*

The project test plan is provided as a separate document to this progress report.

*Transition to operations activities in the last 6 months*

There have been no official transition to operations activities in the last 6 months. However, the Program Manager requested a Research to Operations transition plan, which has been provided as a separate document to this progress report. This document has been revised based on feedback from NOAA personnel and as of this report no additional comments have been received.

*Summary of testbed-related collaborations, activities, and outcomes*

We have worked closely with our NOAA POC to revise the Research to Operations plan and our Testbed plan, and while the season thus far has been quiet, we will be engaging our POCs further to obtain feedback on the performance of our model. We have also interacted with NOAA personnel at the Interdepartmental Hurricane Research Forum where we gained important advice

to improve our models prior to the testbed. Many of those improvements have been implemented as a result of our collaboration with NOAA, with the rest being worked on presently.

*Has the project been approved for testbed testing yet?*

The project has been involved in the testbed since June 1, 2018.

*What was transitioned to NOAA?*

Nothing has been transitioned to NOAA as of this progress report. The product is currently in use for the 2018 Testbed, but the product is housed on a local server at Mississippi State. Preliminary discussions for the transition, including a revised transition plan, have been completed as of this progress report.

## 7. BUDGETARY INFORMATION

No major budgetary issues have arisen at this stage. The only budgeted funds to be spent by the end of the first quarter of the project were salary and benefits to the Ph.D. student, as well as her graduate tuition waiver. Additional funds will be encumbered with upcoming budgeted travel in Winter 2019. The project is on-budget.

## 8. PROJECT OUTCOMES

*What are the outcomes of the award?*

No formal outcomes have been attained yet. Once the project finishes, the resulting AI ensemble should produce an outcome of improved RI forecasts, which should provide tremendous benefit to society in terms of early warning times for major hurricane landfalls and associated infrastructure preparations.

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

At this stage, performance metrics of the AI ensemble have not entered into the proposed work, but the objective of the AI ensemble outperforming the currently available RI products has been realized. According to the results of the 2017 hurricane season, the AI ensemble forecast skill for RI forecasts outperformed the SHIPS-RII model for 13 of the 17 named storms (76%), yielding much needed improvement in RI forecasts.

As seen in Table 1, the tasks expected to be completed by the end of quarter 2 of the proposed project were all successfully completed. Currently, the AI ensemble is being tested in the Joint Hurricane Testbed for the 2018 season, with forecast performance (the primary objective in the proposal) being tracked in real-time. However, as of this progress report no RI event has occurred, so the performance metrics are not informative, since no system has forecast an RI.