NOAA/OAR Joint Hurricane Testbed

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Improved Eyewall Replacement Cycle Forecasting Using a Modified Microwave-Based Algorithm (ARCHER)

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1. ACCOMPLISHMENTS DURING THIS PERIOD

The milestones for this project, first described in the project proposal, are summarized in the following table. The major goals for this reporting period (Aug 2016-Feb 2017) are highlighted in yellow and described in turn directly below.

Milestones/Deliverables

Milestone	Start Date	Forecasted Completion	Actual Completion	% Complete
1. Create a double eyewall module for ARCHER	July 2015	Dec 2015	Dec 2015	100%
2. Create real-time online display of ARCHER-ERC output	Jan 2016	June 2016	June 2016	100%
3. Evaluate performance of online ARCHER module display	Jan 2016	June 2016	June 2016	100%
4. Produce initial online technical documentation	Jan 2016	June 2016	June 2016	100%
5. Calibrate/validate the ERC probability product	Jan 2016	June 2016	Feb 2017	100%
6. Finalize double eyewall ARCHER module to optimize performance	July 2016	Dec 2016	Dec 2016	100%
7. Finalize online display of algorithm	July 2016	Dec 2016	(May 2017)	90%
8. Complete online technical documentation	Jan 2017	June 2017		
9. Deliver ERC module for SHIPS	Jan 2017	June 2017		
10. Create real-time online text file output of ERC module for SHIPS	Jan 2017	June 2017		

Here we report on the progress on **Milestones 5-7** in the previous six-month period:

Milestone 5. Calibrate/Validate the ERC Probability Product

The ARCHER model provides radial profiles of "Ring Score" calculated from brightness temperatures in satellite microwave imagery. A time evolution of these profiles is shown in Fig. 1.

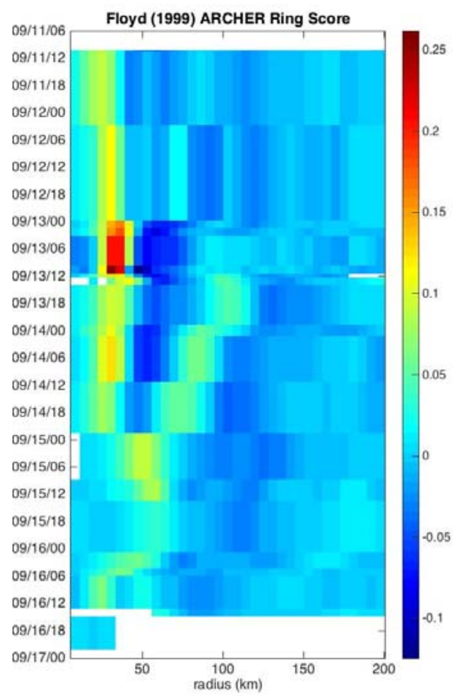

Figure 1: Hovmöller diagram of ARCHER Ring Score profiles in Hurricane Floyd (1999). Radius is distance from storm center in km. An outer eyewall starts to form on Sep 12–13, then becomes stronger in Ring Score and contracts, eventually "replacing" the inner eyewall on Sep 15.

A typical Ring Score (RS) profile in a storm with a single eyewall is shown in the left panel of Fig. 2. The maximum RS is found in the eyewall, and there is a minimum outside the eyewall in the subsidence region of the moat. A typical RS profile in a storm with concentric eyewalls is shown in the right panel of Fig. 2. Here the maximum is in the inner eyewall and a secondary maximum is located in the outer eyewall, and the moat is confined between these two maxima.

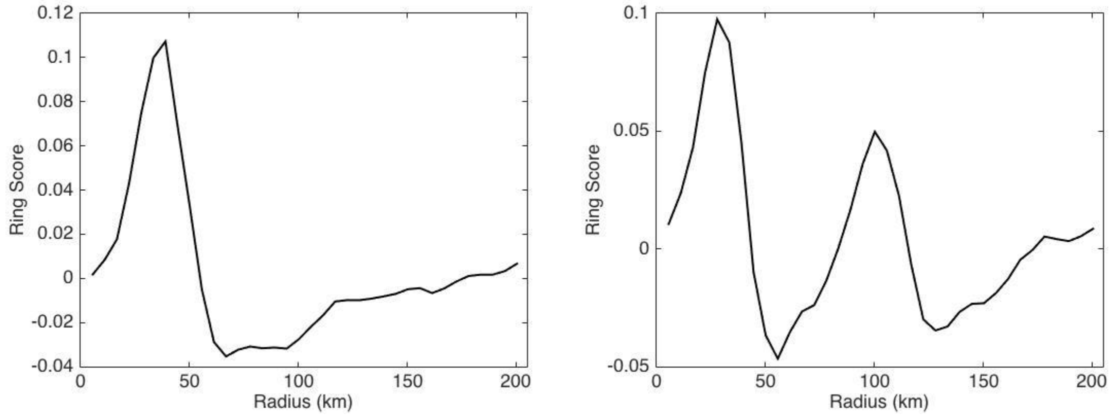

Figure 2: Typical Ring Score profile in a storm with a single primary eyewall (left) and a storm with concentric eyewalls (right).

The temporal evolution of these profiles during an eyewall replacement cycle (ERC) is intuitive; the inner RS maximum decreases while the outer maximum increases and contracts radially inward. The moat can become very pronounced when both eyewalls are convectively active. As the ERC evolves, the inner maximum eventually vanishes as the contracting outer eyewall "replaces" it.

So, to diagnose the onset of an ERC, there should be quite a lot of information in this temporal evolution of the RS profiles. After considering and exploring a number of methods to objectively capture this information (e.g., using Peaks Analysis software), we have arrived at a method that is comparatively simple and seems to be highly effective. The RS profiles for all times in all storms that we have data for (about 1500 profiles) were first decomposed into a set of Empirical Orthogonal Functions (EOFs). The profiles were first standardized to avoid too much focus on the high variability region of the inner eyewall. The first 8 EOFs, which can also be referred to as "RS profile loading patterns", are shown in Fig. 3, and they do a good job of capturing the radial variability of the RS profiles.

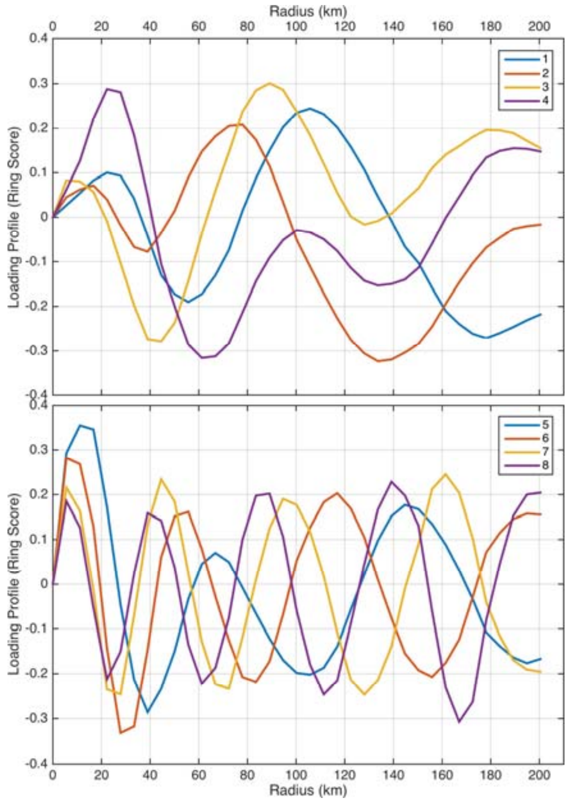

Figure 3: RS profile loading patterns determined using Principal Component Analysis. Any RS profile can be largely reconstructed by summing over these profiles with the appropriate weights.

When the loading patterns are projected onto an RS profile, each of the 8 projections will provide a different "weight" (or, alternatively, principal component or PC) so that the eight PCs together describe the shape of that profile. By looking at these PCs and how they evolve over time, we can objectively isolate the behavior seen in the Hovmöller diagram of Fig. 1.

Our goal is to provide a probability of ERC onset using these PCs as predictors. We also use storm intensity as a predictor because of its known relationship to ERC onset. The two methods that we have used in the past are to construct a Bayesian model and/or a binomial regression model, which is simpler to implement. Here we chose to first explore the binomial regression model with the thought that we could potentially create a second Bayesian model in the future.

One of the great advantages of using PCs as predictors in a regression is that they are completely independent of each other by construction (the EOFs are orthogonal). So issues of predictor cross-correlation are completely eliminated and this makes for a very "clean" model. The addition of the intensity-based predictors does introduce some cross-correlation back into the model since the PCs are also likely to be correlated with intensity, but this should be comparatively minimal. The model predictand (response variable) is an ERC-onset flag that was determined subjectively using microwave imagery. The flag is 1 at ERC-onset, 2 during the ERC, and 0 everywhere else. Using the flag = 2 during the ERC allows us to exclude those times from model training and testing. Our thinking is that the forecaster wouldn't be interested in the model-estimated probability of ERC-onset during an ERC.

Our model development and implementation procedure is as follows: We begin with a predictor pool consisting of the first 8 PCs and current intensity (in knots) for all times in all storms. The previous 6, 12, 18, and 24 h change in these 9 predictors form the remainder of the 45-predictor candidate suite. A backward stepping routine is used to reduce the predictor pool, which selected 38 predictors. If the current intensity is less than 65 kt, a probability of zero is assigned. We also constructed a second model for comparison that uses only the intensity-based predictors (no microwave information).

In a dependent test, the model, which we are calling M-PERC, explains 48% of the variance of the ERC-onset flag and the Brier Skill Score is 49%, which is actually quite remarkable. Some examples of the model performance are shown in the Fig. 4. In these figures, the solid line is the new M-PERC model and the dashed line is the intensity-based model. The colored lines show the ERC events deduced subjectively using the microwave imagery. ERC-onset is at the earliest point on each of the colored lines, and the line spans the period of the ERC duration. The lines are green, yellow, and red for high, medium, and low confidence in the true existence of the ERC events.

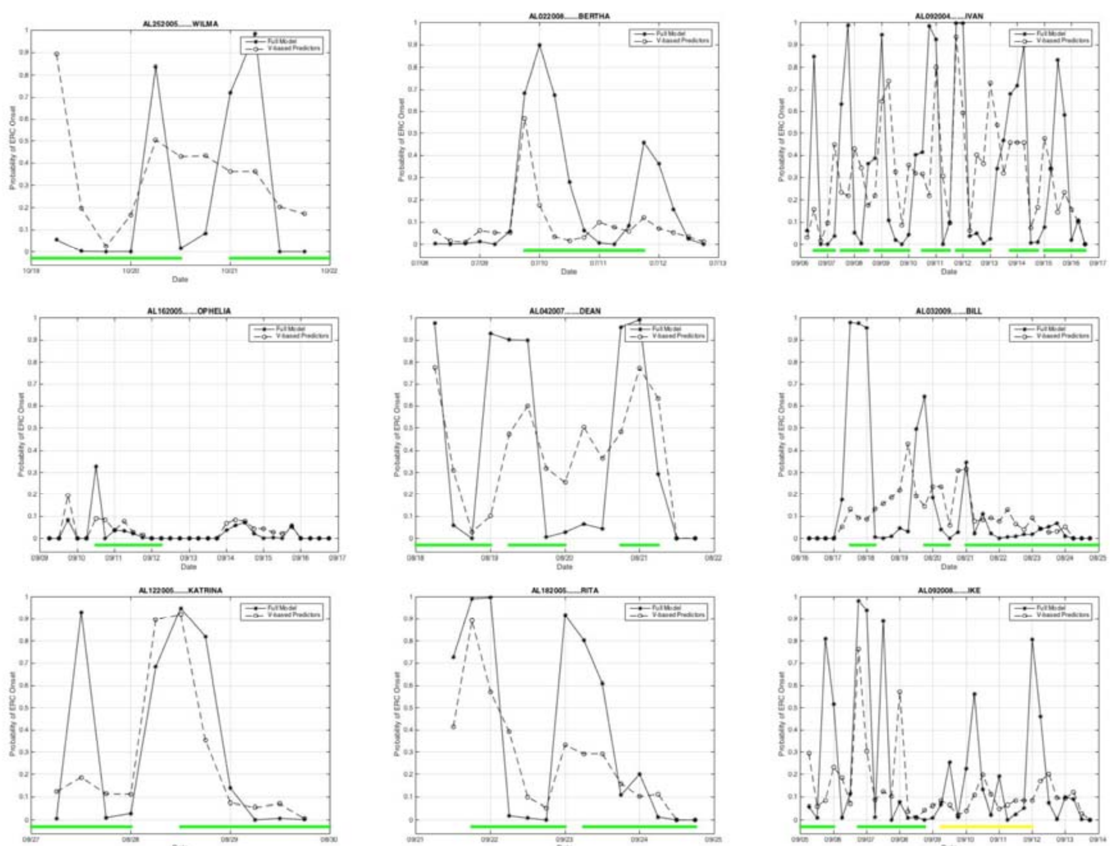

Figure 4: M-PERC diagnostic estimate of probability of ERC-onset in a few storms. In some cases (e.g., Wilma, Dean, Katrina, Ike), the model is started during an ongoing ERC, and the estimates during the ERC should be ignored. That is, only the earliest point of the colored lines are relevant to ERC-onset, and only periods with no colored lines are relevant for non-ERC cases.

In summary, we have completed a working model to diagnose ERC-onset using microwave information. We are calling it the M-PERC model, and it appears to perform remarkably well, at least in dependent testing. The main challenges to the operational implementation of M-PERC will lie in the data availability and latency constraints, but that is nothing new.

Milestone 6. Finalize double eyewall ARCHER module to optimize performance.

During the calibration/validation of M-PERC, it remained an option to revise ARCHER to work more effectively in the objective ERC scheme, and we explored this option while the calibration/validation was underway. However, M-PERC worked very effectively with the existing ARCHER modifications, so any extra effort to revise ARCHER was not necessary, and the existing version is now considered final.

Milestone 7. Finalize online display of algorithm.

The real-time ERC guidance page, hosted at CIMSS, has been stable and generating ERC products as part of the larger ARCHER system since September 2016. The only remaining task is to add the M-PERC probabilities as a column in the Hovmöller plots, as in Fig. 5. This will be finished by May 2017, well ahead of the 2017 North Atlantic hurricane season.

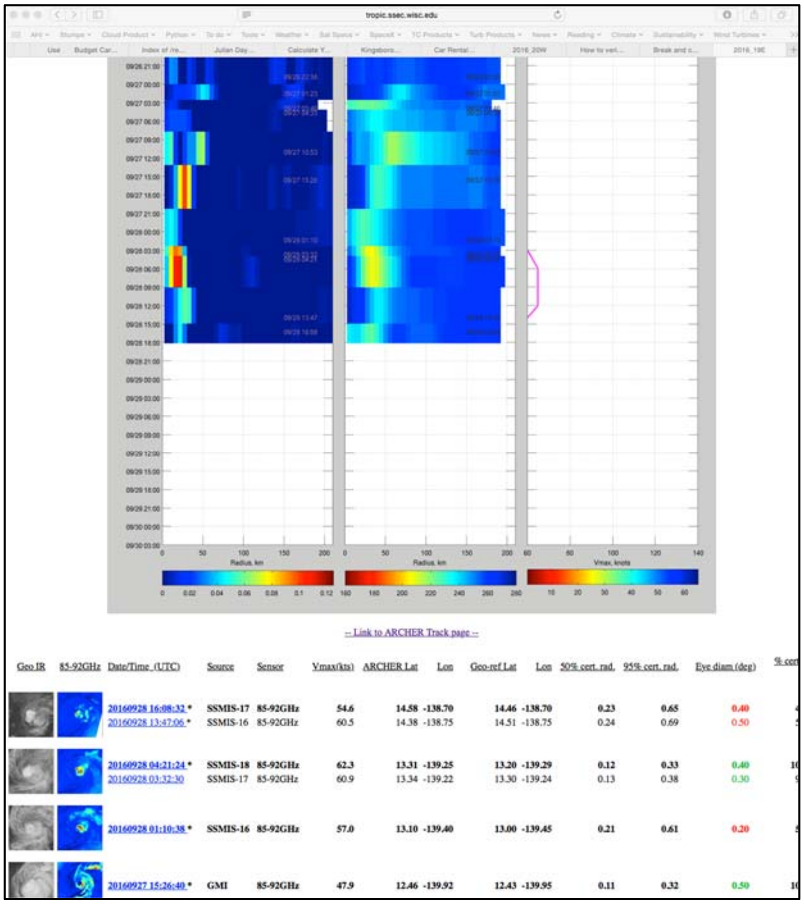

Figure 5. Screenshot of ERC guidance page for Hurricane Ulika (2016 19E).

2. PRODUCTS

As described in Section 1, we have developed the following deliverables/products during this reporting period:

a. The ERC-Probability model algorithm (M-PERC), which will soon be incorporated into the real-time ERC guidance website at CIMSS.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

As this is a fairly small project, we have kept the activity limited to the three original participants – Anthony Wimmers, Derrick Herndon and Jim Kossin. We have provided regular updates to our colleagues at the NHC.

4. IMPACT

The expected impact of this project is to improve the forecasting accuracy for intense hurricanes in one of the current areas of need for the NHC: understanding and predicting eyewall replacement cycles. We attempt to do this using an automated analysis of eyewall (and developing eyewall) sizes and trends from 85-92 GHz microwave imagery. The information is organized into real-time online graphics and we will soon have an associated probabilistic model. These new tools under development will offer a more rigorous analysis of a phenomenon that requires greater understanding and analysis to provide adequate warning during weather-related emergencies.

5. CHANGES/PROBLEMS

No changes to the original project design are currently necessary.

6. SPECIAL REPORTING REQUIREMENTS

Test Plans for the ARCHER-ERC / M-PERC Project

For the remainder of Year 2 of this project, we will test the ARCHER-ERC / M-PERC in the following manner. We will continue to run ARCHER-ERC for the real-time website at CIMSS, and within the next two months we will have M-PERC running in conjunction and display the results. While we wait for real-time cases in the North Atlantic, we will run the algorithm on an independent validation dataset from 2012-2016 and report on the product accuracy and Brier Skill Score.

The product evaluation is already well underway, as described in this report (Section 1) and in the Year One report. The ARCHER-ERC product is performing in real-time as expected, and we have reported on performance metrics for the M-PERC product. The performance of M-PERC on the independent validation dataset will be evaluated in a similar manner. The last component of evaluation is for NHC forecasters to confirm that the products are performing in the 2017 hurricane season as expected based on the prior validation. This will require a no-cost extension and simple regular monitoring of the automated ARCHER-ERC and M-PERC algorithms by the CIMSS team.

The primary criterion for success is a positive review from NHC participants within the JHT. Their decision will be based on quantitative performance metrics compiled by the CIMSS team (accuracy, Brier Skill Score), case histories (as in Fig. 4) as well as the NHC's professional judgment of the skill of the algorithm in real-time.

7. BUDGETARY INFORMATION

We are currently on budget and our planned expenditures are as expected. Our proposal stated that the product development should proceed quickly by following the development pathways of the original ARCHER project and the pERC model. This has gone as expected.

8. PROJECT OUTCOMES

The anticipated outcome of this project is a new system to automatically analyze near real-time microwave imagery of hurricanes and provide comprehensive forecaster guidance on the potential for an upcoming eyewall replacement cycle. This guidance will take the form of an online graphical depiction of the relevant image characteristics, and a probabilistic model using microwave image information in the same fashion as the pERC model.

REFERENCES

n/a