NOAA Joint Hurricane Testbed Project
Final Progress Report
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"Updating the Secondary Eyewall Formation Probabilistic Model, Completing New Climatologies of Intensity and Structure Changes Associated with Eyewall Replacement Cycles, and Construction of New Forecast Guidance Tools based on the New Climatologies"

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Report:
All proposed Year-1 milestones were met:

- *Append model training/testing dataset with 2010 data.*
    - **Completed**. Table 1 shows appended dataset (this was further expanded to 2012 in Year-2).
- *Perform cross-validation studies to explore weighting of satellite-based features and to explore the utility of additional features.*
    - **Completed**. Results shown in Table 2 and Figure 1.

- *Adapt feature selection code (used in a regression framework) to the Bayesian framework of the model with the goal of better feature optimization and increased skill.*
    - **Completed**. Figure 1 and Table 2.

      Details: Optimal feature selection and cross-validation for the Bayesian probability model were performed for both the original dataset (1997-2006) and the expanded (1997-2010) dataset (completion noted above). An objective function, *J*, was defined as:

      $$J = \sum_{i=1}^{N} (f_i - o_i)^2,$$

      where f and o represent the model predicted and observed probability of secondary eyewall formation, respectively. The minimum of this function was determined using a standard sequential feature selection software package and the features selected were employed in the model for cross-validation purposes for both training datasets.

- *Write new routines to utilize logistic regression as a second model, and form a simple two-member ensemble with the Bayesian model (again with the goal of improving overall model skill). These will be added to our current suite of subroutines running within SHIPS.*
    - **Completed**. Results shown in Figure 1 and Table 2.

- *Complete the formation of a more inclusive and relevant climatology of intensity and structure changes associated with ERCs.*

    - **Completed**. Published papers listed in bibliography.

All proposed Year-2 milestones were met:

- *Transform the new ERC climatologies into an objective forecasting tool that will provide guidance on how best to adjust the intensity forecasts in the case that an ERC occurs (the probability of an ERC is given by our existing model). An analogous tool to provide guidance on structure changes will also be constructed.*
    - **Completed**. The models constructed from the ERC climatologies are described in Kossin and Sitkowski (2012).

- Appended model training/testing dataset with 2011 and 2012 data. The data now span 2008–2012.
- Performed cross-validation (operational) on the Bayesian probability model, the optimized Bayesian probability model, the logistic regression probability model, and a model ensemble (simple average).
    - The Brier Skill Scores are shown in Table 2. The models have been performing skillfully in a consistent and robust manner. In 2012, the Brier Skill Scores were quite high because there were so few ERC events and the models were providing low probabilities of ERCs. Still, it is difficult to claim too much success in 2012 as the one observed ERC event in Hurricane Michael was not forecasted well and was missed. After-the-fact analyses showed that anomalously low MPI and ocean heat content lowered the model probability substantially. Here, the environment that Michael was in when the ERC occurred was highly anomalous with respect to the training data the models are based on, and updating the models with the expanded training data from 2012 is expected to help.
    - The Attributes Diagrams are shown in Fig. 1. The Bayesian and optimized Bayesian models have performed skillfully at all forecast lead times and have been skillful at providing both low and high probabilities, but the logistic regression model has not been skillful at providing high probabilities at the longest lead time (36-48h).
- New models to predict intensity and structure changes during an ERC were constructed from the ERC climatologies (described by Sitkowski et al. 2011). The new models are described in Kossin and Sitkowski (2012) and are summarized in Fig. 2.
    - The new models have been converted to FORTRAN subroutines and transitioned into SHIPS, and should be operational in the 2014 season. The models are expected to provide additional objective guidance preceding and during ERCs that may help forecasters when they are subjectively adjusting the usual numerical and statistical intensity guidance.

Tables and Figures

Table 1: Number of North Atlantic hurricanes, major hurricanes, hurricanes that exhibited at least one secondary eyewall during their lifetime, and number of individual SEF events from 1997-2010.

	1997	1998	1999	2000	2001	2002	2003	2004
Hurricanes	3	10	8	8	9	4	7	9
Major Hurricanes	1	3	5	3	4	2	3	6
SEF Hurricanes	2	3	2	1	3	2	2	5
SEF Events	3	3	3	1	3	2	4	16
	2005	2006	2007	2008	2009	2010	Total	
Hurricanes	15	5	6	8	3	12	107	
Major Hurricanes	7	2	2	5	2	5	50	
SEF Hurricanes	5	1	2	3	2	6	39	
SEF Events	9	1	5	4	3	9	66	

Table 2: Brier skill scores from operational testing on the years 2008-2012 for the Bayesian probability model, the optimized Bayesian probability model, the logistic regression probability model, and a model ensemble (simple average) for all model lead times.

Operational Model Verification 2008-2012 (Brier Skill Scores)

Year	N (TS)	N (HUR)	N (ERC)	00-12 hr	12-24 hr	24-36 hr	36-48 hr
2012	19	10	1	+57 +54 +54 +56	+58 +53 +51 +54	+58 +54 +42 +52	+57 +54 +35 +49
2011	18	6	5	+21 +22 +10 +20	+18 +16 +11 +17	+14 +13 +6 +14	+19 +16 +11 +18
2010	19	11	9	+27 +41 +25 +38	+23 +20 +25 +28	+11 +17 +15 +20	+10 +17 +8 +17
2009	9	3	3	−6 −6 +11 +7	−2 −8 +6 +3	−1 −6 +28 +17	+5 +6 +36 +27
2008	16	8	4	+14 +11 +2 +10	+12 +4 −7 +4	−5 −7 +0 +0	+2 −6 −4 +0
2008-2012	81	38	22	+20 +26 +22 +27	+17 +16 +18 +21	+9 +13 +15 +17	+11 +15 +12 +17

Bayesian **Optimized Bayesian** **Logistic Regression** **Ensemble**

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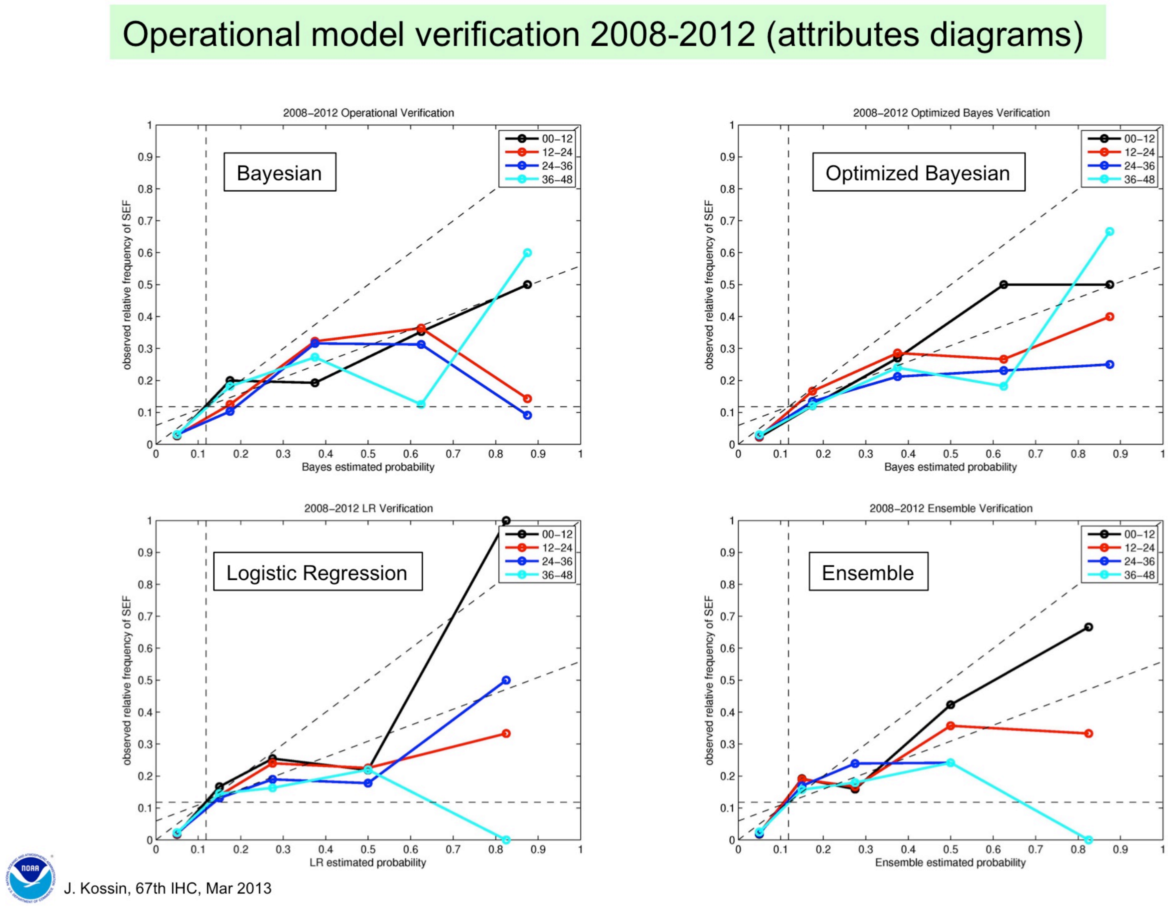

Figure 1: Attributes diagrams for the models.

Can we use this climatology and the SHIPS features (**F**) to create useful predictive models?

Phase II ΔV: mean = –20 kt, STDev = 18 kt

$\Delta V = f(\mathbf{F})$ $R^2 = 68\%$, RMSE = 3.6 kt

Phase II ΔT: mean = –17 hr, STDev = 9 hr

$\Delta T = f(\mathbf{F})$ $R^2 = 49\%$, RMSE = 6.2 hr

Phase III $\Delta V / \Delta T$: mean = +0.8 kt hr^{-1}, STDev = 2.3 kt hr^{-1}

$\Delta V / \Delta T = f(\mathbf{F})$ $R^2 = 47\%$, RMSE = 1.3 kt hr^{-1}

Total expansion of RMW: mean = 22 km, STDev = 13 km

$\Delta \mathrm{RMW} = f(\mathbf{F})$ $R^2 = 51\%$, RMSE = 9.9 km

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Figure 2: Summary of the models created using the ERC climatology of Sitkowski et al. (2011). The first (topmost) model predicts the amount of weakening expected during the ERC, the second model predicts the duration over which the weakening is expected to occur, the third model predicts the re-intensification rate expected at the completion of the ERC, and the third model predicts the expansion of the RMW during the ERC.

Publications

Kossin, J. P., and M. Sitkowski, 2012: Predicting hurricane intensity and structure changes associated with eyewall replacement cycles. *Wea. Forecasting*, **27**, 484-488.

Sitkowski, M., J. P. Kossin, C. M. Rozoff, and J. Knaff, 2012: Hurricane eyewall replacement cycles and the relict inner eyewall circulation. *Mon. Wea. Rev.*, **140**, 4035-4045.

Sitkowski, M., J. P. Kossin, and C. M. Rozoff, 2011: Intensity and structure changes during hurricane eyewall replacement cycles. *Mon. Wea. Rev.*, **139**, 3829-3847.

Kossin, J. P., and M. Sitkowski, 2009: An objective model for identifying secondary eyewall formation in hurricanes. *Mon. Wea. Rev.*, **137**, 876-892.