Ensemble Forecasting of Hurricane Intensity based on Biased and non-Gaussian Ensemble Sampling

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1. Introduction

While the ensemble approach has proven to have positive impact on hurricane track forecast skills, ensemble forecasting of hurricane intensity remains one of the most challenging research topics in numerical weather prediction (Fig. 1).

The improvement of hurricane intensity forecast skills by ensemble technique is hampered by two factors: 1. Model deficiencies or model biases, which are mainly caused by inaccurate model representations of atmospheric physics, such as cumulus convection scheme; 2. Non-Gaussian distribution of the intensity errors, which is a result of model non-linearity.

This study investigates all possible uncertainties that are caused by either initialization process or model physics. Two ensemble generation methods have been used in this study: single model with multi-initial condition and multi-model, multi-physics. The intensity error probability density function (PDF) is then estimated from the ensemble members. The PDF shows that the predicted hurricane intensity errors are biased and non-Gaussian distributed, which indicates that arithmetic mean among the ensemble members will not improve the intensity forecasts.

Two post-process methods are introduced in this study: 1. to correct the model bias through ensemble PDF; 2. to find most probable mode through PDF kernel density estimation method. The first method is applied to the single model with multi-initial condition ensembles while the second is applied to the multi-model, multi-physics ensembles. The results showed that hurricane intensity forecast skills are greatly improved by implementing ensemble post-processes.

2. Methodology

The hurricane model used in this study is the NCEP operational HWRF system. In order to better understand how regional hurricane model responds to the large scale flow perturbations at the initial time and how model physics affects hurricane intensity forecasts, two sets of ensembles were designed. The ensemble one is designed to study the impact of uncertainties from large scale flow, which uses the GEFS data (resolution T190L28) as input data to initialize HWRF domain. It contains three sub-sets that use three different cumulus convection schemes. The second set of ensemble is intended to understand the impact of uncertainties in multi-model and multi-physics, which include the operational HWRF with various physics and GFDL model.

Two statistical methods are used to estimate intensity error PDF: histogram estimation and kernel density estimation. In kernel density estimation, Gaussian distribution is used as the kernel function. A simple bias correction is applied to the first set of ensembles based on the PDF estimation from the ensemble members. In the second set of ensembles, Gaussian kernel density estimation is used in the mode analysis to identify the most probable hurricane intensity.

3. Results

The methodology was tested in hurricane Earl 2010, which lasted about 10 days. Forecasts were performed four cycles per day. The experiments contain total 41 sample forecasts.

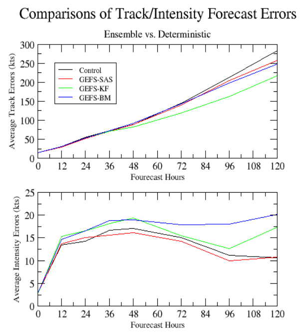


Figure 1: Comparison of Track/Intensity Forecast Errors

The top panel of Fig.2 shows the averaged intensity forecast error distribution. It is clearly indicated that HWRF under-prediction strong

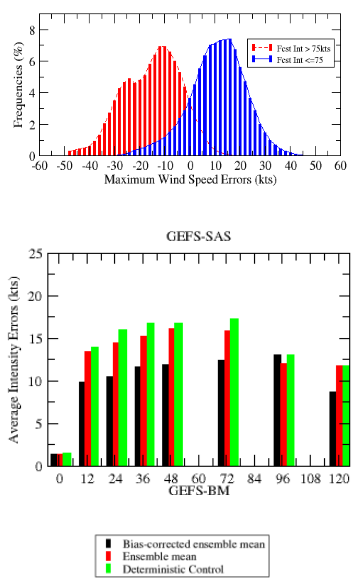
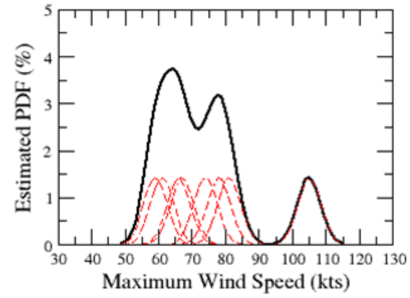


Figure 2: top: Averaged intensity forecast error distribution for Hurricane Earl 2010, total of sample forecasts:41. Bottom: comparison of intensity forecast errors.

storms (greater than 75kts) and over-predicted weaker storms (less than 75kts). The bottom of Fig.2 shows the intensity forecast errors are further reduced by simple bias correction on top of arithmetic ensemble mean.



Obs=65kts, mode=65kts, simple ensemble mean=75kts,

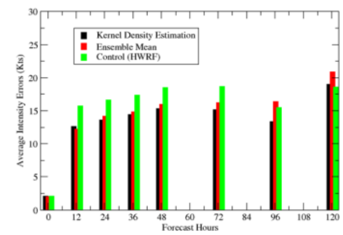


Figure 3: top: Intensity error PDF at 48h estimated from Gaussian Kernel density Estimation. Bottom: comparison of intensity forecast errors.

For multi-model, multi-physics ensembles, the PDF is estimated by Gaussian kernel density and the mode is used as ensemble intensity forecasts. Fig. 3 clearly showed that the mode based hurricane intensity over-performed the control forecasts as well as arithmetic mean intensity forecasts.

4. Conclusions

- Hurricane intensity forecast error PDF is not zero-mean, Gaussian distributed; therefore, arithmetic mean of ensembles will not improve the intensity forecasts.
- Hurricane intensity forecast skills can be improved in the post-process through both bias-correction and PDF mode analysis by kernel density PDF.