Further Improving Intensity Forecast of Tropical Cyclones in the NCEP Operational HAFS Model

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1. Introduction

The Hurricane Analysis and Forecast System (HAFS) has been actively developed as NOAA Unified Forecast System hurricane application since 2019. It was approved for operational use for the 2023 hurricane season, replacing NOAA's current operational tropical cyclone (TC) forecast systems, HWRF and HMON. The first operational version of HAFS was tested and finalized during the 2022 test and evaluation season. Three years (2020, 2021, and 2022) of retrospective runs show that the track forecast errors are smaller than those of the operational HWRF and HMON models for all lead times. The intensity errors are reduced for most lead times, but they are close to or slightly degraded at some lead times. As a result, further improving the intensity forecast is one of the priority tasks for HAFS developers. Previous studies have shown the importance of the parameterization of sub-grid scale (SGS) fluxes to TC simulations. Here we briefly report on an experiment in which the effect of a higher-order term is added to the calculation of SGS fluxes in the HAFS model. Experimental runs show that the modification does improve the intensity forecast at the day 4 and day 5 lead times.

2. Operational HAFS model version 1

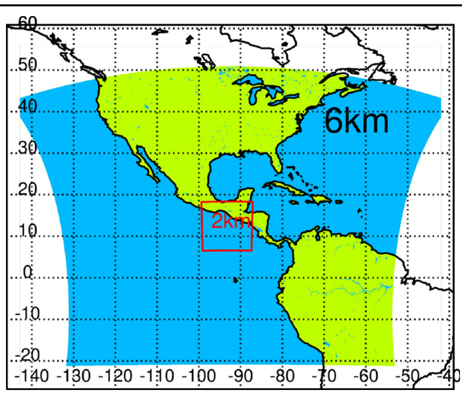

Fig.1 HAFS domains. Horizontal grid spacing is 6km in parent domain, and 2km in nest domain (red square).

The HAFS is designed as a coupled atmosphere-ocean-land multi-scale model and data assimilation system. The atmospheric model dynamics is based on the fully compressible Finite Volume Cubed-Sphere (FV3) dynamical core with a Lagrangian vertical coordinate. The ocean model implemented in HAFS is HYCOM. The first version of the operational HAFS model is configured with one parent domain with one storm-following, two-way interactive moving nest (Fig. 1). The horizontal resolutions are 6km and 2km in the outer and nest domains, respectively. The model uses 81 vertical levels on a sigma-pressure hybrid system with a model top of 10 hPa and the lowest level at ~20 m above the surface. There are 23 levels below 1.5 km, with vertical grid size varying approximately from 20 m to 130 m near 1.5 km, to reasonably resolve PBL processes. A combined vortex modification and DA system is used to initialize the vortex. The lateral boundary conditions are derived from GFS forecasts and updated every 3 hours. Two HAFS configurations (HFSA and HFSB) will be run in the operation to provide diverse model forecast guidance. The GFDL single moment microphysics scheme is used in HFSA, while the double-moment Thompson microphysics scheme is used on HFSB. This is the major configuration difference between HFSA and HFSB. In the following test, HFSA is used.

3. Method

Usually, the sub-grid vertical flux of a variable is parameterized as a sum of a local flux and a nonlocal flux. Above the boundary layer, a simple K-method is used. From the conservation equation of a vertical flux (e.g., potential temperature, θ), the vertical flux is not only a function of the vertical gradient of mean values of θ, but also a function of the variance of θ and other terms. By neglecting time-tendency and diffusion terms, the vertical flux, $\overline{w'\theta'}$, can be written as,

$$\overline{w'\theta'} = -K\frac{\partial\bar{\theta}}{\partial z} + c\tau_1\beta\overline{\theta'^2} \quad (1)$$

Where the bar denotes a spatial (grid) average, K is diffusivity, c is a coefficient, τ_1 is a dissipation time scale. The above equation was used in the 1980s to derive the nonlocal counter-gradient term under convective conditions. In our application, we focus on its impact on the flux calculation under other conditions. The variance term can be solved by adding another prognostic $\overline{\theta'^2}$ equation,

$$\frac{\partial\overline{\theta'^2}}{\partial t} = -\frac{\partial\overline{w'\theta'^2}}{\partial z} - 2\overline{w'\theta'}\frac{\partial\bar{\theta}}{\partial z} - 2\frac{\overline{\theta'^2}}{\tau_2} \tag{2}$$

where τ_2 is a dissipation time scale for $\overline{\theta'^2}$. In order to not increase the computational time, we use a simplified diagnosis, assuming the diffusion term is neglected under a quasi-equilibrium condition. Therefore, $\overline{\theta'^2}$ is estimated as,

$$\overline{\theta'^2} = -\overline{w'\theta'}\frac{\partial\bar{\theta}}{\partial z}\tau_2. \tag{3}$$

Apparently, the above simplified relationship is not valid for the well-mixed conditions usually occurring in the convective PBL where the diffusion term cannot be neglected; this scenario is treated in HAFS by a mass flux method.

4. Results

The operational HAFS-A model version 1 was used to test the impact of the higher-order term on TC simulations. We ran the HAFS model using Eq. (1) for nearly all long-lived TCs over the North Atlantic (NATL, 531 cycles) and East Pacific (EPAC, 487 cycles) ocean basins in 2021 and 2022, denoted by HEXP. Results are compared with those from the operational HAFS-A, denoted by HFSA. The only difference is the use of Eq. (1) in HEXP. The model is initialized every 6 hours.

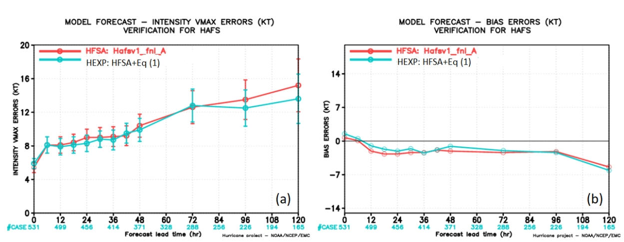

Fig. 2 Intensity error (a) and bias (b) from two runs for NATL storms in 2021 and 2022.

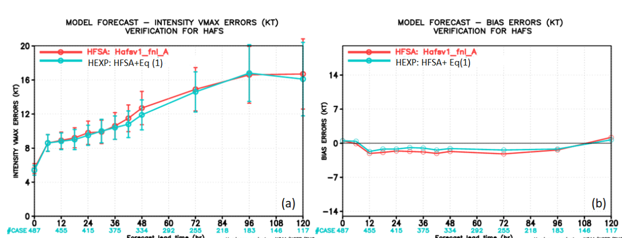

Fig. 3 Same as Fig. 2 except for EPAC storms.

For NATL storms, the root mean square (RMS) intensity errors from HEXP are smaller than HFSA at all lead times, with the largest improvement appearing at the lead times of 96h and 120h. In terms of bias, both runs are very close, with HEXP slightly reducing the negative bias of the operational HAFS. For EPAC storms, HEXP slightly improves the intensity errors, with the largest improvement appearing at the lead times from 36h to 48h. Similar to the NATL storms, the bias are also slightly improved. In general, the improvement in intensity errors by HEXP for EPAC TCs is less than that for NATL TCs.

5. Summary

We tried a modified SGS flux calculation by considering the effect of a higher-order term. Results from experimental runs using the operational HFSA suggest that the modification can improve the RMS intensity errors and biases of TCs in HAFS simulations for both NATL and EPAC storms. Next, we will examine the sensitivity to certain parameters and test the prognostic equation of temperature variance.