An Idealized Hurricane Analysis and Forecast System (I-HAFS)

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1. Introduction

The Hurricane Analysis and Forecast System (HAFS) is an application of NOAA's unified forecast system (UFS) specialized in tropical cyclone (TC) research and forecasting. It was designed to support operational TC forecasts, replacing the Hurricane Weather Research and Forecasting (HWRF) and the Hurricane Multi-scale Ocean-coupled Non-hydrostatic (HMON) operational models, and to further improve dynamic model guidance for TC track and intensity. HAFS was first operationally implemented at NCEP in June 2023, with an updated version, HAFSV2, rolled out in July 2024, featuring physics and infrastructure updates. To further improve the performance of HAFS simulations, an idealized HAFS (I-HAFS) has been developed. This system facilitates the examination and development of model dynamical and physical schemes under controlled boundary and initial conditions, as well as standardized surface properties. This article serves as an introduction to this idealized HAFS system.

2. I-HAFS components and flow chart

I-HAFS mirrors the operational HAFS in structure but excludes the data assimilation system and focuses solely on atmospheric forecasts. Currently, idealized ocean and wave simulations have not been integrated into I-HAFS. I-HAFS consists of the following 5 main components: (1) Pre-processes which prepare forecast parent and nest domains with fixed distributions of geography-related variables, lateral boundary conditions (LBC) and initial conditions (IC) based on TC-vital messages and large-scale GRIB data; (2) Vortex initialization (VI) which includes options to generate high-resolution vortex and/or vortex location and intensity corrections; (3) FV3-based atmospheric forecast; (4) Post-processing which reformats the forecast output to standard levels in GRIB data format, generating data files with ATCF (Automated Tropical Cyclone Forecasting System) format containing forecasted TC track and intensity, and plotting the graphics of key fields; (5) Disk cleanup and data archive.

Figure 1 shows the flowchart of the I-HAFS. The system begins by reading the TC-vital file of a storm, then prepares/configures the parent and nest domains based on storm locations and geography-related information over the domains, including terrain, sea masks, soil, and vegetation information, etc. In I-HAFS, terrain and sea mask values are prescribed to zero over the entire domain. Next, the large-scale GRIB data is processed by FV3 preprocessing codes to generate the files for LBC and IC required by the forecast model. Users can choose to create an initial vortex over high-resolution grids (option '*use_high_res_vortex=yes/no*') and/or modify the vortex ('*run_vi=yes/no*') if the storm's initial intensity and location do not match the TC-vital file. A new feature, the '*cal_vortex*' procedure, has been added to the '*datool*' package of the operational HAFS ('$HAFS/sorc/hafs_tools.fd/sorc/hafs_datool/'). This procedure reads variables from netCDF files generated by the *atm_init* process and recalculates the 3-dimensional wind, temperature, humidity fields based on user-specified vortex formulations. Once the data preparation is completed, the FV3-based forecast system is run for forecasts, with an option to use an f-plane (where the Coriolis parameter remains constant) or not. The post-processing package converts the FV3 output to standard variables and rewrites them to GRIB2 files at standard vertical levels. The tracker code then generates intensity and track data in ATCF format.

3. Data preparation

To prepare for an I-HAFS run, two essential datasets are required. The first is a tcvitals file, which contains key information about the location and intensity of the idealized TC. The second is a GRIB2 dataset of global-scale atmospheric fields, which provides idealized initial and boundary conditions for a regional I-HAFS run.

The tcvitals file is used to initiate an I-HAFS run and prepare the regional parent and nest domains with the correct location. It is also utilized by the HAFS vortex initialization process to adjust the TC's location and intensity within the large-scale dataset. Below is an example of the content of the tcvitals file used in the current I-HAFS, *NHC 88E IDEAL 20190824 0000 100N 1799W 070 047 1000 1003 0269 25 055*, where the idealized tropical cyclone is called IDEAL and its number is 88E with the initial location at (179.9W, 10N).

The large-scale dataset is obtained by running the global FV3 model for 5 days with a specified vortex and its environment (i.e., idealized TC), where all terrain and sea mask values are prescribed to zero (i.e., all surfaces are covered by water). The current I-HAFS utilized the idealized TC from the Dynamical Core Model Inter-comparison Project (DCMIP2016). The same idealized TC formulation is also applied in the ‘cal_vortex’ procedure to recalculate an initial vortex over the HAFS parent and nest domains, which have higher spatial resolutions than those in the global GRIB2 data.

4. Examples

As an example, I-HAFS is run to compare the impact of different damping levels (n_sponge) on TC simulations. An idealized TC (88E) was simulated using the same configuration as the operational HAFSv2, with the exception of DA and ocean coupling, and initializing with the idealized large-scale GRIB2 data and tcvitals, as described in Section 3. The parent and nest domains are approximately 80X60 and 10X10 degree^2 (Fig. 2), with horizontal resolutions of 6 km and 2 km, respectively. There are 81 levels in the vertical, extending to a top level of 2 hPa. The primary physics schemes employed include the GFS surface layer, TKE-EDMF PBL, scale-aware SAS, Thompson microphysics, and NOAH land surface schemes. In the control run n_sponge is set to 24 (as in the HAFSv2), while in the experimental run s_sponge is set to 81. Both runs are initialized directly from GRIB2 data without VI. The HAFS with more damping levels simulates a slightly more compact vortex (Fig. 3), with a stronger Vmax for all lead times and a rightward track deviation after 2 days (Fig. 4). Figure 5 is the same as Fig. 4 but assumes a constant Coriolis parameter. Both simulated TCs remain near the initial location and exhibit similar Vmax values due to zero background wind and the constant Coriolis parameter.

5 Summary and future work

An idealized version of HAFS has been introduced. It closely resembles the operational HAFS but is driven by idealized surface data, large-scale atmospheric fields, and tcvitals. Future enhancements will include the incorporation of idealized ocean and wave components, as well as more idealized vortex configurations.

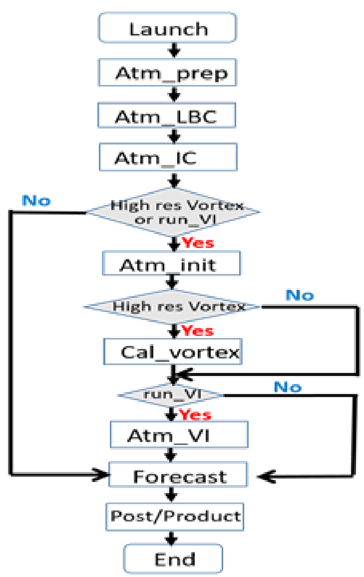

Fig.1 Flow chart of Idealized HAFS. All components are the same as those in the operational HAFS, except for the added ‘high_res_vortex’ and ‘cal_vortex’ blocks.

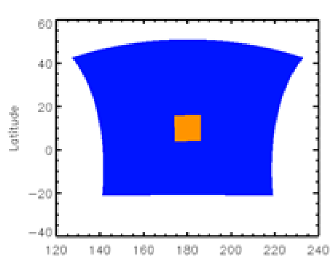

Fig. 2 HAFS two domains

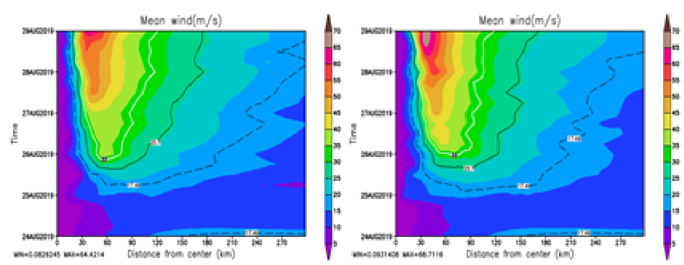

Fig. 3 Hovmöller diag of 10-m wind control (L) & experimental (R) runs.

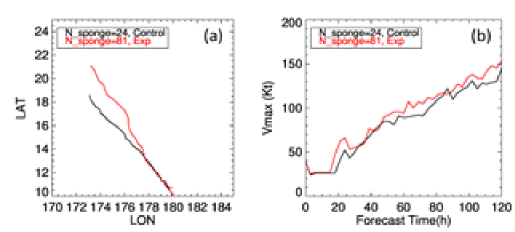

Fig. 4 (a) track and (b) Vmax from I-HAFS runs.

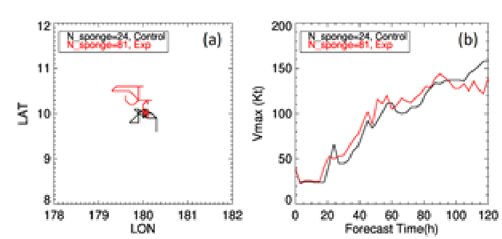

Fig. 5 (a) track and (b) Vmax from I-HAFS runs, assuming a constant coriolis parameter (10^-4).