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# The Development of Next NCEP Global Ensemble Forecast System

Xiaqiong Zhou[1], Yuejian Zhu[2], Bing Fu[1], Dingchen Hou[2], Jiayi Peng[1], Yan Luo[1], and Wei Li[1]
*[1]IMSG at Environmental Modeling Center, NOAA/NWS/NCEP*
*[2]Environmental Modeling Center, NOAA/NWS/NCEP*

## 1. Introduction

The current operational Global Ensemble Forecast System (GEFS v11) was implemented at Dec. 2015 (Zhou *et al.*, 2017). It uses a semi-Lagrangian global spectrum model (NCEP GFS/GSM version 12.0.0) with the horizontal resolutions $T_L574$ (34 km) for the first 8 days and $T_L384$ (52 km) for the second 8 days. There are 64 vertical levels on sigma pressure hybrid layers. The initial conditions for 20 ensemble members are generated from GSI/EnKF hybrid analysis by adding the 6-h EnKF forecast ensemble perturbations (Zhou *et al.*, 2016). The stochastic total tendency perturbation (STTP) scheme is used to represent model uncertainties by perturbing the total tendency of the model prognostic variables (surface pressure, temperature, wind, and humidity) with an empirical formula (Hou *et al.* 2006, 2008).

GEFS version 12 (FV3-GEFS) is still under development and will be implemented at Q3FY2020. FV3-GEFS uses the NOAA new generation global forecast model with the GFDL Finite-Volume Cubed-Sphere (FV3) dynamical core (Lin and Rood, 1997; Lin 2004). The physics package remains similar with the one used in the current operational GFS except some updates. In this new system, the GFS convection scheme is updated with a scale-aware parameterization (Han *et al.* 2017). The convection scheme is also modified to reduce excessive cloud top cooling for the model stabilization. The GFDL cloud microphysics scheme with five predicted cloud species (cloud water, cloud ice, rain, snow and graupel) will replace the Zhao-Carr microphysics scheme with only total cloud water. Other updates also include a revised bare-soil evaporation to reduce dry and warm bias, an updated parameterization of ozone photochemistry with additional

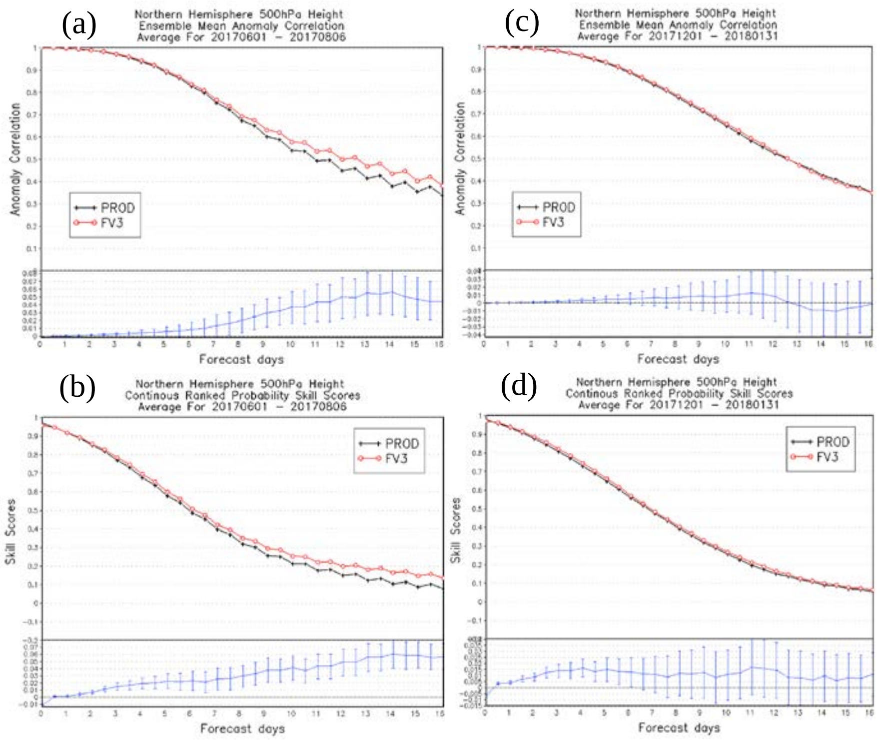

**Fig. 1** (a) PAC and (b) CRPSS for the 500-hPa geopotential height over the NH for the warm season (2017060100-2017080600). (c) and (d) are as same as (a) and (b) except for the cold season (2017120100-20170130). The black curves represent the operational GEFS and the red ones represent the FV3GEFS. The lower graphs show the difference and bootstrap significance test (blue bars). The difference is significant at the 95% confidence level when the value is outside the bars.

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Correspondence to: Xiaqiong Zhou, IMSG at Environmental Modeling Center, NOAA/NWS/NCEP;
E-mail: xiaqiong.zhou@noaa.gov

production and loss terms (McCormack *et al.* 2006) and a new parameterization of middle atmospheric water vapor photochemistry (McCormack *et al.* 2008).

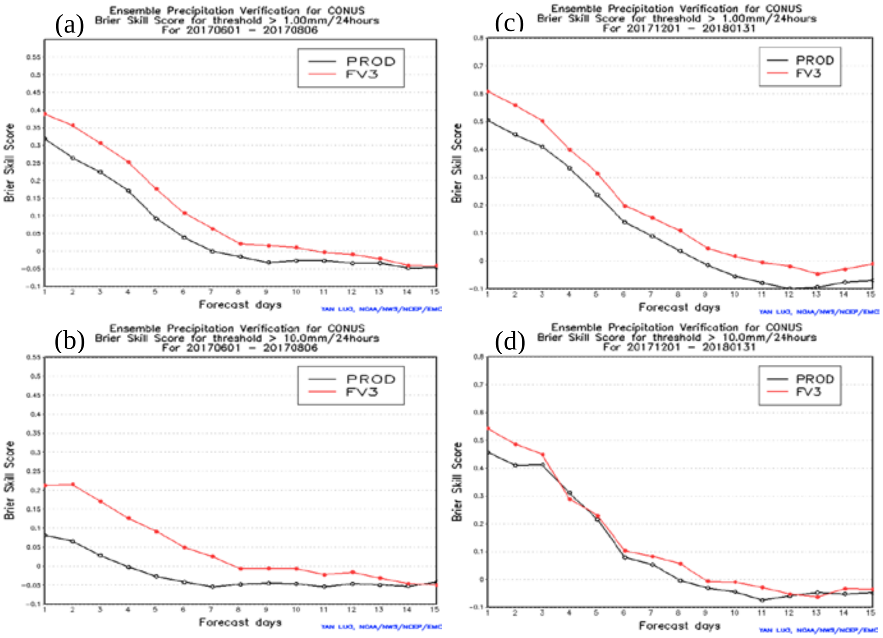

**Fig. 2** BSS for the ensemble mean precipitation greater than (a) 1mm (24 h)$^{-1}$ and (b) 10 mm (24h)$^{-1}$ averaged over the warm season. (c) and (d) are as same as (a) and (b) except for the cold season.

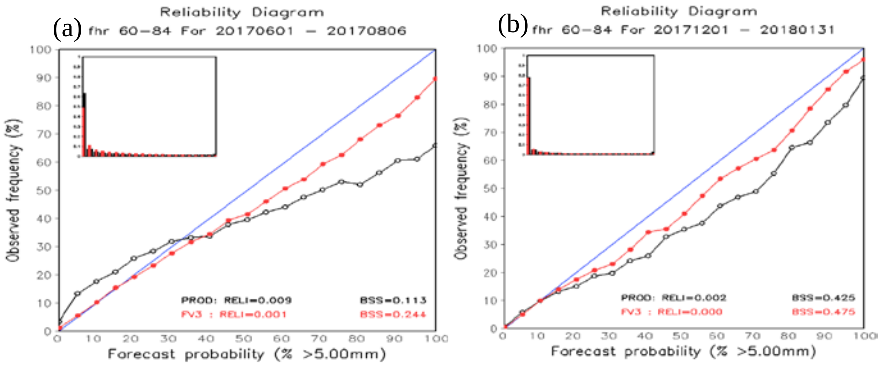

**Fig. 3** Reliability of precipitation > 5mm/day calculated with the 21 probability categories from a 21-member ensemble for the (a) warm season and (b) cold season. The top-left inset in each plot shows the proportion of cases in each probability category.

In contrast to the current operational GEFS v11, FV3-GEFS will extend the forecast from 16 to 35 days with increased and uniform horizontal resolution through model integration (about 25 km). A Near-Surface Sea Temperature (NSST) model is used to predict the vertical profile of sea temperature between the surface and a reference level (about 5m) by only considering two physical process: diurnal thermocline layer warming and thermal skin layer (also known as sub-layer) cooling (Li 2015). This scheme could resolve SST diurnal variabilities and provide a more realistic thermal boundary condition for the atmosphere. A 2-tiered representation of the foundation temperature (sea temperature at the NSST reference level) is used to better represent the variation of ocean temperature forcing with the forecast time (Zhu *et al.* 2018; Wei *et al.* 2018). The STTP scheme used in the operational GEFS is replaced by a stochastic physics suite. It has three components, including 1) stochastically perturbed physics tendencies (SPPTs; Buizza *et al.* 1999; Palmer 1997, 2001), 2) stochastically perturbed planetary boundary layer humidity (SHUM), and 3) stochastic kinetic energy backscatter (SKEB; Berner *et al.* 2009; Shutts 2005) to represent model uncertainty. All these three schemes use a random pattern generator and AR(1) process to produce spatially and temporally correlated perturbations with horizontal length/time scales up to five different categories: 500 km/6 hours, 1000 km/3 days, 2000 km/30 days, 2000 km/90 days and 2000 km/1 year.

## 2. Experiment and verification

Experiments with the FV3-GEFS configuration as discussed in the previous section were performed for one warm season (from Jun. 1 to Aug. 8, 2017) and one cold season (from Dec. 1 2017 to Jan. 30 2018). The initial conditions for the control run and ensemble members are generated by using hybrid analysis and EnKF 6-hour forecasts from FV3GFS parallel runs. The FV3-GEFS performance is verified against the hybrid analysis of FV3GFS parallel runs and compared with the operational GEFS against its own analysis.

The comparison shows that FV3-GEFS improves the ensemble-mean forecasts of 500 hPa geo-potential height with higher pattern anomaly correlation (PAC) and continuous rank probability skill scores (CRPSSs) in the Northern Hemisphere (NH) than that in the operational GEFS (Fig. 1). The improvement is generally statistically significant at 95% confidence level and the skillful forecast (PAC> 0.6) extends 12 hrs in the warm season (Fig 1a). Similar improvement can be seen in the cold season but the difference between FV3-GEFS and the operational GEFS in the cold season is not statistically significant (Fig 1c and Fig.1d).

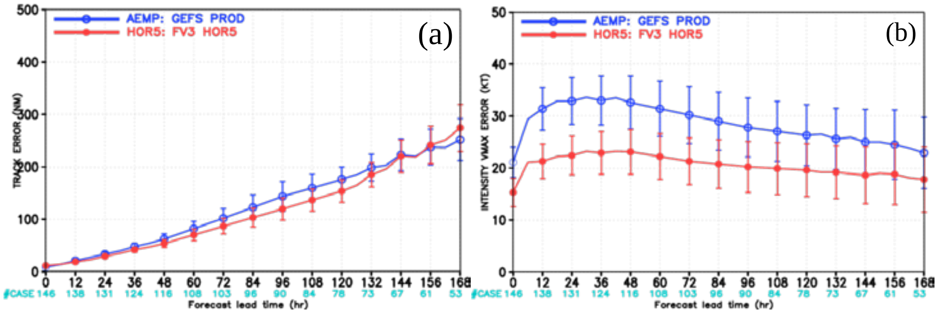

**Fig. 4** Tropical cyclone forecast (a) track and (b) intensity errors over Atlantic basin for 2017 hurricane season. The blue curves represent the operational GEFS ensemble mean, while the red curves represent the FV3GEFS. The number of TC cases verified for the forecast lead time from 0 - 168 hr listed below the X axis.

Quantitative precipitation forecasts (QPFs) and probabilistic QPFs are verified against the climatology-calibrated precipitation analysis (CCPA) over the contiguous United States (CONUS). In the categorical verification methods, precipitation is categorized by the 24-h accumulated precipitation with threshold amounts greater than 1, 5, 10, and 20 mm. Brier skill score (BSS) uses the 10-yr mean of CCPA as the climatology to calibrate the Brier score in order to avoid the dependence on the event frequency. FV3-GEFS generally outperform the operational GEFS in terms of precipitation BSSs in each category over CONUS. The BSSs for the precipitation categorized with the threshold amounts greater than 1mm and 10 mm in both warm and cold seasons are shown in Fig. 2. Reliability diagrams display the observed probabilities conditioned with the forecast probabilities of all forecast samples. They provide information about probability forecast bias. If the forecasts have perfect reliability (no bias), the reliability curve would lie along the diagonal line. The comparison shows that FV3-GEFS reliability curves are generally closer to the diagonal line than those from the operational GEFS. The probabilities for higher probability categories are overestimated as the reliability curve is located at the right side of the diagonal line. Apparently, the issue of overestimated probability in FV3-GEFS is significantly improved compared with the operational GEFS (Fig. 3). For the low probability categories, FV3-GEFS presents close perfect reliability.

The 2017 hurricane season over Atlantic was a catastrophic season. There are 17 named storms of which 10 became hurricanes including six major hurricanes (Category 3, 4 or 5) – two category-4 hurricanes (Hurricane Harvey and Jones) and two category-5 hurricanes (Hurricane Irma and Maria). The forecasted tropical cyclone tracks are promising with slightly smaller errors in FV3-GEFS in the first 5-6 days but with larger errors in longer lead times (Fig. 4a). The intensity forecasts are significantly improved (Fig. 4b) as the tropical storms are more intense in the new system than in the operational GEFS.

The MJO prediction skill using Wheeler-Hendon MJO indices (Wheeler and Hendon 2004) in FV3-GEFS is compared with the experimental GEFS extended forecast system which was developed to support the Subseasonal Experiment (SubX) project (Fig. 5). The comparison shows that the skillful MJO prediction with AC > 0.5 extends from 20 days in Subx GEFS to 22 days in FV3-GEFS.

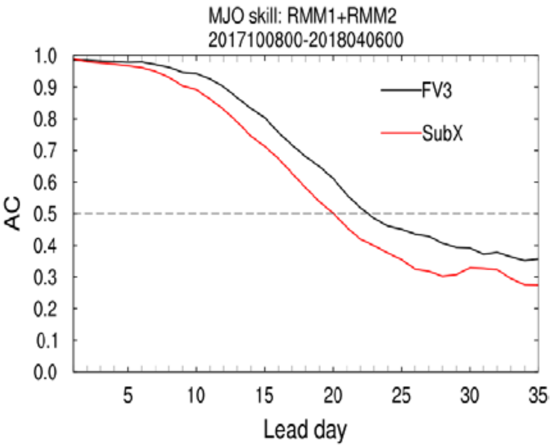

**Fig. 5** MJO prediction anomaly correlation skills of using Wheeler–Hendon indices for FV3GEFS (black curve) and SubX (red curve).

## 3. Summary and discussion

NCEP FV3-based GEFS is scheduled for implementation at Q3FY2020a system. The integration of this new system with all pre-processes and post processes is almost completed and the configuration of FV3-GEFS (GEFS v12) is close to be frozen. The preliminary results from the experiments based on FV3-GEFS was studied. The performance of FV3-GEFS is promising based on the comparison with the operational GEFS for one warm season (from Jun. 1 to Aug. 8, 2017) and one cold season (from Dec. 1 2017 to Jan. 30 2018). FV3-GEFS is generally more skillful than the operational system over extratropical regions with respect to the ensemble mean and probability forecasts of large-scale patterns. The improvement of precipitation forecast over CONUS are very encouraging. FV3-GEFS outperforms the operational GEFS in terms of the reliability and BSSs of precipitation forecasts. In addition, the performances of FV3-GEFS in tropical cyclone track and intensity forecast and MJO skill forecasts are generally positive. Note that this is a preliminary study with very limited sample size. Comprehensive verification will be performed after 2.5-year parallel testing with FV3-GEFS is finished in the near future.

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