Data Assimilation in the Next-Generation Global Prediction System Era: Initial Implementation of FV3-based Global Forecast System

Daryl Kleist (NOAA/NWS/NCEP/EMC) & Catherine Thomas (IMSG @ NOAA/NWS/NCEP/EMC)

Email: daryl.kleist@noaa.gov & catherine.thomas@noaa.gov

As part of the Next-Generation Global Prediction System (NGGPS), the National Centers for Environmental Prediction (NCEP) is replacing the spectral dynamical core of the Global Forecast System (GFS) with the Finite-Volume Cubed-Sphere Dynamical Core (FV3) of the Geophysical Fluid Dynamics Laboratory (GFDL). The initial implementation of the FV3-based GFS is focused on incorporating the FV3 core into the existing infrastructure and is tentatively scheduled to go operational in June 2019.

The operational GFS and global data assimilation system (GDAS) utilize a Gridpoint Statistical Interpolation (GSI)-based hybrid 4D Ensemble-Variational solver (4DEnVar, Kleist and Ide, 2015). The system uses a dual resolution configuration, with a deterministic component at T1534 (~13km) horizontal resolution and an 80 member ensemble run at T574 (~35km) horizontal resolution, all which utilize 64 hybrid sigma-pressure vertical layers and a model top of ~55km. The ensemble is updated every cycle utilizing the ensemble square root filter (EnSRF) of Whitaker and Hamill (2002). The hybrid 4DEnVar deterministic analysis is performed on the ensemble grid and is used to replace the EnSRF analysis ensemble mean.

The initial FV3-based GFS implementation seeks to utilize existing infrastructure as much as is feasible. The FV3 dynamic core utilizes a cubed-sphere grid, though with the addition of the NOAA Environmental Modeling System (NEMS) write-grid component, forecasts are also available on the Gaussian lat-lon grids that the GSI and EnKF infrastructure can ingest without much additional effort. This allows for the deterministic and ensemble analysis increments to be computed on the Gaussian grid, which are subsequently interpolated to the cubed-sphere grid within the model itself and added onto the native grid restart state.

The stochastic components that are used in the GFS spectral model have been modified and adapted for use within the NEMS-FV3 model. For the initial implementation, stochastically perturbed boundary layer specific humidity (SHUM, Tompkins and Berner, 2008) and stochastically perturbed physics tendencies (SPPT, Buizza et al., 1999) are targeted for use. Stochastic energy backscatter (SKEBS, Shutts, 2005) is available as an option in the NEMS-FV3 model, but is not utilized as part of this initial implementation.

One significant decision that was made early in the development and testing phase was to increase the spatial resolution of the ensemble to be exactly half of the deterministic control. The prototype FV3-based GFS is configured to run at C768 resolution (~13 km) for the control with an 80 member ensemble cycled at C384 (~26 km). Likewise, the analysis increment is also computed on a Gaussian grid that roughly corresponds to C384 resolution.

The initial FV3-based GFS implementation utilizes physics parameterizations primarily from operations, with the largest exception being the microphysics. The operational prognostic cloud scheme has been replaced with a single moment, six-class cloud microphysics scheme from GFDL (Lin et al., 1983). However, the operational GSI analyzes a total cloud condensate (a description of this within the context of all-sky assimilation can be found in Zhu et al., 2016). For this initial implementation, the cloud liquid water and cloud ice hydrometeors from the background are combined into a total cloud condensate in order to mimic current operations and produce a total cloud analysis increment. However, this increment is never passed back to the model itself, but instead serves as a so-called “sink variable.” In practice, the other control variables are being updated to be consistent with the total cloud increment through the multivariate correlations contained in the background error specification.

Other aspects that have changed from the operational system are turning on all sky assimilation for the Advanced Technology Microwave Sounder (ATMS) instrument, reducing the near-surface sea temperature (NSST) background error correlation length scale, and the omission of tropical cyclone relocation and the full field digital filter. New observations include Geostationary Operational Environmental Satellite (GOES)-16 atmospheric motion vectors, NOAA-20 Cross-track Infrared Sounder (CrIS) and ATMS radiances, additional Infrared Atmospheric Sounding Interferometer (IASI) water vapor channels, Suomi National Polar-orbiting Partnership (NPP) Ozone Mapping Profiler Suite (OMPS) data, and select Meteosat-11 Spinning Enhanced Visible and Infrared Imager (SEVIRI) channels.

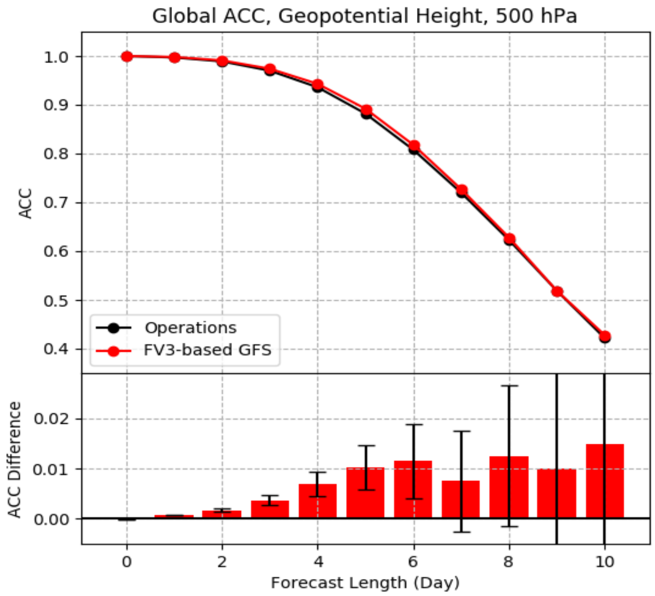

Figure 1: Global time-averaged 500 hPa anomaly correlation coefficients (ACC) as a function of forecast lead time (top) for the operational GFS (black) and the FV3-based GFS real-time parallel (red) with forecasts initialized at 00 UTC for January 27 - April 24, 2019. The bottom panel shows the difference between the FV3-based GFS and the operational GFS for the same timeframe. The error bars represent 95% confidence threshold as derived from a student t-test.

To formally evaluate the full implementation package, several seasons of retrospective parallels were performed and a substantial amount of case studies covering a breadth of high impact meteorological events were examined. Results were predominantly positive, such as the significantly improved anomaly correlation scores (Figure 1), better representation of the wind-pressure relationship in tropical cyclones, precipitation skill, and stratospheric ozone forecasts. Development of the second FV3-based implementation has already begun, with a focus on advanced physics, raising of the model top, and increased vertical resolution.

Acknowledgements: The work described in this article contains contributions from many people at NCEP/EMC and ESRL/PSD. We would like to specifically thank Rahul Mahajan, Fanglin Yang, Russ Treadon, Jun Wang, Jeff Whitaker, Phil Pegion, Yanqiu Zhu, and Andrew Collard.

References

Buizza, R., M. Miller, and T. N. Palmer, 1999: Stochastic Representation of model uncertainties in the ECMWF Ensemble Prediction System. *Quart. J. Roy. Meteor. Soc*., **125**, 2887–2908. doi: 10.1002/qj.49712556006.

Kleist, D.T., and K. Ide, 2015: An OSSE-Based Evaluation of Hybrid Variational–Ensemble Data Assimilation for the NCEP GFS. Part II: 4DEnVar and Hybrid Variants. *Mon. Wea. Rev*., **143**, 452–470, doi: 10.1175/MWR-D-13-00350.1.

Lin, Y., R.D. Farley, and H.D. Orville, 1983: Bulk Parameterization of the Snow Field in a Cloud Model. *J. Climate Appl. Meteor*., **22**, 1065–1092, doi: 10.1175/1520-0450(1983)022<1065:BPOTSF>2.0.CO;2.

Shutts, G., 2005: A kinetic energy backscatter algorithm for use in ensemble prediction systems. *Quart. J. Roy. Meteor. Soc*. **131**, 3079-3102, doi: 10.1256/qj.04.106.

Tompkins, A. M., and J. Berner, 2008: A stochastic convective approach to account for model uncertainty due to unresolved humidity variability. *J. Geophys. Res*., **113**, D18101, doi: 10.1029/2007JD009284.

Whitaker, J.S. and T.M. Hamill, 2002: Ensemble Data Assimilation without Perturbed Observations. *Mon. Wea. Rev*., **130**, 1913–1924, doi: 10.1175/1520-0493(2002)130<1913:EDAWPO>2.0.CO;2.

Zhu, Y., E. Liu, R. Mahajan, C. Thomas, D. Groff, P. Van Delst, A. Collard, D. Kleist, R. Treadon, and J.C. Derber, 2016: All-Sky Microwave Radiance Assimilation in NCEP's GSI Analysis System. *Mon. Wea. Rev*., **144**, 4709–4735, doi: 10.1175/MWR-D-15-0445.1.