GOESR3 Periodic Reporting

Reporting Period: January 2019 – June 2019 (2nd half of FY18 funding cycle)

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Project Title: Assimilation of High-Frequency GOES-R Geostationary Lightning Mapper (GLM) Flash Extent Density Data in GSI-Based EnKF and Hybrid for Improving Convective Scale Weather Predictions.

Project Number: 473

Executive Summary

This lighting data assimilation (DA) project is a collaboration between CAPS and NSSL, with involvement from EMC/NCEP. In this project, direct assimilation (DA) capabilities for GOES-R GLM data within the operational GSI framework are developed and tested using advanced ensemble Kalman filter (EnKF) and hybrid ensemble-variational (EnVar) DA methods. The capabilities developed will be first tested using selected, representative cases, then evaluated extensively in real time during the Hazard Weather Testbed (HWT) Spring Experiment. The impacts of assimilating additional GOES-R GLM data with and without operational radar data will also be addressed by comparing against parallel data assimilation and forecast members of the Storm-Scale Ensemble Forecasts to be run by CAPS during the HWT Spring Experiment. In addition, the data assimilation system will also be coupled with multi-moment microphysics schemes to evaluate their impact on the effectiveness of GOES-R GLM data assimilation. The major goal of this project is to develop and evaluate advanced DA techniques, such as EnKF and hybrid ensemble-variational (EnVar), utilizing the GLM Flash Extent Density (FED) data. The project aims help accelerate the use of GOES-R GLM data in operational numerical weather prediction (NWP) models at NCEP, and thereby help meet the Weather Ready Nation objectives and realize the Warn-on-Forecast goals.

Our paper summarizing results assimilating GLM FED data for a MCS case using GSI EnKF was submitted to Monthly Weather Review (Kong et al. 2019) during this reporting period, and it received overall positive reviews from three reviewers. A revised version has been submitted and we expected acceptance of the paper over the next reporting period.

Towards the goal of establishing hybrid EnVar assimilation capabilities for FED within the GSI framework, adjoint code for GOES-R GLM FED observation operator was developed and implemented within GSI to allow it to assimilate GLM FED data variationally. Based on this and the GSI EnKF, a hybrid EnVAR DA capabilities are established that couples the GSI En3DVar with GSI EnKF. The FED

observation operator based on graupel mass (FEDM) instead of graupel volume (FEDV) from Allen et al. (2016) is used in the variational system, because the gradient of the cost function with respect to graupel mixing ratio would be zero in FEDV given its sensitivity to graupel threshold only not the actual value.

In this reporting period, experiments are performed for a different case, i.e., the May 2018 supercell storm case, to evaluate and compare the performance of GSI 3DVar, EnKF, and hybrid En3DVar in assimilating GLMFED data. The experiments are named 3DVar, EnKF, and HEn3DVar20%B (with 20% static background error covariance **B**), respectively. One-minute FED observations are assimilated every 5 min for 1 h. The grid spacing is 1 km for this case, instead of the 3 km of the previous MCS case. The analyses at the final DA cycle are used to initialize the WRF forecasts. Similar to the previous MCS case, the initial ensemble is initialized from 3 h NAM forecast valid at 2100 UTC plus perturbations derived from the SREF ensemble analyses valid at the same time. Spin up ensemble forecasts are run for 1 h to 2200 UTC, and FED DA cycles at 5 min intervals are run from 2200 to 2300 UTC, when a 6-h forecast is run starting from the final 3DVar/En3DVara analysis or ensemble mean analysis of EnKF at 2300 UTC in each experiment (Fig. 1). For comparison purpose, control experiment (CTRL) forecast is run exactly the same way as in 3DVar and En3DVar, except that during the 1 –hour period between 2200 and 2300 UTC, no data is assimilated. Different DA experiments (3DVar, EnKF, and HEn3DVar20%B) are compared and also evaluated against CTRL based on objective verifications and the analyses and forecasts of reflectivity field.

The grid-point based equitable threat score (ETS; Mason 2003) for the 2D composite reflectivity forecasts, and analyses during the DA cycles, are computed for all the experiments, for the thresholds of 20 and 35 dBZ, respectively. During the 1-h DA window, the ETSs of the composite reflectivity analyses from different experiments all improved relative to the corresponding background forecasts, especially for the threshold of 35 dBZ; the saw-tooth structure of the ETS (within the 1-h DA window) for 35-dBZ threshold (Fig. 1b) is more obvious than those for 20-dBZ threshold (Fig. 1a), indicating that the impact of lightning DA is more direct on convective precipitation than on stratiform precipitation. For stratiform precipitation at the 20 dBZ threshold, all DA experiments are able to produce higher ETSs than CTRL (Fig. 1a). Hybrid En3DVar performs slightly better than EnKF within the 1-h DA window, but similarly for later forecasts with small fluctuations in score relative to EnKF. EnKF and hybrid En3DVar obviously outperform 3DVar in terms of ETS. For convective precipitation at the 35-dBZ threshold, all DA experiments are better than CTRL for up to 5 h of free forecast (corresponding to hour 6 in the figure), after which the ETSs become lower than CTRL for all cases (Fig. 1b). This is mainly because the ETS score increases after 6 h for CTRL for reasons that is not clear. Overall, Hybrid En3DVar performs slightly better than EnKF and 3DVar during most of the forecasting period.

To evaluate how the lightning DA experiments capture the overall structure and intensity of the storms, 2-h composite reflectivity forecasts are compared to the MRMS composite reflectivity observation product (Fig. 2). Overall, both EnKF and hybrid En3DVar are able to better capture the individual storm cells than 3DVar and CTRL, although there exist obvious location errors relative to observations. 3DVar outperforms CTRL for better capturing the locations of convective area, but the storm structure looks much more similar to that of CTRL, with more of a line structure than discrete cell structure. Give that 3DVar only directly updates graupel mixing ratio which appears within the FEDM observation operator without the help of flow-dependent cross-variable covariance, its poorer performance is expected. More

experiments are being performed to fine tune the DA experiment configurations to hopefully obtain even better performance. However, because the storm environment is not directly improved with the FED data, and there are uncertainties with the FED observation operator, the improvement to longer range storm forecasts may be limited. Still, given that FED data are only two dimensional, and are not very height specific, and are only directly linked to graupel based on the observation operator used, the results obtained so far are very encouraging, and are likely to be very valuable in regions without good 3D radar volume coverage.

Progress toward FY18 Milestones

1. A manuscript for Mon. Wea. Rev on FED DA for a MCS case using GSI-EnKF was submitted and conditionally accepted. A revision has also been submitted.

2. Compared the relative performance of FED DA using 3DVar, EnKF, pure and hybrid En3DVar for a new, supercell case. The 3DVar and hybrid En3DVar are all new capabilities and were applied to FED DA for the first time.

Plans for Next Reporting Period

3. Prepare and submit a manuscript on FED DA using 3DVar, EnKF, pure and hybrid En3DVar for the supercell case.

4. Compare the performance of FED DA with radar reflectivity DA based on the study of the MCS or the supercell case.

Additional Information

1. Interaction with operational partners –

Discussions with Drs. Alex Fierro and Edward Mansell on revisions to a paper submitted to Monthly Weather Review. See below.

2. Conference/workshop participation –

Rong Kong, Ming Xue, Alexandre O. Fierro, Youngsun Jung, Chengsi Liu, Edward R. Mansell, and Donald R. MacGorman. Assimilation of GOES-R GLM Flash Extent Density in GSI EnKF for the Analysis and Forecast of the 13 July 2018 Mesoscale Convective System. *16th Asia Oceanic Geoscience Society*, 28 Jul- 2 Aug 2019, Singapore.

3. Outside project publicity –

4. Journal articles –

Rong Kong, Ming Xue, Alexandre O. Fierro, Youngsun Jung, Chengsi Liu, Edward R. Mansell, and Donald R. MacGorman. Assimilation of GOES-R GLM Flash Extent Density in GSI EnKF for the Analysis and Forecast of the 13 July 2018 Mesoscale Convective System. *Monthly Weather Review.* Conditionally accepted.

Key Graphics

Fig. 1 Flow diagram of the experiments

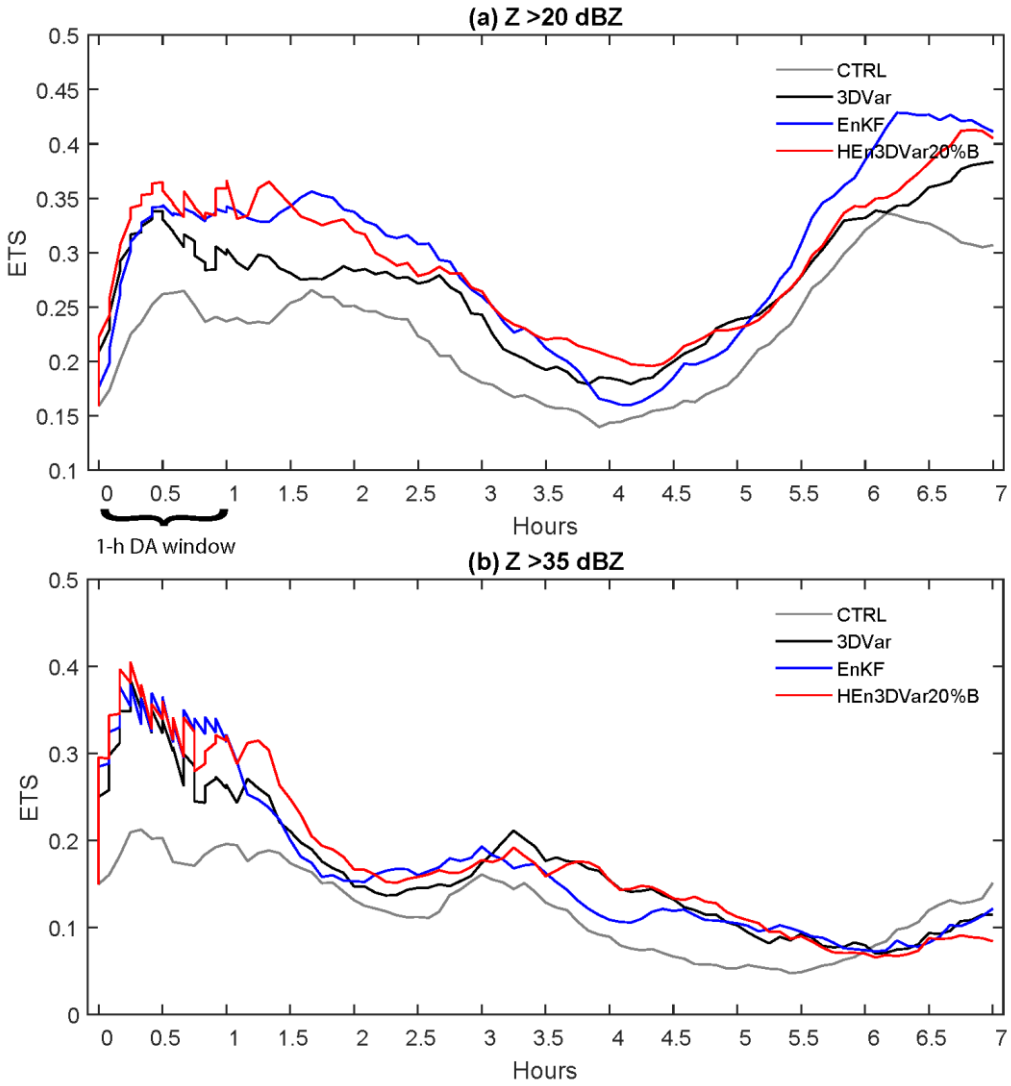

Fig. 1 ETSs of the 2D composite reflectivity forecasts for CTRL (grey curve), analyses and forecasts within the 1-hr DA window from 3DVar (black), EnKF (blue), and hybrid En3DVar with 20% of **B** (red), and 0~5 h free forecasts of composite reflectivity from different DA experiments, for (a) 20 dBZ and (b) 35 dBZ thresholds, respectively.

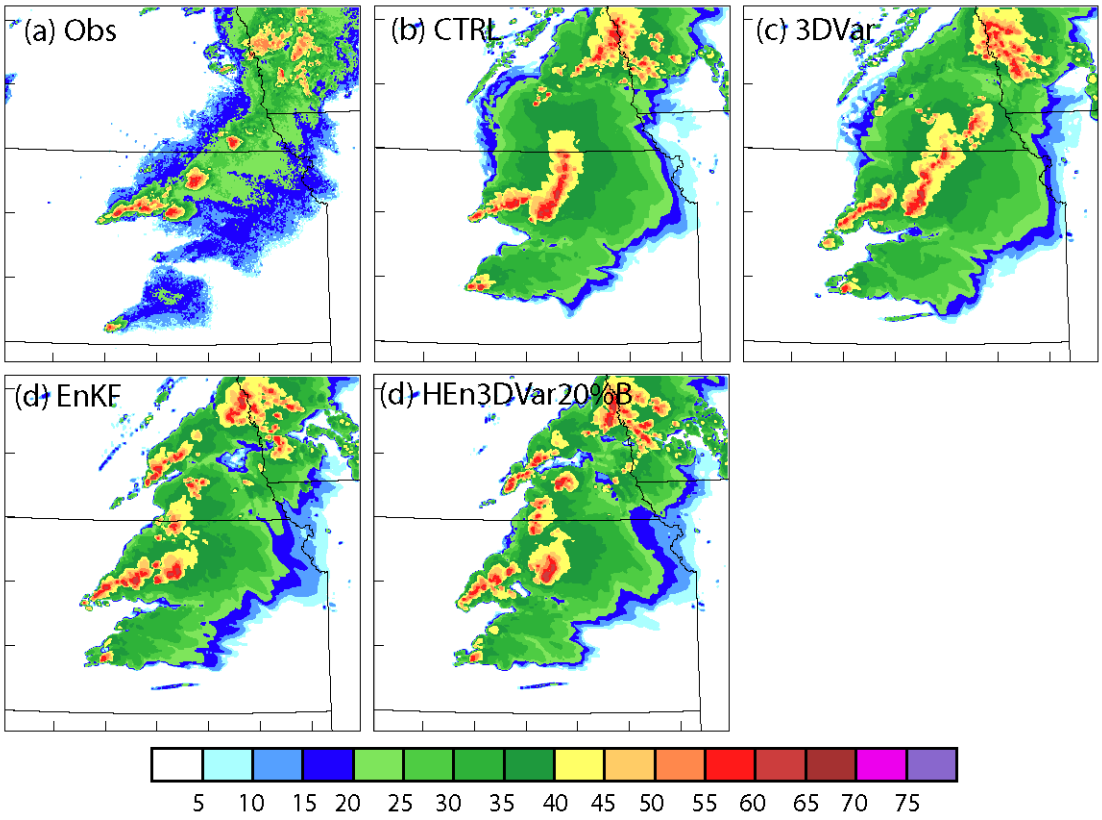

Fig. 2 Comparisons of (a) the composite reflectivity observations, 2-h forecasts of composite reflectivity after DA from (b) CTRL, (c) 3DVar, (d) EnKF, and (e) hybrid En3DVar with 20% of **B**.