GOESR3 Periodic Reporting

Reporting Period: **Jan 2020 – Jun 2020 (2nd half of FY20 funding cycle)**
Have requested for no cost extension for one more year.

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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 tested using selected, representative cases. 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.

In the past reporting periods, the capabilities to assimilate GOES-R GLM-derived flash extent density (FED) data were added to the operational GSI EnKF and variational DA systems. The assimilation of GLM FED data using EnKF were evaluated for an MCS, and its performance were also compared with 3DVar and hybrid En3DVar for a supercell storm case. The assimilation of FED using EnKF was found to improve short term forecasts of the MCS. The results are published recently in Kong et al. (2020a). For another supercell case, EnKF, 3DVar, pure and hybrid En3DVar are shown to all able to better capture the intensity and distribution of storm analyses and forecasts in terms of either FED or reflectivity compared to the no-FED-assimilation case, and among the schemes pure En3DVar performs slightly better than EnKF, and both are better than 3DVar. These results were submitted for publication recently (Kong et al. 2020b).

The results obtained earlier assimilated FED data without radar data. During this reporting period, the impacts of assimilating additional GOES-R GLM data with and without operational radar (radial velocity and reflectivity) data are examined for the MCS case tested in Kong et al. (2020a). The experiments use our radar and FED-enhanced GSI EnKF. The graupel-mass-based FED observation operator tuned in Kong et al. (2020a) is used. Radar and FED observations are assimilated (every 5 min for 1 h) separately or together in experiments OnlyZVr (that assimilates reflectivity and radial velocity observations only), OnlyFED (that assimilates FED observations only), and ZVrFED (that assimilates both radar and FED observations), respectively. These experiments are also compared with the CTRL that did not assimilate any data. Following the setup of Kong et al. (2020a), the DA and forecast experiments are performed at 3 km grid spacing, and the FED and/or radar data are assimilated at 5 minute intervals for 1 hour, and the final analyses are used to initialize WRF forecasts up to 6 hours.

The 3-km and 9-km neighborhood ETS scores of the FED forecasts from OnlyZVr, OnlyFED, ZVrFED, and CTRL are compared in Fig. 1. For the threshold of 1 flash min^{-1}pixel^{-1}, OnlyFED actually outperforms OnlyZVr and ZVrFED in the 0 – 2 h FED forecasts 1-hour DA cycles and become similar for the rest of the forecast hours. For the threshold of 5 flashes min^{-1} pixel^{-1}, OnlyFED outperforms OnlyZVr and ZVrFED in 1 h FED forecast but underperforms in the rest of hours in terms of ETSs. ZVrFED outperforms both OnlyZVr and OnlyFED in FED forecasts after 2.5 h, especially for the threshold of 5 flashes pixel^{-1} min^{-1} and neighborhood scale of 9 km (Fig. 1d). All DA experiments produce higher ETSs than CTRL that does not assimilate any data. The 0 -5 h forecasts of composite reflectivity from different experiments are verified against 2D MRMS composite reflectivity and their ETSs are shown in Fig. 2. ZVrFED performs slightly better than OnlyZVr, both are better than OnlyFED for both thresholds and neighborhood scales. All DA experiments again produce higher ETSs than CTRL.

Over, FED DA with GSI EnKF produces comparable results as radar DA for the MCS case examined which is very encouraging considering the much lower data volume and horizontal resolution of FED data compared to those of radar. When radar data are assimilated together with FED observations, the additional positive impacts of FED DA are small but still present, e.g., in terms of FED forecast after 2.5 hours.

Our previous experiments were performed using the Thompson microphysics scheme. The NSSL microphysics scheme is a fully two-moment scheme had been shown to produce better hail/graupel forecasts, and is the scheme originally used to create the simulation data set to fit the FED observation operator. If the use of NSSL microphysics scheme within the FED DA and subsequent forecasting may improve the overall performance is a question we want to investigate. For this reason, we repeated the EnKF experiment with a supercell storm reported in Kong et al. (2020b) using the NSSL scheme instead (called FEDDA_NSSL), and compare it with the experiment using Thompson scheme (FEDDA_Thompson). The graupel-mass based FED observation operator tuned in Kong et al. (2020b) is used, and FED data are assimilated again at 5-minute intervals for 1 hour, this time on a 1-km grid (as in Kong et al. 2020b to better resolve the supercells).

The 1- and 2-h forecasts of composite reflectivity from FEDDA_Thompson and FEDDA_NSSL are compared in Fig. 3, and their results are also compared with corresponding control experiments (i.e., CTRL_Thompson and CTRL_NSSL) without FED DA. The 1 – 2 h composite reflectivity forecasts from FED_Thompson (Fig. 3 d, i) obviously outperform the corresponding control experiments (i.e., Fig. 3 b, g) in better capturing the discrete storm structures. The storms in CTRL_Thompson look more like bow echoes than discrete supercells (Fig. 3 b, g). In FEDDA_NSSL, the storm structures (Fig. 3 e, j) match observations than CTRL_NSSL (Fig. 3 c, h). The 2 -h composite reflectivity forecasts from CTRL_NSSL also exhibit a bow echo structure, presumably related to stronger cold pool outflows. With FED DA, the distributions of storms are more consistent with those of observations (Fig. 3j, f). The distributions of discrete storm cells are better captured in CTRL_NSSL (Fig. 3c, h) relative to CTRL_Thompson (Fig. 3 b, g), so do those in FEDDA_NSSL (Fig. 3 e, j) relative to FEDDA_Thompson (Fig. 3 d, i).

To evaluate how well different DA experiments predict rotating updrafts and tornado potential, the accumulated swaths of 2 – 5 km updraft helicity (UH) from the 0 – 2 h forecasts are compared in Fig. 4. The locations of the simulated swaths are evaluated against official Storm Prediction Center (SPC) tornado reports. As can be seen in Fig. 4, FEDDA_NSSL produces more accurate UH tracks than FEDDA_Thompson with more overlap between the UH tracks and tornado reports, and both outperform the corresponding control (i.e., CTRL_Thompson and CTRL_NSSL) in capturing the three updraft helicity swaths in south central Kansas that are consistent with the tracks of tornado reports. Thus, the assimilation of FED data using either Thompson or NSSL scheme produces more accurate prediction of potential tornado threats for this case, and the use of the NSSL microphysics scheme performs slightly better.

Progress toward FY20 Milestones

1. Published one paper related to assimilating FED observations using GSI-EnKF for an MCS case.
2. Submitted one manuscript comparing the relative performance of 3DVar, EnKF, pure and hybrid En3DVar algorithms in GSI for FED assimilation for a supercell case.
3. Investigated the impacts of assimilating GOES-R GLM data with and without operational radar (radial velocity and reflectivity) data for an MCS case.
4. Evaluated the impacts of FED DA when coupling with different microphysics schemes in the forecast model.

Plans for Next Reporting Period

1. Further investigate the impacts of assimilating FED with and without radar data and publish the results.

2. Further evaluate the impacts of FED DA when coupling with different microphysics schemes and publish the results.

3. Develop an alternative FED observation operator based on nonlinear fit of observed GLM FED data to model-simulated column total graupel mass for well-predicted convective storms, and perform DA experiments using the new operators and publish the results.

4. Merge the code to the current version of operational GSI, and deliver the code to NOAA.

Additional Information

1. Interaction with operational partners –

2. Conference/workshop participation

Invited presentation at the 2020 AMS Meetings 24 IOAS Conference by Ming Xue: "Assimilation of GOES-R Global Lightning Mapper Total Flash Rate Data for the Analysis and Short-Term Forecast of Convective Storms using EnKF and Hybrid En3DVar Methods"

3. Outside project publicity –

4. Journal articles –

1) Kong, R., M. Xue, A. O. Fierro, Y. Jung, C. Liu, E. R. Mansell, and D. R. MacGorman, 2020a: Assimilation of GOES-16 Geostationary Lightning Mapper Flash Extent Density Data in GSI EnKF for the Analysis and Short-Term Forecast of a Mesoscale Convective System. *Mon. Wea. Rev.,* **148**: 2111-2133.

2) Kong, R., M. Xue, C. Liu, A. O. Fierro, E. R. Mansell, and D. R. MacGorman, 2020b: Assimilation of GOES-R Geostationary Lightning Mapper Flash Extent Density data in GSI 3DVar, EnKF, and Hybrid En3DVar for the Analysis and Short-Term Forecast of a Supercell Storm Case. *Mon. Wea. Rev.,* under review.

Key Graphics

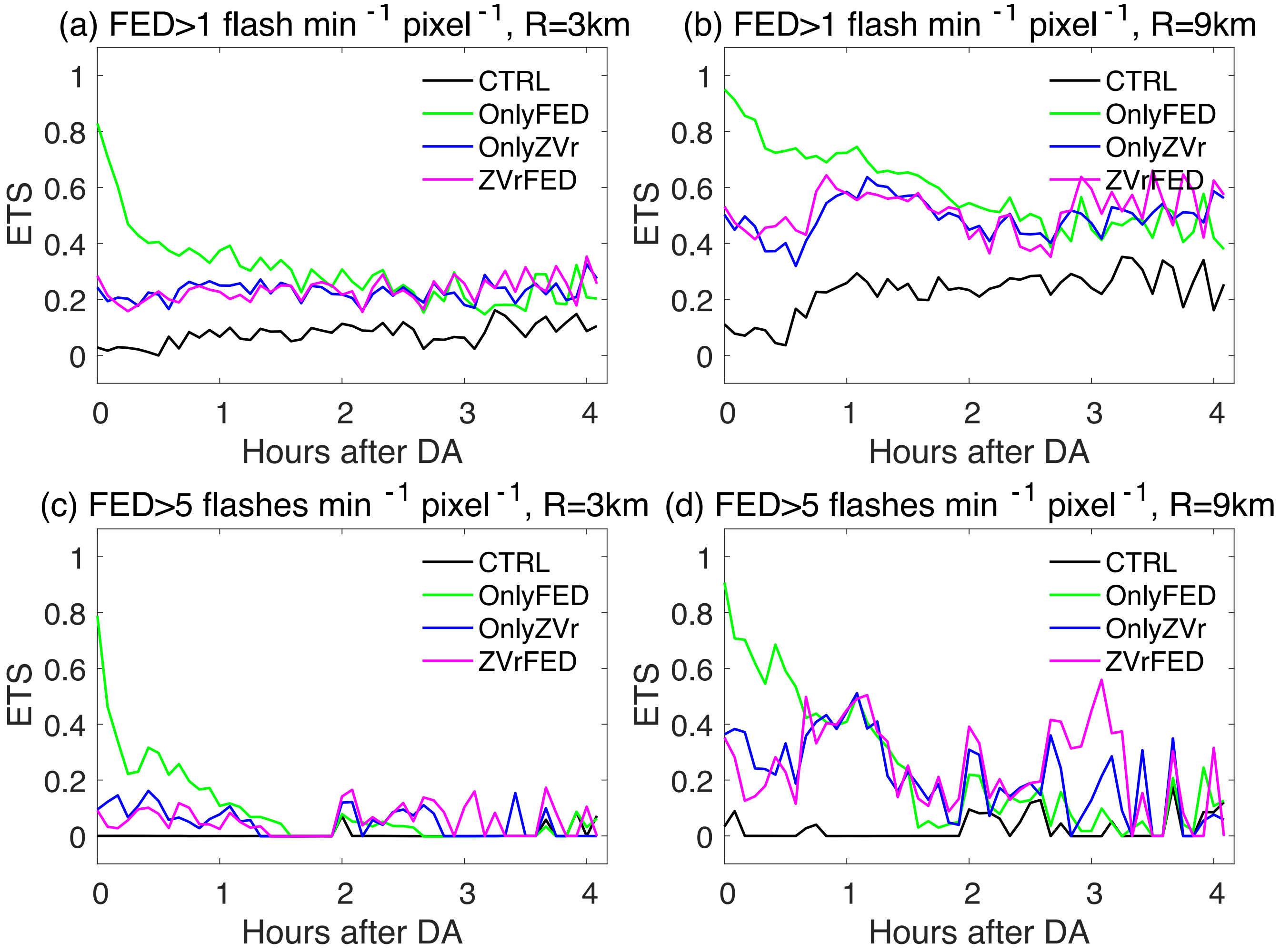

Fig. 1 (a, c) 3-km and (b, d) 9-km neighborhood ETSs of the 0 – 4 h FED forecasts after DA for the thresholds of (a, b) 1 min^{-1} pixel^{-1} and (c, d) 5 flashes min^{-1}pixel^{-1} in experiments OnlyFED, OnlyZVr, ZVrFED, and CTRL that does not assimilate any data.

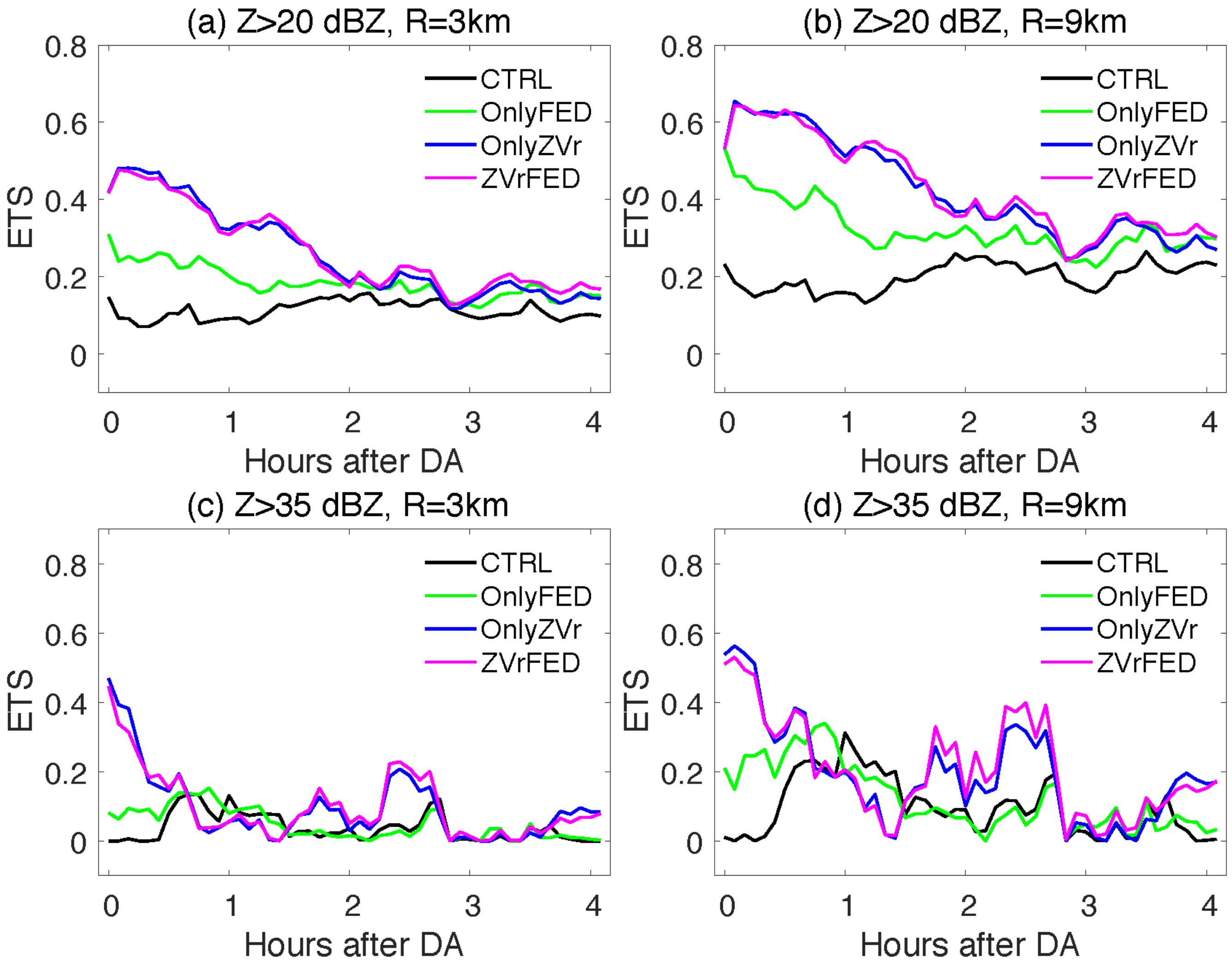

Fig. 2 (a, c) 3-km and (b, d) 9-km neighborhood ETSs of the 0 – 4 h forecasts of the composite reflectivity for composite reflectivity greater than (a, b) 20 dBZ and (c, d) 35 dBZ from experiment CTRL, OnlyFED, OnlyZVr, ZVrFED, respectively.

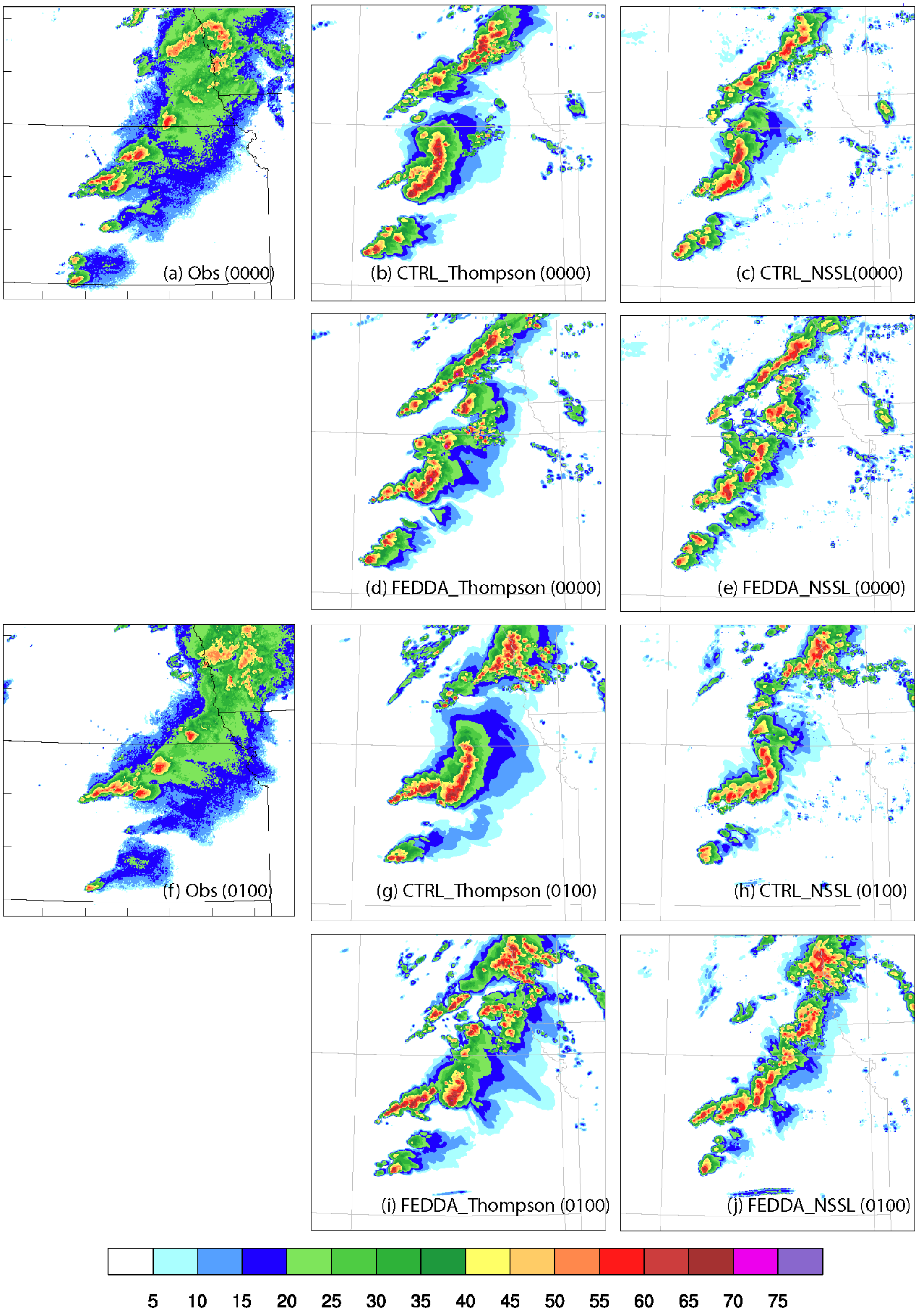

Fig. 3 Composite reflectivity fields (dBZ) for: (a, f) observations, (b, c, d, e)1-h (valid at 0000 UTC 2 May 2018) and (g, h, i, j) 2-h (valid at 0100 UTC) forecasts after DA from (b, g) CTRL_Thompson, (c, h) CTRL_NSSL, (d, i) FEDDA_Thompson, and (e, j) FEDDA_NSSL.

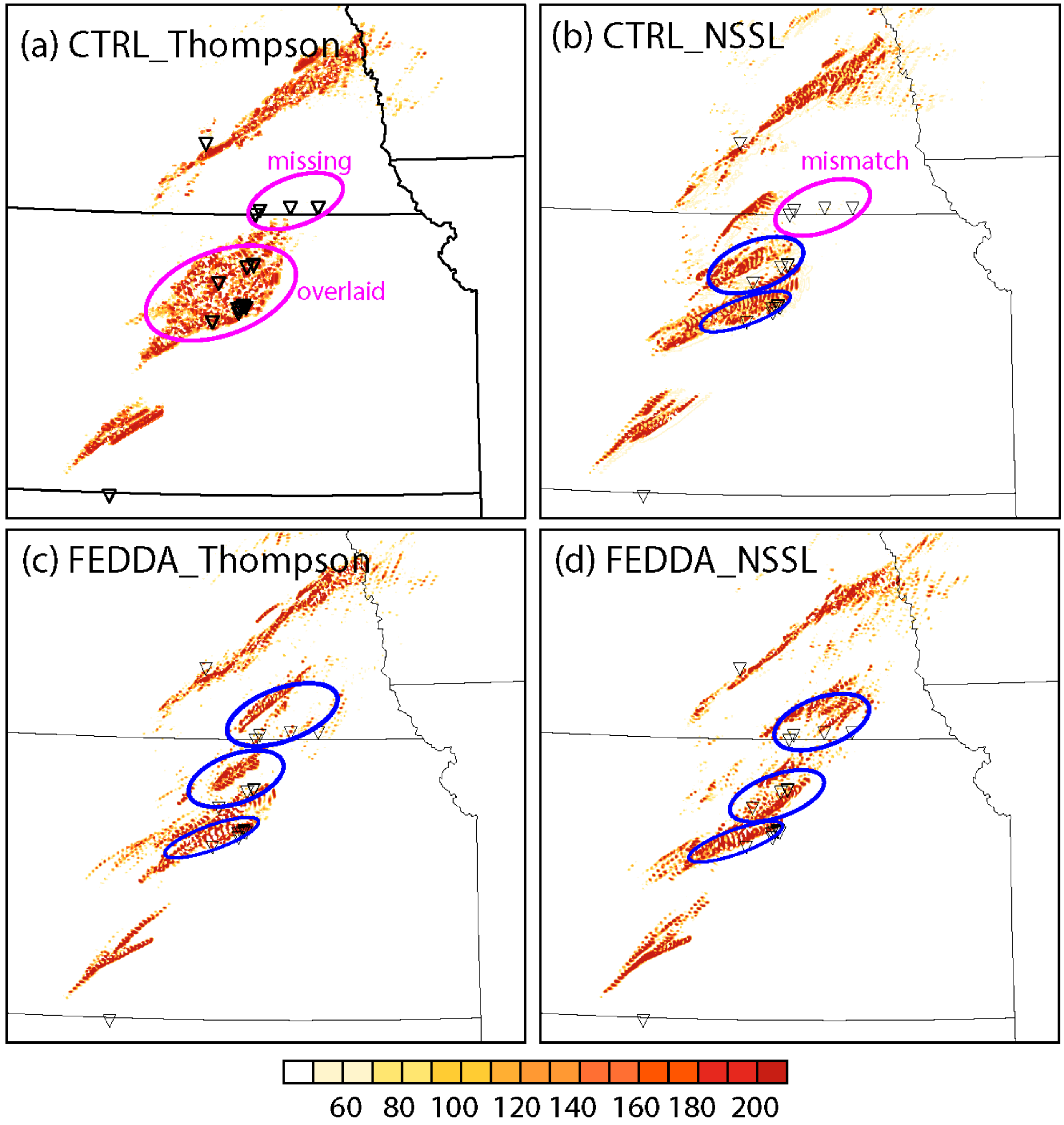

Fig. 4 The 0 – 2 h forecasted 2 -5 km updraft helicity (m^2 s^{-2}) from (a) CTRL_Thompson, (b) CTRL_NSSL, (c) FEDDA_Thompson, and (d) FEDDA_NSSL, respectively.