GOESR3 Periodic Reporting

Reporting Period: **January 2018 – June 2018 (2nd half of FY17 funding cycle)**

Team Lead: **Xuguang Wang (PI, OU)**

Team Members: **co-PIs Aaron Johnson (OU), Thomas Jones (OU), Jason Otkin (WI), Yanqiu Zhu (EMC)**

Project Title: **Assimilation of high resolution GOES-R ABI infrared water vapor and cloud sensitive radiances using the GSI-based hybrid ensemble-variational data assimilation system to improve convection initiation forecast.**

Project Number: **NA16OAR4320115**

Executive Summary

The primary objectives of the project include (a) further extend the GSI EnKF/EnVar DA system for assimilating high resolution GOES-R ABI infrared water vapor and cloud sensitive radiance observations by ingesting convection resolving model's own high-resolution EnKF ensemble rather than the GFS ensemble and by directly updating cloud hydrometeor variables; (b) improve the usage of GOES-R ABI water vapor and cloud sensitive radiances for rapidly updated DA by refining data quality control, using high-resolution infrared land surface emissivity databases and exploring all-sky bias correction and observation error methods, and (c) test different DA configurations and evaluate the impact of assimilating GOES-R water vapor and cloud sensitive radiance observations for the prediction of diverse CI events when combined with ground based observation networks.

During this reporting period, further code development has been completed to (a) pre-process raw radiance observations from all 10 ABI channels, including cloud information and parallax correction of cloudy pixels, and (b) include both cloudy and clear air regions in the case study data assimilation experiments. A monitor-only experiment was conducted that assimilated only the conventional and radar data, in order to monitor satellite radiances in comparison to model fields within the GSI-based EnKF system. These results are being investigated for purposes of developing new non-linear radiance bias corrections as shown below. An all-sky (i.e., including cloudy pixels) assimilation experiment was also conducted for the 18 May 2017 case study using the existing bias correction procedures in GSI-EnKF. Further details and results of these studies are discussed below.

Progress toward FY17 Milestones

The project progresses as planned in general. In addition to the first three milestones for year-one that were described in the previous report, milestone 4 (UW implements surface emissivity database in the CRTM and begin to explore all-sky infrared bias correction) has also been accomplished. The DA experiments will be rerun as soon as the high-resolution infrared surface emissivity databases are released in the community CRTM-CSEM. Further work has also been accomplished on milestones (1)-(3) that were also reported on previously. In particular, further code development in GSI and post-processing codes has been undertaken to improve the QC and pre-processing for GOES-R water vapor and cloud sensitive radiances.

Specific progresses are summarized below.

DEVELOPMENT OF PRE-PROCESSING CODES

The observed brightness temperatures used in the baseline experiment reported on previously were obtained from our NSSL collaborator (Jones) from preliminary processing algorithms. However, only four ABI channels were included in this data set while the nonlinear bias correction methods being developed would benefit from having access to all ten channels. Therefore, the officially released L1b radiances, which appear to have used a different processing algorithm from the data provider were downloaded from the NOAA archive. Since the magnitude of the systematic bias of the new brightness temperatures is more than 6 K less than the previous dataset (in the water vapor channels) for our case study, we developed our own post-processing software to convert the radiance to brightness temperature for all ten channels, perform thinning of the data to three times the model resolution, and apply parallax correction of the cloudy pixels. Cloud variables from the L2 radiance data set, including Cloud Optical Depth, Cloud Top Height, Cloud Top Pressure, Cloud Fraction and Cloud Probability were also added to the data set and GSI routines were updated accordingly to monitor these additional variables.

DEVELOPMENT OF GSI/ENKF FOR IMPROVED BIAS CORRECTION AND QC

The addition of the five additional cloud-related variables in the GSI data structures will allow for more refined cloud-aware bias correction procedures. Quality control routines are also relaxed to properly assimilate all-sky radiances. Based on our previous experiences with radar reflectivity data assimilation, where very large observation minus first guess values can occur with small displacements in/near convective storms, we no longer assume that all observations with significant differences from the first guess should be omitted from data assimilation. The gross error check is therefore increased from 2 K to 20 K. This allows for larger departures of the first guess from good observations that should be kept, while still checking for extreme differences that the data assimilation step would have trouble properly correcting during the present cycle even if the observation is good. This large ob-ges tolerance is especially important for our purpose of improving the prediction of initiating convection because it allows for rapid spin-up of convective storms while the model catches up to the observations. The distribution of observed brightness temperatures at 1710 UTC 18 May 2017 is shown in Figure 1a, while the ensemble mean first guess of all observations without bias correction is shown in Fig. 1b. Figure 2 shows the corresponding innovations only of observations passing the updated quality control checks. The larger ob-ges values that are passing QC show areas where the model is able to be brought closer to the all-sky radiances where large differences between the observation and model first guess are related to deep convection or high clouds, rather than unreliable observations. Although this would of course provide some limited improvement to the CI forecast, additional work to improve the bias correction procedure using non-linear cloud-sensitive methods is also ongoing in order to demonstrate the full potential for ABI infrared radiance assimilation to improve convective scale CI forecasts.

IMPLEMENTATION OF NON-LINEAR BIAS CORRECTION METHOD

During this reporting period, we began exploring the utility of a new nonlinear bias correction method developed by Otkin et al. (2018) as a means with which to remove biases from clear and cloudy-sky GOES-16 ABI brightness temperatures. As described in Otkin et al. (2018), this method uses a Taylor series polynomial expansion of the observation-minus-background departures to remove both linear and nonlinear conditional biases from the observation departures. For example, if a third-order Taylor series expansion is used, this means that the first two terms represent the constant and linear bias components, whereas the last two terms represent the nonlinear second-order (quadratic) and third-order (cubic) components. This methodology is currently being used as an off-line tool to more efficiently explore the ability of various predictors to remove both linear and nonlinear biases from the observation departures.

Preliminary work is underway using output from a GSI EnKF data assimilation experiment in which the GOES-16 ABI brightness temperatures were passively monitored. Figure 3 shows 2D probability distributions of the observation departures for the 6.9 μm band when the observed 6.9 μm brightness temperatures are used as the bias predictor. The departures are plotted as a function of the predictor values along the x-axis. The results are evaluated separately for the original departure distribution and for distributions for which the biases were removed using a zeroth- (constant), first- (linear), second- (quadratic), third- (cubic), or fourth- (quartic) order Taylor series polynomial expansion. The short horizontal black lines on each panel depict the conditional bias in each column of the distribution and are used to assess how the bias varies as a function of the predictor value. The horizontal red line shows the mean bias of the entire distribution.

Inspection of Fig. 3a reveals a strong nonlinear pattern in the conditional biases, with a tendency for the simulated brightness temperatures to be too warm (cold) when the observed brightness temperatures are colder (warmer) than approximately 239 K. Though the mean bias of the entire distribution is relatively small (~ 1.0 K), the nonlinear pattern in the conditional biases indicates that constant and linear bias correction terms alone will be unable to remove all of the bias. For example, even though the constant bias correction term removes the mean bias from the distribution (Fig. 3b), its shape remains the same and, therefore, large conditional biases remain throughout the distribution. Likewise, the first-order bias correction (Fig. 3c) removes the linear bias component by raising (lowering) the cold (warm) end of the distribution, which reduces the conditional biases for the coldest brightness temperatures, but turns a positive bias into a negative bias for the warmest brightness temperatures (Fig. 3c). Removal of the constant and linear bias components also exposes an asymmetric arch shape pattern in the conditional biases that is largely removed when the second-order quadratic term is used (Fig. 3d). Finally, when the third-order cubic and fourth-order quartic terms are used (Fig. 3e-f), the general shape of the distribution remains mostly unchanged; however, subtle improvements were made to it. Together, these results show that even though each departure distribution technically has zero mean bias, the conditional biases in the distribution are smaller when higher-order, nonlinear bias correction terms are applied to the observation departures. Ongoing work is assessing the ability of other predictors such as cloud top height and simulated brightness temperature, when used individually or in combination, to effectively remove the bias from the observation departures. The performance of the various predictors is being evaluated for each of the three water vapor bands in preparation for the real data assimilation experiments which will be compared to the ongoing experiments using the standard bias correction procedure.

Plans for Next Reporting Period

During the next reporting period, we will continue to explore the use of different bias predictors when assimilating all-sky infrared brightness temperatures. This will be accomplished through passive monitoring of the observation-minus-background brightness temperature departures from the control experiment in which the brightness temperatures were passively monitored. Sensitivity tests will be performed to identify suitable predictors (such as the cloud top height or integrated water content over some vertical layer) that are able to effectively remove biases from the all-sky brightness temperatures prior to their assimilation.

Also during the next reporting period, the newly implemented bias correction, as well as high resolution surface emissivity, procedures will be used to demonstrate the potential advantages of optimally assimilating all-sky infrared ABI radiances during the initiation phase of this rapidly developing high impact severe convective weather event. The work will then be extended to additional cases for demonstration of systematic impacts in subsequent reporting periods.

Additional Information

1. Interaction with operational partners –

The proposing team interacted with NCEP/EMC collaborator Yanqiu Zhu during the extension and testing of the GSI EnKF system with the ABI clear air and cloudy radiance assimilation including pre-processing, QC, code modifications. The proposing team also interacts with NCEP/EMC collaborator Ming Chen on the implementation of high resolution surface emissivity with CRTM-CSEM.

2. Conference/workshop participation –

We continue participating the bi-weekly GSI developers meeting hosted by NCEP/EMC. Scientific results with more experiments will be presented in future workshops and conferences.

3. Outside project publicity –

N/A during this project period.

4. Journal articles –

N/A during this project period as the primary effort is system development. Papers including scientific results will be submitted in the future.

Key Graphics

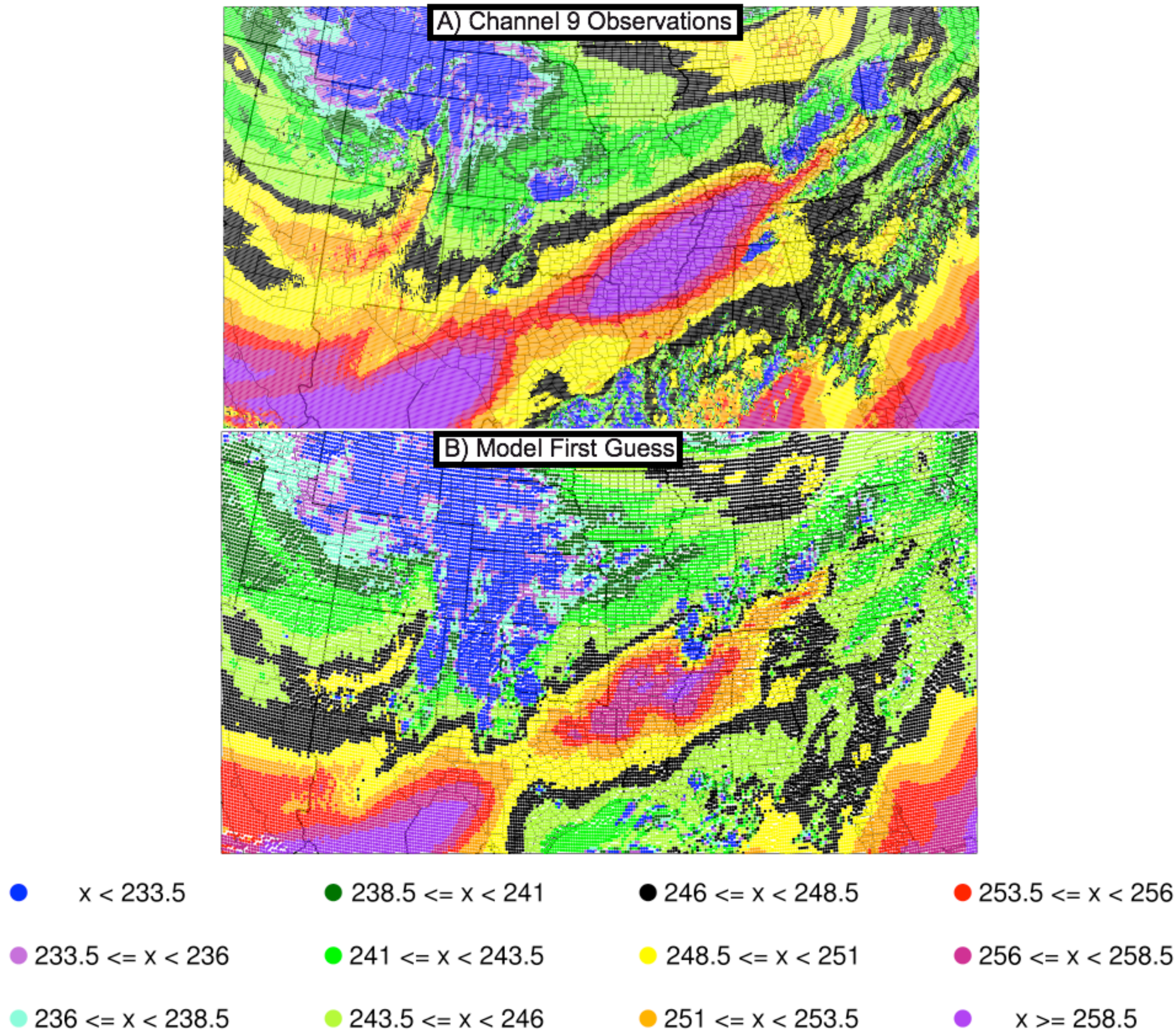

Figure 1. Observation space plot of 6.93 micron ABI channel brightness temperatures (degrees Kelvin) at 1710 UTC 18 May 2017 (a) for the observations and (b) for the ensemble mean model first guess.

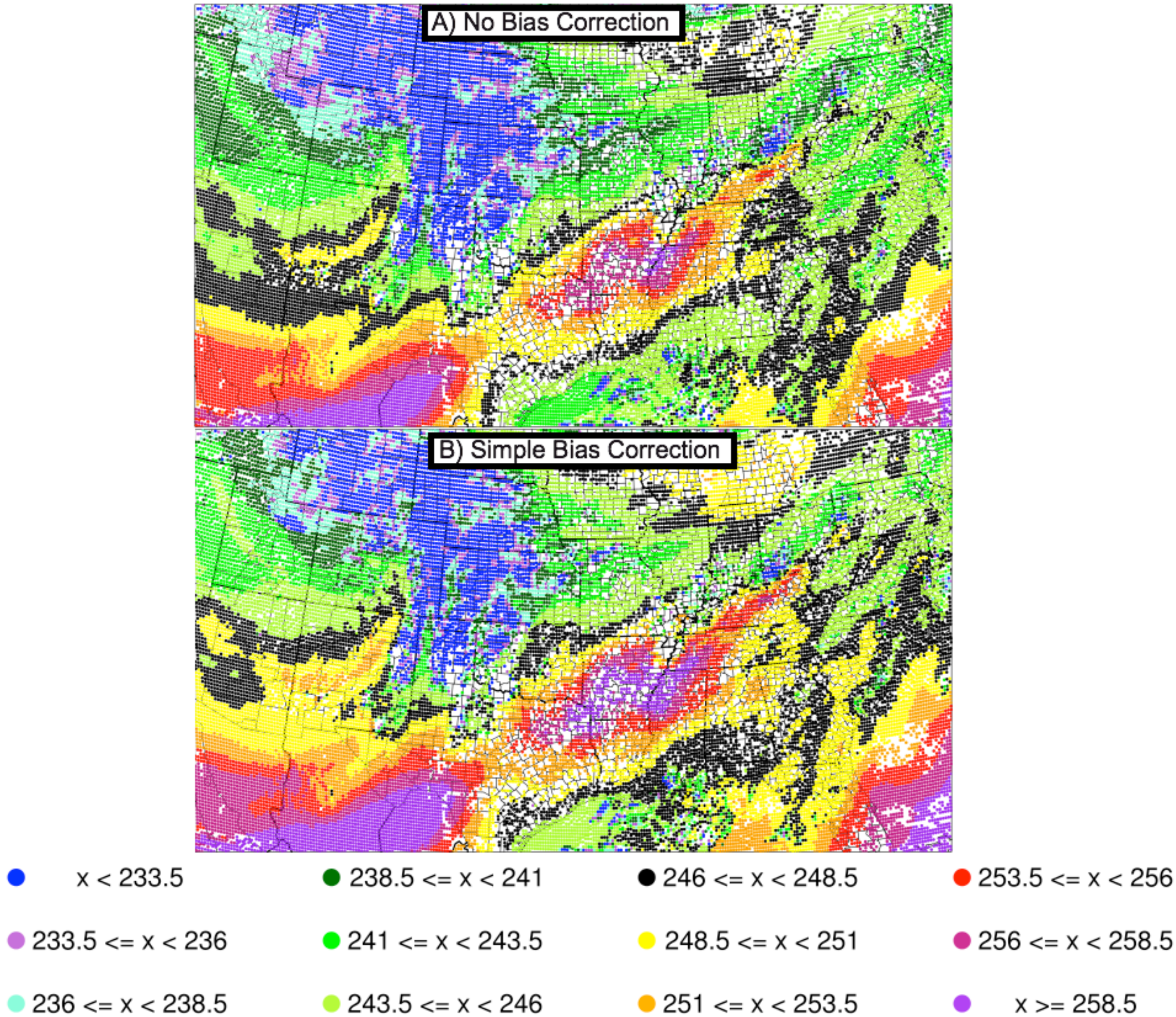

Figure 2. Model first guess of observations assimilated (i.e., passing QC check for large innovations and partial cloudy pixels) (a) before and (b) after applying a standard average bias correction.

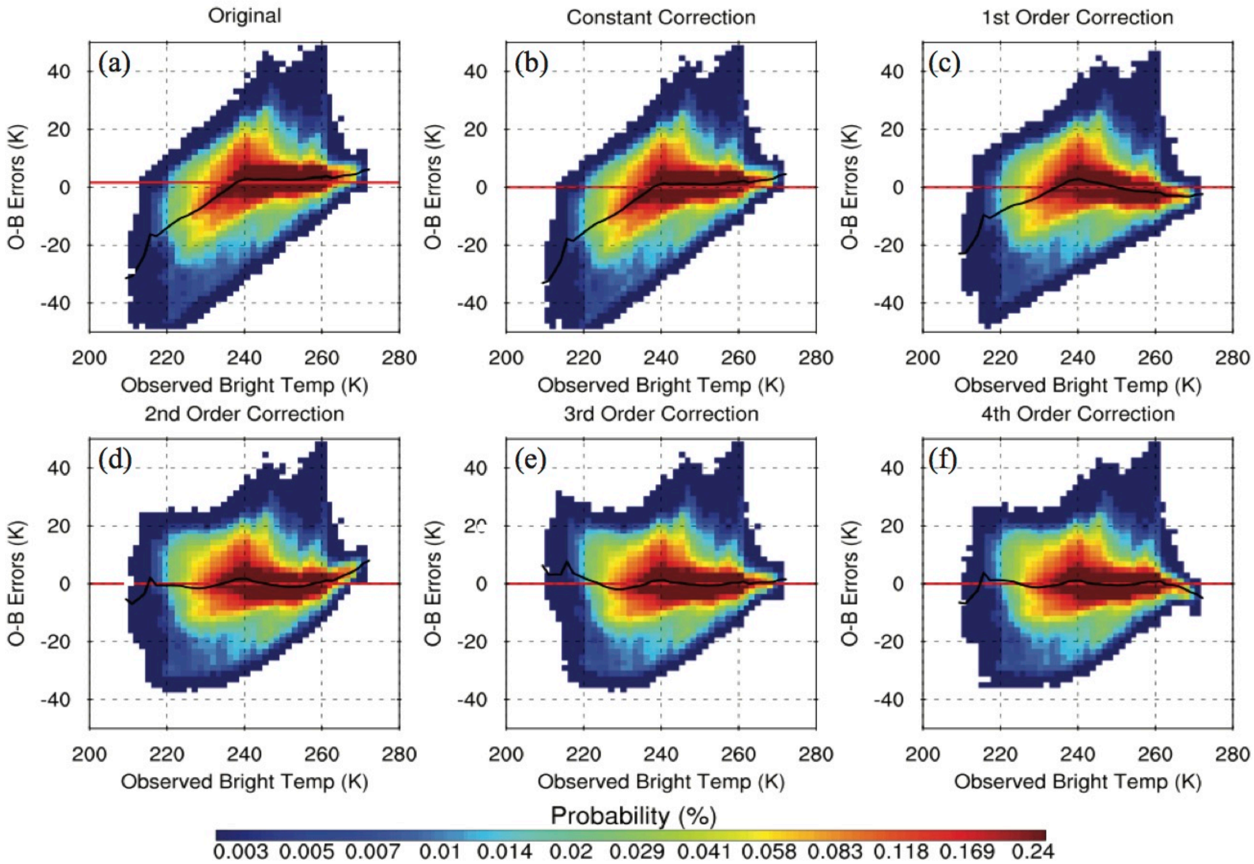

Figure. 3. Probability distributions of 6.9 μm observation-minus-background departures plotted as a function of the observed 6.9 μm brightness temperatures (K) for the (a) original data, and the (b) constant, (c) 1st order, (d) 2nd order, (e) 3rd order, and (f) 4th order bias corrected observations when the observed 6.9 μm brightness temperature is used as the predictor. The horizontal black line segments in each panel represent the conditional bias in each column. The distributions were generated using data from a single assimilation cycle in which the 6.9 μm brightness temperatures were passively monitored.