Direct Assimilation of ABI Infrared Radiances in NWP Models

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Abstract—GOES-R satellite was successfully launched on November 19, 2016 with an Advanced Baseline Imager (ABI) on board. ABI is a new imager and provides more advanced capabilities for weather applications through more channels and higher temporal and spatial resolutions than the earlier GOES imagers. In this study, impacts from assimilating ABI brightness temperatures in NWP models on quantitative precipitation forecasts (QPFs) are presented and compared with those from assimilating GOES-13/-15 imager data. Cloudy and precipitation-affected brightness temperatures are removed in assimilation through using an infrared (IR) cloud algorithm in quality control. This quality control can be applied for ABI data both at day and at night. Assimilation of the ten ABI IR channels improves the 24-h forecast accuracy of both temperature and specific humidity fields when compared with radiosonde observations. It is also shown that the assimilation of ABI IR channels produces positive impacts on QPFs. The impacts of ABI data assimilation on QPFs are slightly larger than those from assimilation of GOES-13 and -15 imager observations.

Index Terms—Data assimilation, geostationary satellite, quantitative precipitation forecast (QPF).

I. INTRODUCTION

The United States (US) geostationary operational environmental satellites (GOES) are perched 35 800 km above the equator to spot potentially life-threatening weather, including tropical storms in Atlantic Ocean, Gulf of Mexico, and Pacific Ocean, at a full earth imaging refresh rate of 10 min.1 They have been receiving more and more attentions in the past two decades, especially since the preparation and finally the launch of GOES-16. The observations from GOES satellites are not only used for weather applications, but also for tracking space weather, oceanographic changes, forest fires, and other hazards, and for search and rescue operations. The tropical storm Debby (2012), which moved in a relatively data-void region in the Gulf of Mexico, was well sampled by GOES-13 and -15 and was used for investigating the potential impacts of GOES data assimilation for tropical storm prediction [1].

Direct assimilation of GOES imager IR observations was demonstrated in regional numerical weather prediction (NWP) models. Past studies demonstrating positive impacts of the GOES data assimilation can be found in many former studies [1]–[8]. Assimilation of GOES-11/-12 imager observations significantly improved quantitative precipitation forecasts (QPFs) over the US continent in both the absence [5] and presence [7] of assimilating the following polar-orbiting environmental satellite microwave and IR channel observations: the advance microwave sounding unit-A, the hyperspectral atmospheric IR sounder, high-resolution IR sounder, the advance microwave sounding unit-B, and the microwave humidity sounder. Zou et al. [6] incorporated GOES-13 and -15 IR channel brightness temperature data into the HWRF system with two different vortex initialization schemes to assess the impacts of GOES-13 and -15 imager data assimilation on tropical storm Debby forecasts. It was shown that a direct assimilation of GOES-13 and GOES-15 imager IR radiance observations resulted in a consistently positive impact on tropical storm’s track and intensity forecasts. The largest positive impact was achieved when an asymmetric vortex initialization scheme was incorporated to assimilation of GOES data since it resolved the hurricane’s asymmetric structures.

On November 19, 2016, the US successfully launched GOES-16. It carries the newest generation of the geostationary visible and IR imager—the Advanced Baseline Imager (ABI). The ABI onboard GOES-R is similar, but not identical, to the Advanced Himawari Imager (AHI) onboard Japanese Geostationary Meteorological Satellite—Himawari-8 and -9. The ABI observes the earth atmosphere with more visible, near-IR, water vapor (WV) IR and surface-sensitive IR channels than the previous US GOES imagers (i.e., GOES-11, -12, -13, and -15). The ABI inherits some channels for providing a continuity of the US GOES mission series. It is expected for ABI to provide continual imagery and atmospheric observations of earth’s western hemisphere with higher temporal and spatial resolutions.

Being positioned in a geostationary orbit currently at 89.5 °W and later in November 2017 at 75 °W above the equator, ABI data, if appropriately assimilated, shall contribute to an improved QPF over the US continent. In this paper, we investigate the potential benefits of directly assimilating ABI brightness temperature data for improving QPFs over eastern US. The
National Centers for Environmental Prediction (NCEP) Gridpoint Statistical Interpolation (GSI) Analysis System and the advanced research weather research and forecasting (ARW/WRF) model will be used for this study [9]–[11]. Both the NCEP GSI analysis system and the ARW model were made publicly accessible for NWP user community [12]. By comparing the analyses and forecasts that are generated with and without assimilating ABI brightness temperature measurements, the potential impacts of ABI data assimilation on QPFs over eastern US can be assessed. A brief description of ABI data characteristics, case selection, and experimental design are provided in Section II. Details of cloud detection and quality control (QC) are described in Section III. Section IV presents numerical results of the assimilation of the ABI and GOES-13/-15 IR brightness temperature data and its impacts on short-term (e.g., up to 24 h) QPFs. Summary and conclusions are provided in Section V.

II. CHANNEL CHARACTERISTICS

GOES-13 became the official GOES-EAST satellite on April 14, 2010, replacing GOES-12, while GOES-15 replaced GOES-11 on December 6, 2011 as National Oceanic and Atmospheric Administration (NOAA)’s GOES-WEST spacecraft. GOES-13 and -15 satellites are perched 35 800 km above the equator at 75 °W and 135 °W, respectively. Both GOES-13 and -15 imagers have five channels. GOES imagers onboard both GOES-13 and -15 have only one visible channel (0.65 µm, channel 1), a shortwave IR window channel (3.9 µm, channel 2), an IR WV sounding channel (6.5 µm, channel 3), and two longwave IR window channels centered at 10.7 µm (channel 4) and 13.3 µm (channel 6), respectively. The geometric instantaneous field of view (IFOV) at the subsatellite point is 1 km for the visible channel, 4 km for IR channels 2–5, and 8 km for GOES-13 channel 6.

The five channels of GOES-13 and -15 are designed for different purposes. The visible channel 1 is for detecting clouds, aerosols, and surface features during daytime based on their observed radiation reflected from the visible portion of the spectrum. Channel 2 allows cloud patterns, fires, hot spots, and snow coverages be identified. Channel 3 measures WV in the mid- and upper troposphere based on its measured earth-emitted, water-vapor-attenuated radiation. Measurements of brightness temperatures at channel 4 are close to earth’s surface skin in the absence of cloud and cloud top temperatures since most surfaces and cloud types have a unit emissivity and the earth/cloud emitted radiation is not significantly attenuated by the atmospheric gases at 10.7-µm wavelength. On the contrary, a considerable amount of cloud- and surface-emitted radiation at 13.3 µm (channel 6) is attenuated by the atmospheric gas—carbon dioxide (CO₂).

The ABI is onboard GOES-16. Fig. 1 shows the spatial coverage of the imagers onboard GOES-13, -15, and -16 at full disk and zenith angle 60 °, respectively. The GOES-13 and -15 are located near 75 °W and 135 °W, respectively. Now, GOES-16 is already moved to 75 °W on December 18, 2017 to replace GOES-13.

Instead of having five channels from previous GOES imagers, ABI has a total of 16 channels, ten of which are IR channels (7–16) that are assimilated in NWP models. Instead of having only one WV imaging channel for GOES-13 and -15, ABI has three WV channels (channel 8, 9, and 10) centered at 6.25, 6.95, and 7.35 µm, respectively. Fig. 2 shows the weighting function profiles for the ten ABI IR channels 7–16 and four GOES IR channels 2–4 and 6. It is seen that the weighting function peaks of the three ABI WV sounding channels 8, 9, and 10 are located near 370, 420, and 560 hPa, respectively. Channel 7 is a shortwave IR window channel whose central
frequency is located at 3.85 $\mu$m. Channels 11–16 are located at 8.6, 9.63, 10.45, 11.20, 12.35, and 13.3 $\mu$m. Channel 12 is sensitive to stratospheric ozone and thus has a peak weighting function around 40 hPa. This channel is not assimilated in this study. The weighting function peaks of ABI IR channels 7, 11, 13–16 that will be assimilated over ocean are all located at the earth surface.

All ABI IR channels have a 2-km IFOV size at the subsatellite point. Compared with 4-km spatial resolution of GOES-13 and -15, the 2-km high spatial resolution of ABI channels 8–10 is advantageous for depicting smaller scale jet streaks, cloud streaks, banded clouds, and precipitation structures. A consistent IFOV size among all ABI IR channels is also better for deriving ABI multichannels retrieval products and cloud masks (CMs), QC and data assimilation than inconsistent IFOV sizes of GOES-13 channels. The differences of brightness temperatures between different channels could reflect more exactly the physical differences than those from inconsistent IFOV sizes among different channels.

III. EXPERIMENT DESIGN

The case selected for this study is characterized by a typical spring precipitation event that occurred downstream of an eastward propagating middle latitude trough and upstream of a well-developed subtropical high (see Fig. 3). The 3-h accumulative rainfall observations are provided in Fig. 3 at 12-h interval for the time period from 1200 UTC 29 April to 0000 UTC 1 May 2017. The rainfall observations were obtained from the NCEP multisensory observations [13]. To associate the rainfall distributions with large-scale flow features, the 500-hPa geopotential heights and wind vectors from the NCEP global forecast system (GFS) at the beginning of the corresponding 3-h rainfall observations are also plotted in Fig. 3. It is seen that rainfall occurred as a middle latitude trough propagated eastward and intensifying. A heavy precipitation band is oriented zonally around 35°N downstream of the cyclone around 1200 UTC April 29, 2017. As the cyclone further intensifies and deepens, a meridionally oriented heavy precipitation band is located near the Gulf of Mexico coast. A continuous supply of WV from the Gulf of Mexico is thus important for an NWP model to perform well on QPFs.

Three data assimilation and forecast experiments were carried out. For each experiment, a 12-h data assimilation cycling procedure with a 6-h interval is first carried out, followed by a 24-h model forecast. The first data assimilation minimization at the beginning of the 12-h data assimilation cycle is carried out at 1200 UTC 29 April 2017 using the NCEP GFS output as the background field. The NCEP GSI analysis system is used for data assimilation at all analysis times. The community radiative transfer model [14], [15] is employed as the observation operator for all satellite instruments. The 6-h model forecasts that serve as the background fields for the second and third data assimilation minimization within the data assimilation cycle, as well as the final 24-h model forecast initialized by the analyses at the end of the data assimilation cycle are generated by the ARW model. The GSI analysis system and the ARW model have a horizontal resolution of 15 km and a total of 65 vertical levels from the earth surface to a model top around 1 hPa. The regional model domain is shown in Fig. 3(a). The total model grid points in the 3-D space are $500 \times 300 \times 65$. The ARW employs the following physical parameterization schemes; the WRF single-moment three-class microphysics scheme developed by Hong and Lim [16], the Kain–Fritsch cumulus parameterization scheme [17]–[19], and the Yonsei planetary boundary layer scheme [20].

The first control experiment (EXP1-CTRL) assimilates surface and upper air reports operationally collected by NCEP, including land surface, marine surface, radiosonde and aircraft reports from the global telecommunications system, profiler and radar-derived winds, oceanic winds retrieved from special sensor microwave imager observations, atmospheric total column water and satellite wind products that are routinely made available by the Center for Satellite Applications and Research at the NOAA National Environmental Satellite, Data and Information Service.

In the second experiment, the ABI IR channels 7–16 are assimilated along with all data assimilated in EXP1-CTRL (EXP2-ABI). Since ABI data assimilation was not yet included in the GSI analysis system, we had to add the ABI data assimilation...
First, a cloud detection algorithm developed by Zhuge and Zou [21] is applied to the ABI data at 2-km resolution to select ABI observed brightness temperatures under clear-sky conditions. Second, the clear-sky ABI brightness temperature observations without any data thinning are put into the Binary Universal Form for the Representation (BUFR) of meteorological data [22] that is required by the GSI analysis system. Finally, the ABI data are thinned to a spatial resolution of 60 km before assimilation. In the GSI, only those ABI observations with the satellite zenith angle less than 60° (i.e., the area within the red thick solid curve in Fig. 1) are assimilated.

In the third experiment (EXP3-GOES), the GOES-13/-15 channels 2–4 and 6 are added to all data assimilated in EXP1-CTRL. GOES-13/-15 clear-sky image brightness temperature observations that are thinned to a 60-km resolution are put into the BUFR format operationally. More details on the assimilation of GOES-13/-15 brightness temperature measurements can be found in [6].

IV. CLOUD DETECTION

Only the ABI observations of IR channels under clear-sky conditions are assimilated in the GSI analysis system. Therefore, the same IR-only CM algorithm that was developed and tested by Zhuge and Zou [21] for AHI observations is used in this study. A spatial distribution of brightness temperature observations for ABI channel 11 over ocean at 0000 UTC 29 April 2017 is shown in Fig. 4(a). The CMs in the area indicated by the black box in Fig. 4(a) are detected by 11 IR-only CM tests [see Fig. 4(b)], whose abbreviations are listed in Table I. It is seen that the ABI observed brightness temperature at channel 11 [see Fig. 4(a)] is extremely low when ETROP detects clouds. It is seen that areas with cloud and precipitation [see Fig. 4(b)] are characterized by much lower brightness temperature observations of channel 11 [see Fig. 4(a)] due to cloud emission and scattering.

V. QC

The differences of the ABI brightness temperature between observations (O) and model simulations (B) under clear-sky conditions are first collected for the ten IR ABI channels over ocean and three WV sounding channels over land. The data bias of the ith channel ($\mu_i$), which is defined as the mean of the O–B

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TABLE I

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<thead>
<tr>
<th>Name</th>
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<tr>
<td>NOTC</td>
<td>New optically thin cloud test</td>
<td>RFMFT</td>
<td>Relative 11–12 micron test</td>
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<td>EMISS4</td>
<td>4 micron emissivity test</td>
<td>CIRH2O</td>
<td>Cirrus WV test</td>
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<td>Uniform low stratus test</td>
<td>TEMPR</td>
<td>Temporal IR test</td>
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<td>Relative thermal contrast test</td>
<td>TUT</td>
<td>11 micron clear uniformity test</td>
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<td>ETROP</td>
<td>Emissivity at tropopause test</td>
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<td>NFMFT</td>
<td>Negative 11–12 micron test</td>
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differences, must be subtracted from the “O–B” expression in the data assimilation of the ith ABI channel. It is found that the O–B differences at the edges of clear-sky areas next to clouds are much larger in magnitude than those in the remaining areas [see Fig. 5(a)]. It is therefore determined that to reject a “clear” ABI observation from assimilation is if the O–B difference is larger than 1.5 K. Biases and standard deviations after cloud detection with the added QC of |O–B| < 1.5 K are much smaller than those without adding this QC step (see Fig. 6).

VI. NUMERICAL RESULTS
The ABI data are expected to significantly improve the quality of model fields. Fig. 7 compares the means and standard deviations of the differences of brightness temperature between ABI observations and model simulations from background fields and those from the analysis fields. All ABI data assimilated during the two data assimilation cycling period are included. As expected, the model fit to ABI brightness temperature observations is statistically significantly improved.

Fig. 8 presents spatial distributions of the differences of brightness temperature between observations and the background fields (O–B) and those between observations and analysis fields (O–A) at those ABI data points that pass the GSI
QC and are assimilated at 1200 UTC 29 April 2017 in the ABI experiment (EXP2-ABI) for ABI channel 11. The spatial distribution of the O–A differences at 1200 UTC 29 April 2017 [see Fig. 8(b)] seems consistently smaller than that of the O–B differences [see Fig. 8(a)]. The scatter plot [see Fig. 8(c)] corresponding to Fig. 8(a) and (b) further confirms this conclusion.

Similarly, the model fit to GOES brightness temperature observations is presented in Figs. 9 and 10. Both biases and standard deviations of the differences between GOES-13 imager observations and model simulations are significantly reduced after data assimilation in the EXP3-GOES experiment. Fig. 10 presents the spatial distributions of O–B [see Fig. 10(a)] and O–A [see Fig. 10(b)] as well as the scatter plot of O–B and O–A for GOES-13 channel 3 at 1200 UTC 29 April 2017 in the experiment EXP3-GOES. As expected, the O–A differences are spatially consistently smaller than the O–B differences. There are fewer pixels in Fig. 10(a) because applications of the cloud detection algorithm remove more GOES-13 observations than GOES-16 ABI data.

Impacts of ABI data assimilation are most apparent for WV analysis fields in the low troposphere. Fig. 11 shows the spatial distributions of specific humidity analysis at 750 hPa from EXP2-ABI (black curve, unit: g·kg$^{-1}$) and differences of specific humidity and wind at 750 hPa between EXP2-ABI and EXP1-CTRL, i.e., EXP2-ABI minus EXP1-CTRL, at the three analysis times: 1200 UTC, 1800 and 2400 UTC 29 April 2017. It is seen that the WV specific humidity is significantly increased ($\sim 5$ g·kg$^{-1}$) near and off the Gulf of Mexico coast at 1200 UTC April 29, 2017, which is the starting time of the data assimilation cycle. Since the same NCEP GFS background fields are used and the same conventional observations are assimilated in both EXP1-CTRL and EXP2-ABI experiments, the analysis differences in the WV fields at 1200 UTC 29 April arise purely from an assimilation of ABI observations of window channels 7–11 and 13–16 are assimilated. As the data assimilation cycle advances to 1800 UTC 29 April, large differences of specific humidity between the EXP1-CTRL and EXP2-ABI are found.
over Jacksonville and the middle of Gulf of Mexico. At 0000 UTC 30 April, differences of specific humidity between the EXP1-CTRL and EXP2-ABI are found further north over land.

In order to examine the vertical extent of the analysis differences between the EXP1-CTRL and EXP2-ABI experiments, Fig. 12 shows three cross sections of the WV analysis differences between the EXP2-ABI and EXP1-CTRL experiments and the ABI analysis increments along the line indicated in Fig. 11. It is seen that the WV differences are the largest below 800 hPa and east of 90°W at 1200 and 1800 UTC 29 April 2017. However, by 0000 UTC 30 April, the large analysis differences of WV moved upward to around and above 800 hPa. Below 800 hPa, the EXP2-ABI analysis is slightly drier than the EXP1-CTRL analysis.

Impacts of assimilating ABI IR brightness temperature observations on the QPFs associated with a developing middle latitude cyclone over land are shown as Fig. 13. In order to
show the added values of ABI data assimilation, we first compare the equitable threat scores (ETS) between the EXP1-CTRL and EXP2-ABI experiments. Here, the ETS is defined as follows [23]: at any given rainfall threshold over an accumulation period, the observed rain area exceeding the criterion is O and the model-predicted area is F. Their intersection is denoted by H; the entire verification domain is N

$$\text{ETS} = \frac{(H - R)}{(O + F - H - R)},$$

$$R = F \times \left( \frac{O}{N} \right)$$

where R is the expected area for a random distribution of F to fall inside O just by chance. It is seen from Fig. 13 that assimilation of the ABI IR channels contributes positively to an improved QPF at thresholds 1, 5, and 10 mm from 0–18 h forecast times. Impacts on the QPFs at the beginning 6 h and the last 6 h of the 24-h model forecasts are small or slightly negative.

In order to show the impacts of assimilating ABI three WV channels versus one WV channel of GOES-13/-15, we show in Fig. 14 the spatial distributions of the temperature analysis from EXP2-ABI and temperature analysis differences between
EXP2-ABI and EXP3-GOES experiments [see Fig. 14(a)], as well as the air specific humidity analysis from EXP2-ABI and specific humidity analysis differences between EXP2-ABI and EXP3-GOES [see Fig. 14(b)] at 1200 UTC 29 April 2017, which is the beginning time of 12-h data assimilation cycle. In general, temperature analysis differences [see Fig. 14(a)] are horizontally negatively correlated to specific humidity analysis differences between EXP2-ABI and EXP3-GOES experiments [see Fig. 14(a)]. The most obvious differences between EXP2-ABI and EXP3-GOES are found in the western Gulf of Mexico for both temperature and specific humidity fields. The ABI three WV data assimilation results in a maximum temperature analysis difference of 3.0 g kg$^{-1}$ [see Fig. 14(b)] and a maximum specific humidity analysis difference of $\pm 0.5$ K [see Fig. 14(a)] and a maximum specific humidity analysis difference of $\pm 3.0$ g kg$^{-1}$ [see Fig. 14(b)]. The EXP2-ABI temperature analysis is warmer than the EXP3-GOES analysis over areas where the EXP2-ABI WV analysis is drier than the EXP3-GOES analysis. It is also pointed out that the positive temperature differences between EXP2-ABI and EXP3-GOES are located in the area where the EXP2-ABI analysis increments of temperature are larger [see Fig. 14(a)]. Similarly, positive specific humidity differences between EXP2-ABI and EXP3-GOES are located in the area where the EXP2-ABI analysis increments of specific humidity are larger [see Fig. 14(b)]. In other words, assimilation of three ABI WV channels produced the analysis increments of both temperature and specific humidity of the same signs of but much larger magnitudes those obtained by assimilating a single GOES WV channel.

Fig. 15 provides two vertical cross sections of the EXP2-ABI temperature analysis increments and temperature analysis differences between EXP2-ABI and EXP3-GOES experiments [see Fig. 15(a)] and the EXP2-ABI specific humidity analysis increments (black contour at 0.4 g kg$^{-1}$ interval) and specific humidity analysis differences between EXP2-ABI and EXP3-GOES experiments (shaded in color, EXP2-ABI minus EXP3-GOES) along the dashed line indicated in Fig. 1 at 1200 UTC 29 April 2017. The temperature analysis differences [see Fig. 15(a)] are vertically negatively correlated to specific humidity analysis differences [see Fig. 15(a)] between EXP2-ABI and EXP3-GOES experiments. The altitudes of the maximum analysis differences of temperature [see Fig. 15(a)] and specific humidity [see Fig. 15(b)] between EXP2-ABI and EXP3-GOES experiments increase from about 900 hPa at lower latitudes ($\sim$24 N) to about 750 hPa at higher latitudes ($\sim$29 N). It is noted that specific humidity differences between EXP2-ABI and EXP3-GOES experiments have smaller scale features than those of temperatures. Differences of the analysis fields between EXP2-ABI and EXP3-GOES experiments will result different QPFs.

A comparison among the EXP1-CTRL, EXP2-ABI, and EXP3-GOES experiments for the QPFs can be seen in Figs. 14–16. Fig. 16 gives the ETS of the QPFs for the 3-h accumulative rainfall during the 24-h time period 0000–2400 UTC 30 April 2017 from the EXP1-CTRL, EXP2-ABI and EXP3-GOES experiments calculated at thresholds 1 and 15 mm. It is seen that the ETS of both the EXP2-ABI and EXP3-GOES experiments are consistently higher than those from the EXP1-CTRL experiment throughout the 24-h forecast time period. The EXP2-ABI experiment gives the highest overall scores at 1-mm threshold, but at 15 mm, the average ETS of EXP3-GOES is slightly higher than EXP2-ABI.

Two 3-h time periods are selected for comparing the 3-h accumulative rainfall distributions. Figs. 17 and 18 show the rainfall distributions during 0300–0600 UTC (see Fig. 17) and 1200–1500 UTC (see Fig. 18) on 30 April 2017 from the observations, the EXP1-CTRL, EXP2-ABI, and EXP3-GOES experiments. Since the model forecasts are initialized at 0000 UTC 30 April 2017, these two time periods correspond to the 3–6 h forecasts and 12–15 h forecasts (see Fig. 16), respectively. The rainfall forecasts from the EXP2-ABI experiment compare the most favorably with the observations, especially in terms of the precipitation intensity.

To further highlight the promise of GOES-16 ABI satellite imagery data assimilation for improved QPFs, another case study is carried out to examine the added value of ABI data assimilation. Two additional experiments EXP1-CTRL-2 and EXP2-ABI-2, which are similar to EXP1-CTRL and EXP2-ABI for the previous case, are carried out. The 12-h data assimilation cycle for both EXP1-CTRL-2 and EXP2-ABI-2 experiments starts at 1800 UTC 28 April and ends at 0600 UTC April 29, 2017. Two 36-h model forecasts are initialized using the analysis fields at 0600 UTC April 29, 2017 obtained by the EXP1-CTRL-2 and EXP2-ABI-2 experiments.

Fig. 19 presents the vertical profiles of biases (solid curve with circles) and standard deviations (dashed curve with circles) of the differences of temperature [see Fig. 19(a)] and specific humidity [see Fig. 19(b)] between radiosonde observations and the 24-h forecasts from EXP1-CTRL (black) and EXP2-ABI (red) experiments on April 30, 2017 for case 1, as well as those
Fig. 17. 3-h accumulative rainfall distributions during 0300–0600 UTC April 30, 2017 from observations and three model forecasts, along with the geopotential height (black curve) and wind (black vector) at 500 hPa from NCEP GFS analysis (upper left panel) and model forecasts (remaining three panels) at 0600 UTC April 30, 2017.

Fig. 18. Same as Fig. 17 except for the 3-h accumulative rainfall during 1200–1500 UTC April 30, 2017.
for case 2. It is found that the 24-h forecasts of both temperature and specific humidity fields from EXP2-ABI and EXP2-ABI-2 compared more favorably to radiosonde observations than EXP1-CTRL and EXP1-CTRL-2, respectively, except for a slightly larger bias of specific humidity below 900 hPa. The largest improvements in temperature forecasts are found for the standard deviations between 850 and 950 hPa, with a maximum reduction of standard deviation of about 0.5 K [see Fig. 19(a)]. Large improvements (∼ 0.2 g·kg⁻¹) in specific forecasts from the ABI data assimilation are found for the biases below 600 hPa for case 1 and between 700 and 850 hPa [see Fig. 19(b)].

Fig. 20 presents the ETS at thresholds 1 mm (black), 5 mm (blue), 10 mm (green), and 15 mm (red) of the 3-h accumulative rainfall during the 24-h forecast period from 1800 UTC April 29 to 0600 UTC May 1, 2017 by EXP1-CTRL-2 (dashed) and EXP2-ABI-2 (solid) experiments.

VII. SUMMARY AND CONCLUSION

In this study, we demonstrated the promise of ABI data assimilation for improving QPFs over the continental U.S. Since the ABI data are assimilated through a 3D-Var system as 15-km horizontal resolution and 65 vertical levels from the surface to about 1 hPa. We plan to conduct more case studies to draw a more general conclusion on the role of ABI data assimilation for improved QPFs over the US continent. The GOES-16 ABI will soon replace GOES-13 in November 2017. Since GOES-16 ABI provides higher spatial resolution data and scans the earth five times faster than the current operational GOES satellites, GOES-13 and -15, the work completed in this study for ABI data assimilation will allow an accelerated implementation of GOES-15 imager and GOES-16 ABI data assimilation in the GSI system.

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