Evaluating Added Benefits of Assimilating GOES Imager Radiance Data in GSI for Coastal QPFs

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Abstract

The Geostationary Operational Environmental Satellites (GOES) provide high-resolution, temporally continuous imager radiance data over the West Coast (GOES-West, also known as GOES-11) and East Coast (GOES-East or GOES-12) of the United States. It was first demonstrated that a direct assimilation of GOES imager radiances from GOES 11/12 improved quantitative precipitation forecasts (QPFs) for three coastal storms over the northern Gulf of Mexico and the east coast (Zou et al., 2011). This study further evaluates the benefits of adding GOES 11/12 imager radiances to the satellite data streams in NWP systems for improved coastal precipitation forecasts. The Community Radiative Transfer Model (CRTM) is employed for GOES imager radiance simulations in the National Centers for Environmental Prediction (NCEP) Gridpoint Statistical Interpolation (GSI) analysis system. The GOES imager radiances are added to conventional data for coastal QPF experiments near the northern Gulf of Mexico and the derived precipitation thread score was compared with those from six other satellite instruments. It is found that the GOES imager radiance produced better precipitation forecasts than those from any other satellite instrument. However, when GOES imager radiance and six different types of satellite instruments are all assimilated, the score become much lower than the individual combination of GOES and any other instrument. Our analysis shows that an elimination of MHS data over areas where GOES detects clouds significantly improved the forecast scores from MHS data assimilation.

The Data Assimilation System

The Gridpoint Statistical Interpolation (GSI) analysis system is a three-dimensional variational data assimilation (3D-Var) system for both global and regional applications. It was initially developed as the next generation global analysis system.

Observation Types

GOES-11 and GOES-12 satellites are initially positioned in geostationary orbits at 135° W and 75° W, respectively, and are part of Geostationary Operational Environmental Satellite (GOES) system operated by the United States National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS). Besides, other satellite data on board GOES/POES, such as the Advance Microwave Sounding Unit-A (AMSU-A), the hyperspectral Atmospheric Infrared Sounder (AIRS), High resolution InfraRed Sounder (HIRS), GOES Sounder (GSN), the Advance Microwave Sounding Unit-B (AMSU-B) and the Microwave Humidity Sounder (MHS) are all included.

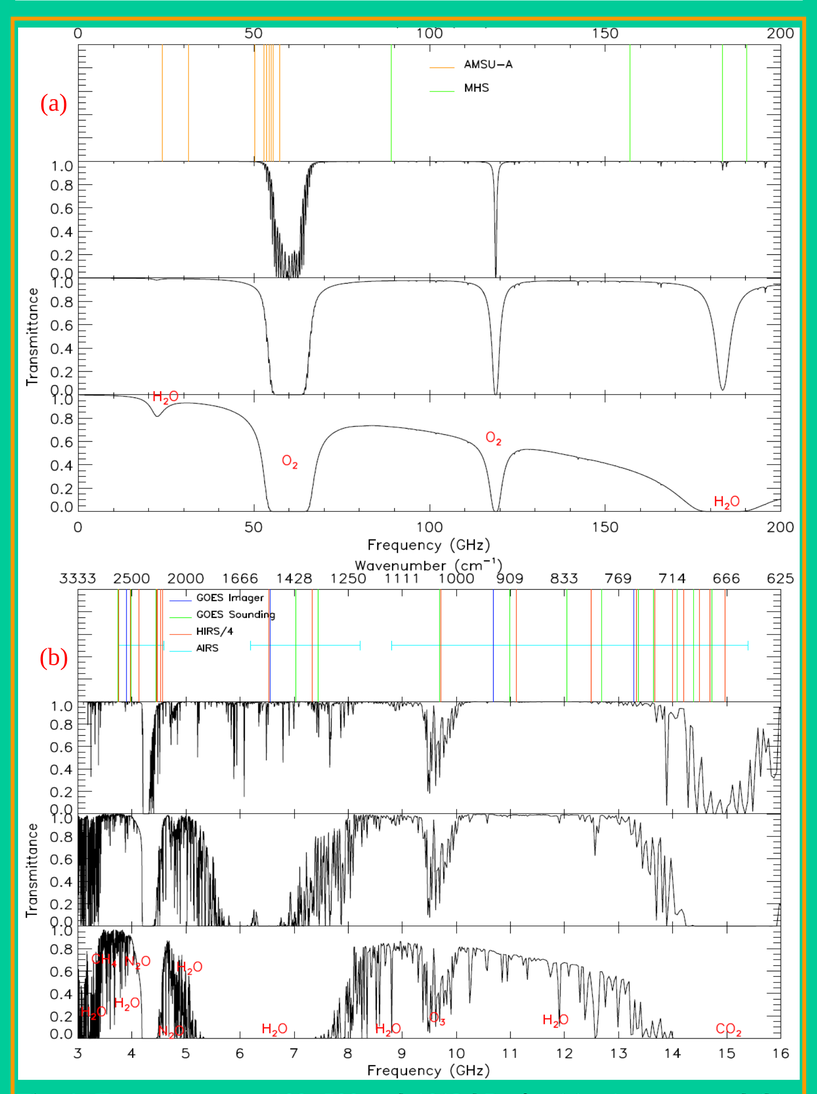


Fig. 1: Transmittance at 100, 500 and 1013 hPa for (a) microwave and (b) infrared channels. Channel frequencies for AMSU-A (orange), MHS (green), GOES imager (blue), GOES sounding (green), HIRS/4 (red), and AIRS (cyan).

Forecast Model

The Advanced Research WRF (ARW) is selected as the forecast model. The horizontal resolution is 10 km. There are 27 vertical levels from the Earth's surface to the model top specified at 50 hPa. The grid size of model domain is 250 × 200 × 27.

Experiment Setup

A total of 25 data assimilation experiments were carried out (Table 1). First three sets data assimilation experiments are designed to evaluate the potential added benefits of GOES to single other satellite data, and its impact in the presence of "all" satellite data, and the fourth set will show the sensitivity of MHS data assimilation to quality control (QC).

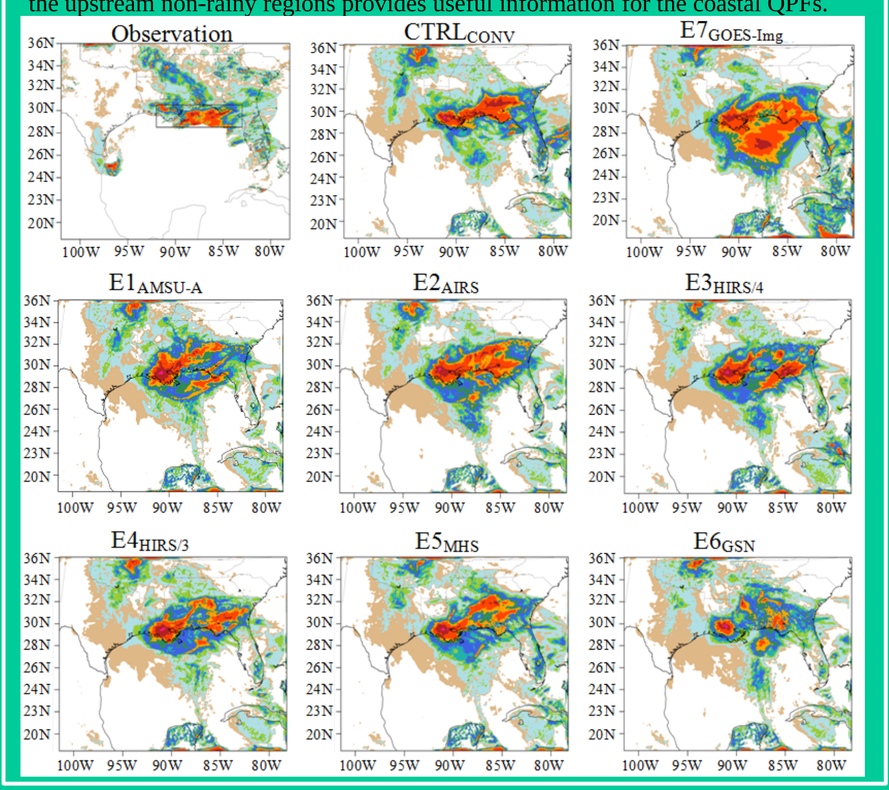
Table 2: List of satellite data assimilated in each experiment (*modified QC)

Group	Experiment Name	AMSU-A	AIRS	HIRS/4	HIRS/3	MHS	GSN	GOES-Img
First Set	$E1_{AMSU-A}$	√						
	$E2_{AIRS}$		√					
	$E3_{HIRS/4}$			√				
	$E4_{HIRS/3}$				√			
	$E5_{MHS}$					√		
	$E6_{GSN}$						√	
	$E7_{GOES-Img}$							√
Single GOES Imager Channel	$E8_{GOES-ch2}$							√ Ch2 only
	$E9_{GOES-ch3}$							√ Ch3 only
	$E10_{GOES-ch4}$							√ Ch4 only
	$E11_{GOES-ch5}$							√ Ch5 only
	$E12_{GOES-ch6}$							√ Ch6 only
Second Set	$GE1_{AMSU-A}$	√						√
	$GE2_{AIRS}$		√					√
	$GE3_{HIRS/4}$			√				√
	$GE4_{HIRS/3}$				√			√
	$GE5_{MHS}$					√		√
	$GE6_{GSN}$						√	√
Third Set	$AE1_{ALL}$	√	√	√	√	√	√	
	$AE2_{ALL-GSN}$	√	√	√	√	√		
	$AE4_{ALL-MHS-GSN}$	√	√	√	√			
	$GAE1_{ALL}$	√	√	√	√	√	√	√
	$GAE2_{ALL-GSN}$	√	√	√	√	√		√
	$GAE4_{ALL-MHS-GSN}$	√	√	√	√			√
Fourth Set	$ME5_{MHS}$					√*		
	$MAE2_{ALL-GSN}$	√	√	√	√	√*		

Precipitation Forecasts

Fig. 2: The NCEP multi-sensor observed and model-predicted 24-h accumulative rainfall (unit: mm) from 0000 UTC to 2400 UTC May 23, 2008. Area within which the threat scores of precipitation are calculated is indicated in observation.

Most precipitation was offshore based on the observations. The precipitation from $CTRL_{CONV}$ was located on land, it is the same for other experiments assimilated different satellite data, while in $E7_{GOES-Img}$, the precipitation maximum was found off the coast over ocean. This suggests that GOES radiances located over the upstream non-rainy regions provides useful information for the coastal QPFs.



Forecast Validation

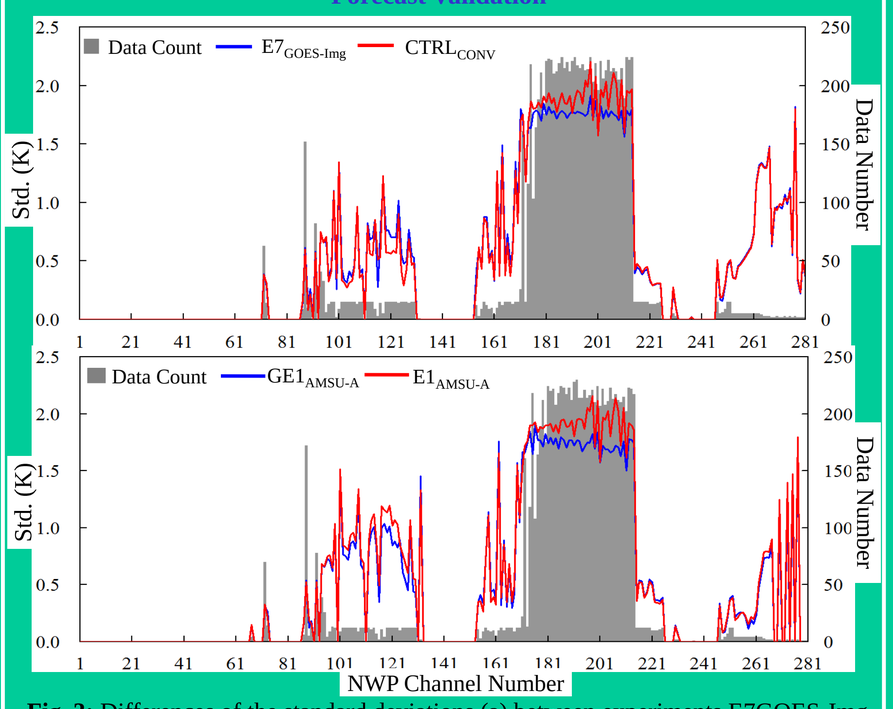


Fig. 3: Differences of the standard deviations (a) between experiments E7GOES-Img and CTRLCONV and (b) between experiments GE1AMSU-A and E1AMSU-A verified with AIRS observations at 1200 UTC 23 May, 2008. Data counts involved in the verification are shown on the right axis (shaded).

The GOES imager radiance assimilation improves the model forecasts from both $CTRL_{CONV}$ and $E1_{AMSU-A}$ in the AIRS water vapor channels (channels 170-210). Forecast improvements are also seen when GOES imager radiance data is added to experiment $E1_{AMSU-A}$ in the AIRS CO2 channels 90-130. A small degradation is noticed in the CO2 channels for $E7_{GOES-Img}$ compared with $CTRL_{CONV}$.

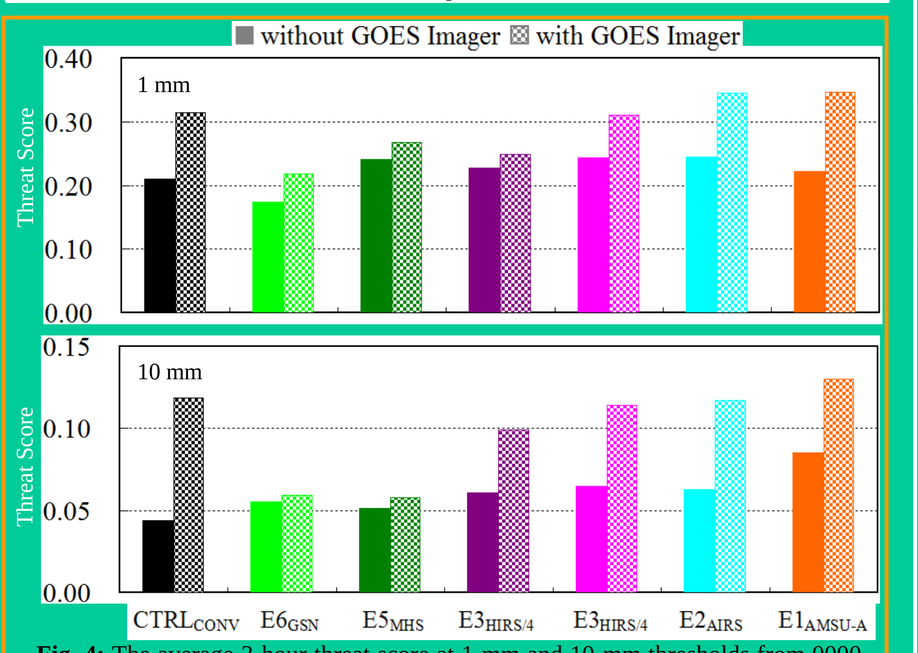


Fig. 4: The average 3-hour threat score at 1-mm and 10-mm thresholds from 0000 UTC to 2400 UTC May 23, 2008 of forecasts without (solid bars) and with (dashed bars) GOES imager data added to conventional data and different types of satellite data.

GOES Single-Channel Experiment Results

In order to see which channel is most crucial for the positive impacts on coastal QPFs seen in Fig. 5, a set of GOES imager single-channel experiments ($E8_{GOES-ch2}$, $E8_{GOES-ch3}$, …, $E12_{GOES-ch6}$) are carried out. It is found that channel 4 at 10.7 um produces the largest impact, indicating the important of surface temperatures. The CO2 infrared channel 6, which has a central wavelength of 13.3um, is of secondary importance. The low-level water vapor channel 5 is slightly more important than the upper-level water vapor channel 3. The near-infrared radiation channel 2 is least important for improving QPFs near the Gulf coast of the case studied.

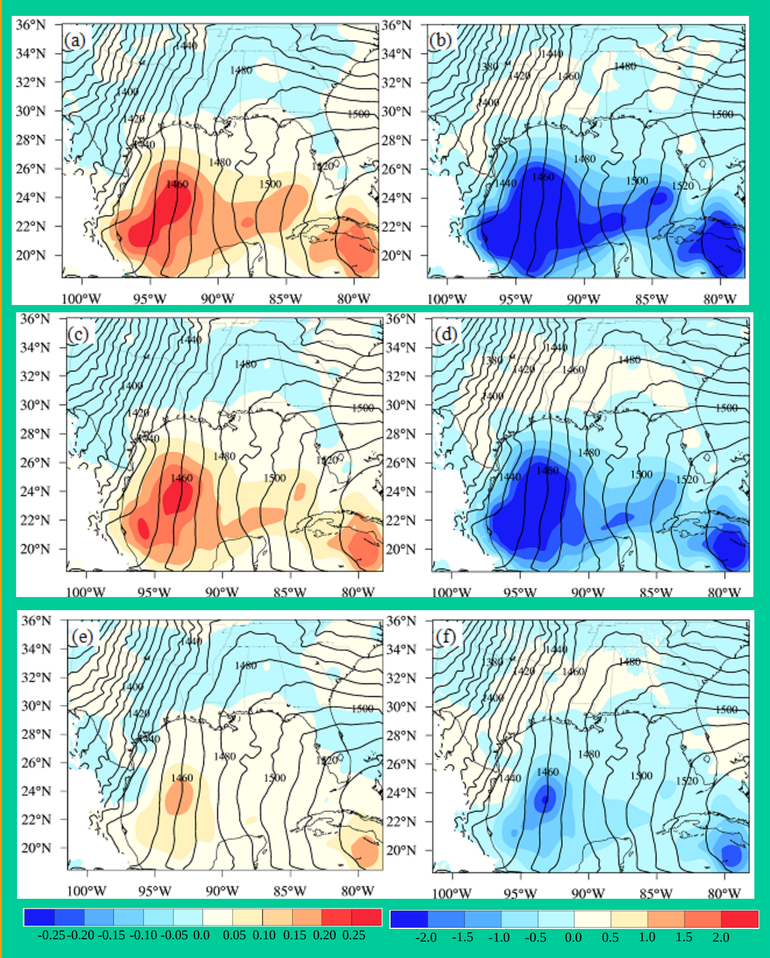


Fig. 5: Analysis differences of 850-hPa mixing ratio (g/kg, left panels) and temperature (K, right panels) at 1200 UTC May 22, 2008 (a)-(b) between E7GOES-Img and CTRLCONV, (c)-(d) between E10GOES-ch4 and CTRLCONV, and (e)-(f) between E12GOES-ch6 and CTRLCONV. The 850-hPa geopotential at 1200 UTC May 22, 2008 from CTRLCONV are shown in contours.

Clear-Sky MHS Data Only

Causes for the degradation of including MHS data are analyzed. In order to show the sensitivity of MHS data assimilation to QC and cloudy radiance assimilation, two additional data assimilation experiments are carried out with a modified GOES imager assisted MHS QC algorithm, which only selects one MHS data that is closest to and within a 10-km distance from a GOES imager channel 3 clear-sky data point. The modified MHS QC algorithm thus keeps only clear-sky data points.

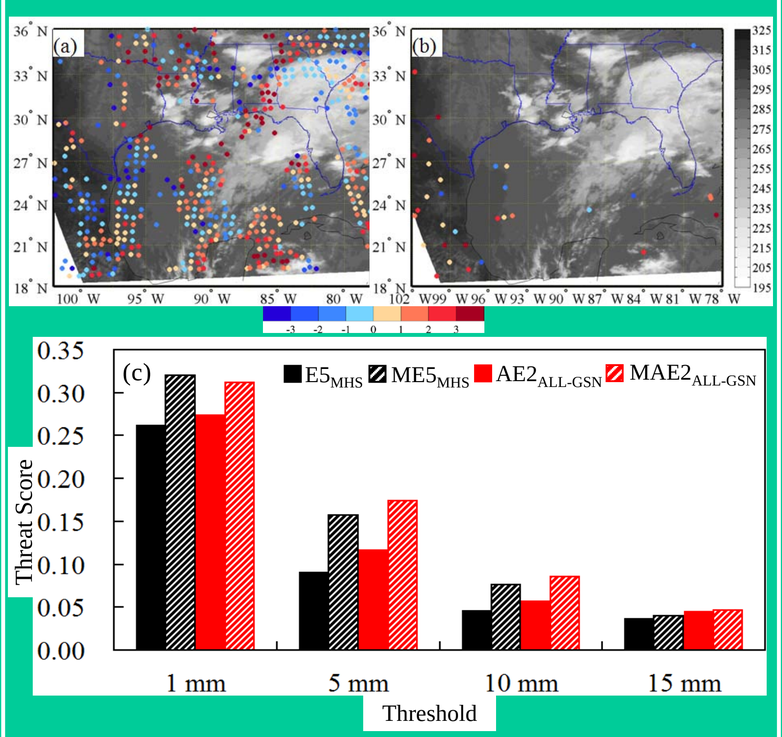


Fig. 6: Spatial distributions of data points of NOAA-18 MHS brightness temperatures assimilated in (a) E5MHS and (b) ME5MHS at 1800 UTC May 22, 2008, with O-B differences indicated in color. The 4-km GOES-11 imager channel-4 brightness temperature field is shown in (a)-(b) in black/white shading. (c) Threat scores of 3-h accumulative rainfall forecasts from experiments E5MHS, ME5MHS, AE2ALL-GSN, and MAE2ALL-GSN at 1 mm, 5 mm, 10 mm, and 15 mm thresholds averaged from 0000 UTC to 2400 UTC May 23, 2008.

It is found that an elimination of MHS data over areas where GOES detects clouds improved the MHS data assimilation results, suggesting that an improved quality control algorithm is urgently required for MHS data assimilation

Summary and Conclusions

GOES imager data produces the largest added value to conventional data for improved QPFs compared with other satellite data. Out of six different GOES imager channels, the surface-sensitive infrared channel 4 (10.7 um) on board both GOES-11/12 contributes most significantly to the improved QPFs. Assimilation of GOES imager radiances during a 12-hours time window prior to convective initiation and/or development contributes positively to any single type of satellite data for improved QPFs near the Gulf coast. However, assimilation of all types of satellite data in the GSI system did not produce a better forecast than any single type of satellite data assimilation, especially when the 3-h accumulative rainfall exceeds 10 mm. The problems with the all-satellite-data assimilation are found to arise from the inclusions of MHS and GSN data. It is shown that an elimination of MHS data over areas where GOES detects clouds significantly improved the MHS data assimilation results, suggesting that an improved quality control algorithm is urgently required for MHS data assimilation.

Reference

Zou X., Z. Qin and F. Weng, 2011: Improved coastal precipitation forecasts with direct assimilation of GOES 11/12 imager radiances, *Mon. Wea. Rev.*, **139**, 3711-329.

Zou X., Z. Qin and F. Weng, 2012: Evaluating added benefits of assimilating GOES imager radiance data in GSI for coastal QPFs. *Mon. Wea. Rev.* (submitted)

Acknowledgements

This work was supported by NOAA GOES-R Risk Reduction Program. Authors would like to express the sincere thanks to Dr. Tong Zhu and Mr. Greg Krasowski at Joint Center for Satellite Data Assimilation (JCSDA) for their help in decoding GOES data and preparing GOES radiance BUFR data.