# Improved Coastal Precipitation Forecasts with Direct Assimilation of GOES 11/12 Imager Radiances

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## Abstract

The infrared imagery instrument on board Geostationary Operational Environmental Satellite (GOES) provides observations that are of high spatial and temporal resolution and can be applied for effectively monitoring and nowcasting severe weather events. In this study, an improved quantitative precipitation forecast (QPF) for a coastal storm over the northern Gulf of Mexico is demonstrated by assimilating GOES-11 and GOES-12 imager radiances into the Weather Research and Forecast (WRF) model. Both the National Centers for Environmental Prediction (NCEP) Gridpoint Statistical Interpolation (GSI) analysis system and the Community Radiative Transfer Model (CRTM) are utilized to ingest GOES IR clear-sky data. A better quality control for removing the cloudy pixels was developed and incorporated into the GSI analysis system. Assimilation of GOES imager radiances during a 12-hour time window prior to convective initiation improved model descriptions of tropospheric humidity, geopotential, temperature and wind, leading to a significantly improved quantitative precipitation forecast (QPF) near the coast in the northern Gulf of Mexico. A detailed diagnosis reveals that the assimilation of GOES data in regions of no or little clouds improved the model description of an upstream middle latitude trough and a subtropical high located in the south of the convection. In the past, GOES imager radiances were not directly used in the GSI system. This study highlights the importance of satellite imagery information observed in the pre-convective environment for improved cloud and precipitation forecasts. The developed data assimilation technique will prepare the NWP user community for accelerated use of advanced satellite data from the GOES-R series.

## The GSI 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.

## Data

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). Orbiting at Earth's rotation speed at an altitude of 35,790-km, both satellites remain stationary with respect to a fixed point on the Earth's surface, providing imager data over the West Coast (GOES-11, also called GOES-West) and East Coast (GOES-12, or GOES-East) of the United States with an imaging refresh rate of 15 minutes.

| | GOES11 Imager Bandwidths | | | | GOES12 Imager Bandwidths | | | |
|---|---|---|---|---|---|---|---|---|
| Ch | 2 | 3 | 4 | 5 | 2 | 3 | 4 | 6 |
| Description | SW window | Water vapor | LW window | Split window | SW window | Water vapor | LW window | CO2 |
| Wavelength Range | 3.78 -4.03 | 6.47 -7.03 | 10.21 -11.20 | 11.54 -12.47 | 3.76 -4.03 | 5.77 -7.33 | 10.23 -11.24 | 12.96 -13.72 |
| Central Wavelength | 3.91 | 6.75 | 10.69 | 11.97 | 3.90 | 6.48 | 10.71 | 13.31 |
| Weight Function | surface | 300-500 hPa | surface | surface | surface | 300-500 hPa | surface | surface |
| IGFOV (km) | 4.0*4.0 | 8.0*8.0 | 4.0*4.0 | 4.0*4.0 | 4.0*4.0 | 4.0*4.0 | 4.0*4.0 | 8.0*8.0 |

## Quality Control

A multiple-step quality control (QC) procedure is applied to GOES imager radiance data before data assimilation:

1. data with less than 70% for GOES 11 and GOES 12 are rejected;
2. data with zenith angle greater than 60 degrees are also rejected;
3. negative brightness temperatures are removed;
4. data from channels 2, 4 and 5 over land are rejected;
5. all data over ice and snow surface are rejected;
6. data is rejected if the standard deviation is greater than a prescribed and
7. data is rejected if it deviates from background value by more than three times of the observation error or the maximum error.

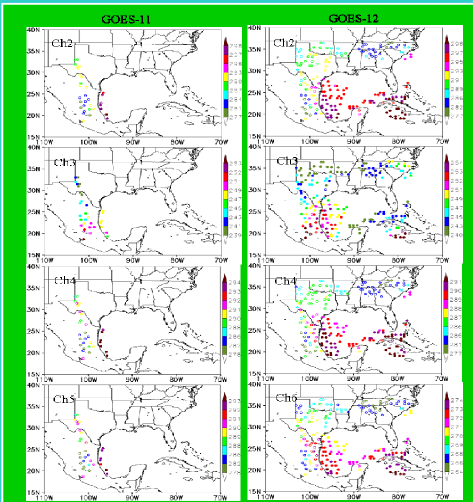


Fig. 1: Observed brightness temperatures (unit: K) of (a) channel two, (b) channel three, (c) channel four and (d) channel five at 1200 UTC May 22, 2008. Observation locations at which the observed radiances did and did not pass quality control are indicated by solid dots and open circles, respectively.

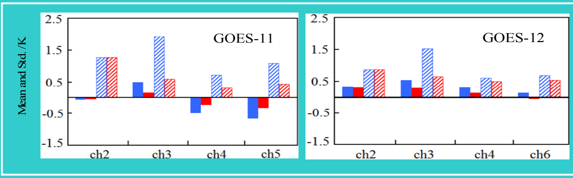


**Fig. 2:** Biases (solid bars) and RMS errors (dashed bars) of GOES-11 and GOES-12 observation departures from background (blue) and analysis (red) for the SATCONV experiment. Calculations were carried out over all observations assimilated.

Biases and RMS errors were reduced after GOES data assimilation for all assimilated channels except for channel 2. The most significant error reduction occurred for the two water vapor channels for which background errors are the large.

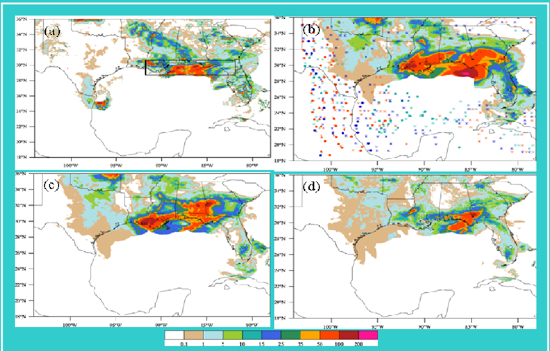

Fig. 3: 24-h accumulative rainfall (unit: mm) on 23 May 2008 near the coast of Gulf of Mexico from (a) multi-sensor NCEP observations, (b) SATCONV, (C) CONV and (d) CTRL1. The locations of brightness temperature observations assimilated in SATCONV from GOES-11 (dots) and GOES-12 (cross symbol) at 1200 UTC May 22, 1800 UTC May 22 and 0000 UTC May 23, 2008, are indicated in blue, red and cyan, respectively.

Most precipitation was offshore based on the observations. GOES radiances assimilated were located over the non-rainy regions. The precipitation maximum from CONV was located at the coast near 92°W where the convection was initiated, while in SATCONV, the precipitation maximum was found off the coast over ocean at about 86°W. However, both SATCONV and CONV over-predicted precipitation over land.

## 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 250x200x27.

## Experiment Setup

The NCEP FNL is used as background fields.

**CTRL:** initialized at 1200 UTC May 22, without assimilation
**CTRL1:** initialized at 0000 UTC May 23, 2008, without assimilation
**CONV:** initialized at 1200 UTC May 22, 2008, only conventional observations were assimilated at 6-h cycling interval ending at 0000 UTC May 23, 2008, then forecast for 24 hours
**SATCONV:** same as CONV except for adding GOES-11 and GOES-12 radiance observations assimilation

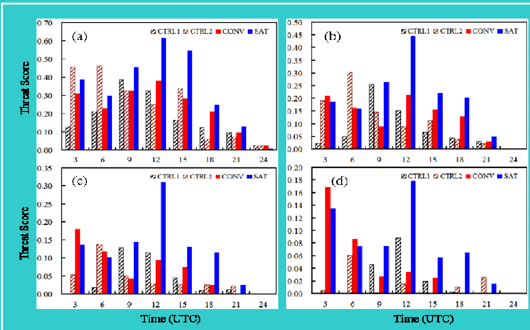


Fig. 4: Threat scores of 3-h accumulative rainfall from CTRL1, CTRL2, CONV and SATCONV at (a) 1 mm, (b) 5 mm, (c) 10 mm, and (d) 15 mm thresholds from 0000 UTC to 2400 UTC May 23, 2008. SATCONV outperforms all other forecast experiments at all thresholds after the 6-h model spin up time.

The largest impact of GOES radiance assimilation is found for rainfall from 0600 UTC to 1800 UTC during which convection was most active, and especially for heavier rain (larger thresholds). Compared with SATCONV, The forecast skill of the other three forecast experiments for light rain is higher than for heavier rain.

## Synoptic Overview

We first present a synoptic overview on the large-scale environment in which convection is initiated and developed. The temperature and relative humidity fields at 1200 UTC May 23, 2008 from SATCONV and CONV are shown in Fig. 5. Temperature in SATCONV is more than 2°C warmer than CONV near the convective region. High relative humidity area in CONV is confined over land, while that in SATCONV extends into the ocean and broader land area. Relative humidity in SATCONV is more than 20% wetter than CONV near the convective region. The equivalent potential temperature $\theta_e$ is chosen for examining the outbreak of severe weather. High equivalent potential temperature indicates regions of warm and moist air where convection is more likely to occur. As shown in Figure 6, a pocket of high $\theta_e$ air is seen near the coast at 850 hPa in both SATCONV and CONV. It reached 500 hPa at 0600 UTC, with SATCONV being slightly larger than CONV. However, the high $\theta_e$ air pocket in SATCONV moves southeastward and into the ocean while that in CONV stayed inland and weakened with time.

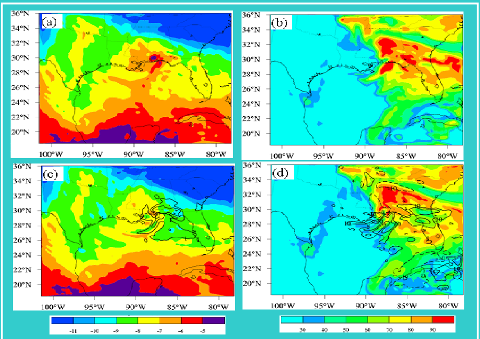


**Fig. 5:** 500-hPa temperature (shaded, left panels, unit: °C) and relative humidity (shaded, right panels, unit: %) at 1200 UTC May 23, 2008 from (a)-(b) SATCONV and (c)-(d) CONV. Temperature and relative humidity differences between SATCONV and CONV (SATCONV-CONV) greater than 1°C and 10% are indicated by solid line in (c) (contour interval: 1°C) and (d) (contour interval: 10%), respectively.

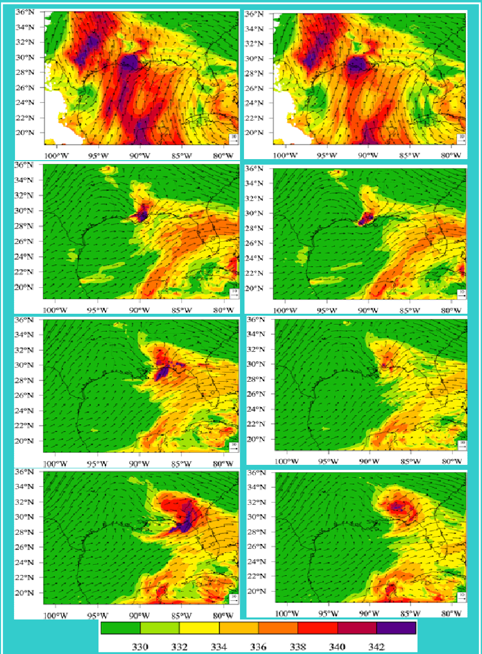


**Fig. 6:** Equivalent potential temperature (shaded, unit: K), wind vector at 0000 UTC, 850 hPa (top panels), 0600 UTC, 500 hPa (second row), 1200 UTC, 500 hPa (third row) and 1800 UTC, 500 hPa (bottom panels) May 23, 2008 from SATCONV (left panels) and CONV (right panels).

## Summary and Conclusions

This paper presents a case study examining the impact of GOES IR radiances on analyses and forecasts of the limited-area ARW using the NCEP GSI analysis system. The channels assimilated were channels 2-5 (3.9 *um*, 6.8 *um*, 10.7 *um* and 12.0 *um*) from GOES-11 and channels 2-4 and 6 (3.9 *um*, 6.48 *um*, 10.7 *um* and 13.3 *um*) from GOES-12. Several data preparation steps were defined to conduct quality control. Two independent data assimilation experiments were carried out to produce model initial conditions for a 24-h coastal convective precipitation forecast using GOES data 12-h prior to convective initiation. The evaluation of the ARW quantitative precipitation forecast accuracy against multi-sensor 3-hourly rainfall revealed very encouraging results for the case investigated in this study. The threat scores of the SATCONV precipitation forecast for all thresholds increased when GOES data were assimilated. The preliminary results from this study highlight the potential benefit of assimilating GOES radiance observations for improved coastal precipitation forecasts. In the future, effort will be made to use effectively the surface sensitive GOES IR channels as well as GOES radiances within cirrus clouds at a data resolution much higher than the current resolution (40-60 km).

## Acknowledgements

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