Assimilation of Simulated High-Resolution All-Sky Radiance and Radar Data for Storm-Scale Ensemble Forecasts

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INTRODUCTION

Most operational numerical weather prediction (NWP) systems assimilate only clear-sky radiance data because of issues with cloudy radiance data - including nonlinearity of the forward observation operator, non-Gaussian observation errors, and non-stationarity of background errors [1] - and because of the coarse-resolution NWP model has limited capability to adequately resolve and represent clouds and precipitation. Recent advances in NWP models, including increaseed convection-permitting and convection-resolving resolutions and better and explicit representation of cloud and precipitation processes, together with advancement in radiative transfer modeling in the presence of clouds and development of ensemble-based data assimilation (DA) techniques more capable of handling nonlinear processes and observations, promise the potentially more effective utilization of radiance data in all-sky conditions to improve convective-scale weather forecasting.

This study investigates the potential impact of simulated radiance data from the future GOES-R satellite on analysis and forecasting using an ensemble Kalman filter (EnKF) through realistic observing system simulation experiments (OSSEs). A nature run was created using the Weather Research and Forecasting (WRF) model running at 4 km grid spacing, using an initial condition that includes radar data. The Community Radiative Transfer Model (CRTM) [2] was used to create the simulated GOES-R radiance data and as the observation operator in the EnKF, while the forecast model used in the OSSE was the Advanced Regional Prediction System (ARPS) running at the same resolution. The radiance data were assimilated with or without simulated WSR-88D radar data.

The 10 May 2010 Oklahoma-Kansas tornado outbreak case, which spawned over 60 tornadoes, was chosen as a test case (Details in B-p09: "Multi-scale ensemble Kalman filter data assimilation and forecasts of the 10 May 2010 tornado outbreak in the central US domain"). Figure 1 shows GOES-East visible images of this event.

OBJECTIVES

- Quantitative assessment of potential impact of all-sky radiance data from GOES-R on precipitation and severe weather forecasting
- Investigation of the optimal DA frequencies in time and space for high temporal- and spatial-resolution GOES-R data
- Evaluation of relative and combined impacts of satellite radiances, channel differences, and radar observations

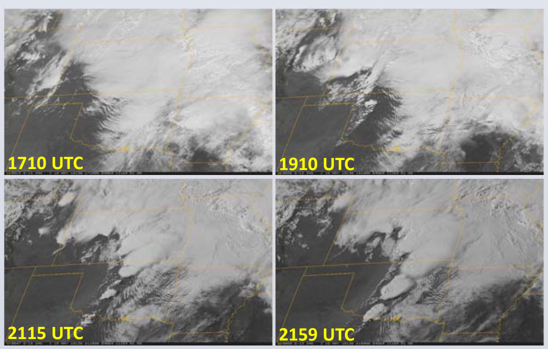

Figure 1. Observed visible image by the GOES-13 on 10 May 2010. Most of Oklahoma was covered by thin clouds during the early morning hours (not shown). As the sun came up, the clouds started to clear out and the area ahead of the dryline developed favorable conditions for storm development (1710 UTC). In the afternoon, a line of supercell storms developed ahead of the dryline (Courtesy of Dan Lindsey).

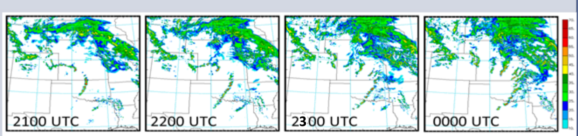

Figure 2. Simulated reflectivity for a truth simulation at model grid level 20 (about 3.6 km above mean sea level).

CONFIGURATIONS

- Natural run
  - Forecast model: WRF-ARW
    (part of the 2010 Hazardous Weather Testbed Spring Experiment, Figure 2)
  - Background: North America Mesoscale forecast system (NAM) analysis
  - DA scheme: ARPS 3DVAR/cloud analysis
  - Microphysics scheme: Thompson [3]
- OSSE runs
  - Forecast model: ARPS
  - DA scheme: CAPS parallel EnSRF [4]
  - 40 ensemble members
  - Observations: radar radial velocity (*Vr*) and reflectivity (*Z*)
    satellite brightness temperature (BT) at 6.95 and 10.35 μm
  - Grid configuration: nested grid (40 km -> 4km) (Figure 3)
  - Microphysics scheme: LFO83 [5]
- Model domain: 1750 × 1920 × 21 km^3 (443 × 483 × 53 grid points)
- 40 ensemble members

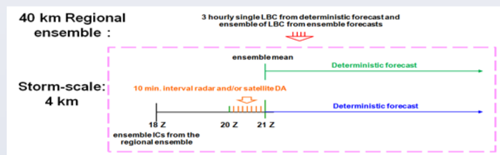

Figure 3. Flow diagram for the experiment. The initial ensemble was generated from the 40 km regional ensemble at 1800 UTC on 10 May 2010. EnKF assimilations of simulated GOES-R radiance and/or radar data were performed at 10 minute intervals between 20 UTC and 21 UTC, and the subsequent 6-hour forecast was launched.

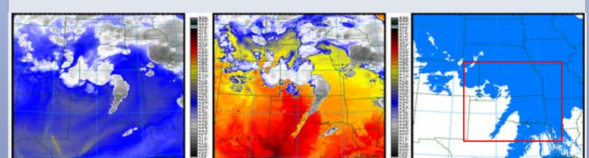

Figure 4. Synthetic GOES-R BTs at 6.95 (left) and 10.35 μm (middle) at 2100 UTC on 10 May 2010. Cloud sky where the vertically integrated water- and ice-mixing ratios ≥ 10^{-3} g/kg is shown in blue in the cloud mask product (right). The interior red box denotes the domain over which RMS errors were calculated.

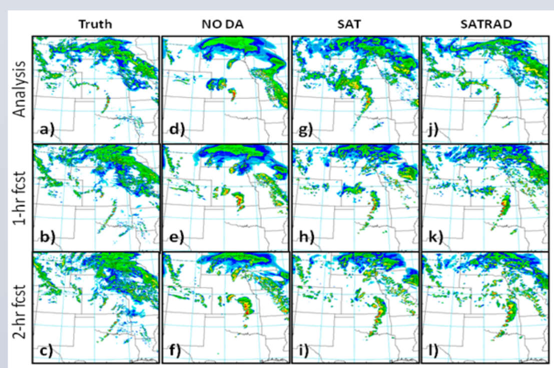

Figure 5. Simulated reflectivity for (a-c) truth simulation, and experiments that assimilated (d-f) no observations (NO DA), (g-i) synthetic satellite radiance at 6.95 and 10.35 μm (SAT), and (j-l) satellite radiance in SAT along with synthetic radar reflectivity and radial velocity data (SATRAD) for one hour from 2000 UTC to 2100 UTC at 10-minute intervals. Images are valid at 2100, 2200, and 2300 UTC (top to bottom) on 10 May 2010.

PROGRESS AND RESULTS

- The CRTM has been implemented within the computationally efficient CAPS's scalable parallel EnKF DA system so that high-density and high-frequency radar and satellite data can be assimilated on high-resolution large-domain grids in a timely-manner.
- Figure 4 shows examples of synthetic GOES-R satellite BTs at 6.95 and 10.35 μm. The cloud mask product was used to compute the root-mean-square errors in clear- and cloudy-sky conditions, separately. The cloud mask compares favorably with the observed visible image (Figure 1).
- The preliminary results show positive impacts of the radiance data on the forecast of a line of supercell storms in Oklahoma, and the forecasts are further improved when radar reflectivity and radial velocity observations are assimilated (Figure 5). When neither radar nor satellite BTs were assimilated, development of convections in Oklahoma and Texas was delayed significantly, and the storms in central Kansan were too intense.
- To focus verification on convective storms with supercell characteristics, RMS errors were computed in the subdomain (red box in Figure 4). As expected, Doppler radar data were in general more helpful in reducing RMS errors in wind variables (Figure 6).
- Assimilation of satellite and radar data individually or in combination resulted in lower RMS errors in cloud (qc), rain water (qr), cloud ice (qi), snow (qs), and hail (qh) mixing ratios in clear-sky condition. In cloudy-sky conditions, larger positive impact was found in mixing ratios that were directly involved in radar reflectivity when radar data were assimilated. When satellite data were assimilated in addition to radar data, the negative impact of radar data in qc and qi in cloudy-sky conditions were alleviated.

RMS errors for clear-sky RMS errors for cloudy-sky

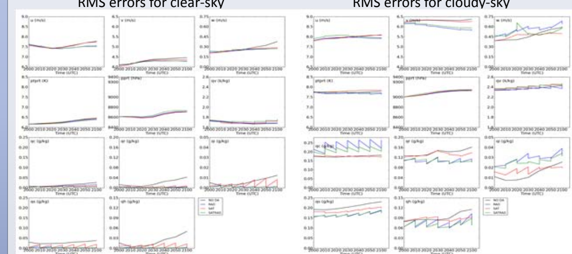

Figure 6. Root-mean-square errors averaged over grid points marked as clear- (left) and cloudy- (right) sky conditions for various model state variables for NO DA (black), RAD (blue), SAT (red), and SATRAD (green) during the assimilation window.

DISCUSSION AND FUTURE WORK

- Rather small impacts of BTs at 6.95 and 10.35 μm on storm forecasts were found when they were assimilated before storms developed. Therefore, the potential impact of other channels and/or channel differences will be assessed in the pre-storm environment.
- Configurations could be optimized to further improve the analyses and forecasts.
- Observed radiance from GOES-East and/or GOES-West will be assimilated in real-data cases.

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