Assimilation of Water Vapor Sensitive Infrared Brightness Temperature Observations during A High Impact Weather Event

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Introduction

A regional-scale Observing System Simulation Experiment (OSSE) was used to examine the impact of water vapor sensitive infrared brightness temperature observations on the analysis and forecast accuracy of a high impact weather event that occurred across the central U.S. Simulated observations from the Advanced Baseline Imager (ABI) to be launched onboard the GOES-R satellite in 2015 were employed. The ABI is a 16-band imager containing two visible, four near infrared, and 10 infrared bands. Accurate radiance and reflectance measurements will provide detailed information about atmospheric water vapor, surface characteristics and cloud top properties with high spatial and temporal resolution (Schmit et al. 2005).

Model Configuration and Simulated Observations

Assimilation experiments were conducted using the Weather Research and Forecasting (WRF) model and the ensemble Kalman filter algorithm in the Data Assimilation Research Testbed (DART) system. Satellite brightness temperature observations were assimilated using the Successive Order of Interaction (SOI) forward radiative transfer model that was implemented in the DART system by Otkin (2010).

Simulated observations from the ABI sensor and from three conventional observing systems were generated using data from a high-resolution "truth" simulation. The SOI forward model was used to compute infrared brightness temperatures for three ABI bands that are sensitive to the water vapor content in the upper troposphere (band 8; 6.19 μm), middle troposphere (band 9; 6.95 μm), and lower troposphere (band 10; 7.34 μm). These bands are also sensitive to clouds if they are located near or above the peak in the weighting function profile for a given band. Simulated brightness temperatures were also computed for band 11 (8.5 μm), which is a standard infrared window channel. Simulated METAR, radiosonde, and aircraft reports were also generated for existing surface and upper air station locations and wherever real pilot reports occurred during the case study period.

Truth Simulation

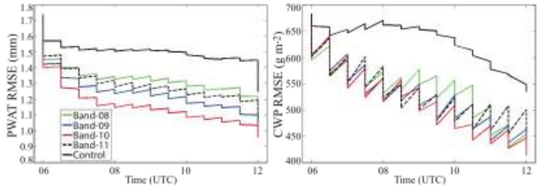
A truth simulation depicting the evolution of a strong mid-latitude cyclone and associated areas of heavy precipitation across the central U.S. on 24 December 2009 was performed using the WRF model. The simulation was initialized using 0.5° GFS analyses. The domain contained 6-km horizontal resolution and 52 vertical levels. The case was characterized by a deep trough across the western U.S., with strong southerly winds ahead of the trough advecting a very moist airmass northward across the central U.S. By the end of the truth simulation, an area of heavy snowfall and dangerous blizzard conditions associated with an intense surface cyclone had developed over the Southern Plains.

Assimilation Cases

The assimilation experiments contained 15-km horizontal resolution and were performed for a subset of the geographic domain used during the truth simulation. Five assimilation experiments were performed. Simulated conventional observations were the only observations assimilated during the Control case, whereas both conventional observations and clear and cloudy sky brightness temperatures were assimilated during the other cases. Observations from the ABI 6.19 μm, 6.95 μm, 7.34 μm, and 8.5 μm bands were assimilated during the the Band-08, Band-09, Band-10, and Band-11 cases. Observations were assimilated every 30 minutes during a 6 hour period. The model state vector included the temperature, water vapor mixing ratio, horizontal and vertical wind components, surface pressure, and the mixing ratios for cloud water, rain water, pristine ice, snow, and graupel.

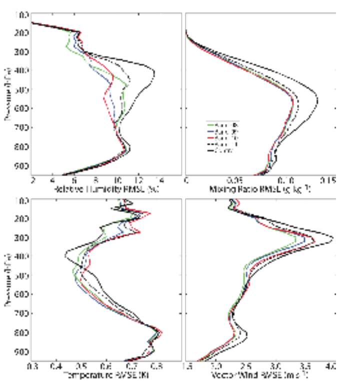
Time Series Error Analysis

The evolution of the prior and posterior RMSE for the precipitable water and cloud water path fields during the assimilation period is shown in the figure to the right. Comparison of the brightness temperature assimilation cases shows that large improvements were made to the moisture and cloud fields regardless of which band was assimilated; however, the smallest errors tended to occur when Band-10 observations were assimilated. Since low level moisture content dominates the PWAT, it is not surprising that the RMSE decreases as the sensitivity of the WV bands moves from the upper troposphere (Band-08) to the lower troposphere (Band-10). Lower CWP errors also occurred during the WV band cases, which is encouraging since this indicates that improvements made to the moisture field by these observations also contributed to a more accurate cloud analysis.



Final Analysis Accuracy

The accuracy of the final analysis at the end of the assimilation period is shown below. Compared to the Control case, the relative humidity, total cloud hydrometeor mixing ratio, and vector wind analyses were all improved during the brightness temperature assimilation cases. With the exception of the upper troposphere, the temperature analysis was also more accurate during these cases. Overall, the analyses for the WV band cases were generally better than the Band-11 case, particularly in the middle and upper troposphere. The temperature and vector wind analyses were most improved when Band-08 observations were assimilated; however, the errors were smaller for the cloud and moisture fields during the Band-09 and Band-10 cases.



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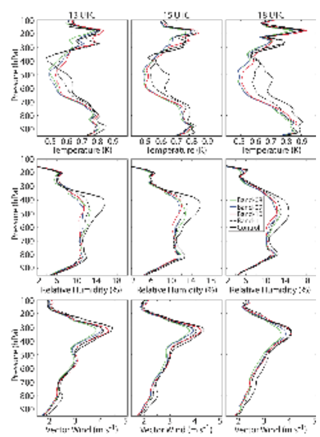
Forecast Accuracy

Short-range ensemble forecasts were performed for each case using the ensemble analyses at the end of the assimilation period. The figure below shows that the improvements made to the moisture and thermodynamic analyses during the brightness temperature assimilation cases persisted during the forecast period. For the WV band cases, the most accurate forecasts in the upper troposphere occurred during the Band-08 case; however, the errors were smaller in the lower troposphere during the Band-09 and Band-10 cases. Errors during the WV band forecasts were generally less than those during the Band-11 and Control cases, especially for the temperature and relative humidity fields.



Accumulated Precipitation Forecasts

The 6-hr accumulated precipitation from the truth simulation and for each assimilation case is shown below. During the Control case, the magnitude and spatial extent of the heavy rainfall along the Mississippi River was generally well predicted; however, the precipitation was too low across the heavy snowfall area over Oklahoma and too high further to the north over northeastern Kansas and Iowa. The precipitation forecasts across the heavy snowfall area were much better during the WV band cases. Much less snowfall occurred over northern Missouri and Iowa during the brightness temperature assimilation cases, which improved forecasts of the aerial coverage of the heaviest snowfall band, but led to maximum precipitation amounts that were slightly less than observed. Equitable threat scores (not shown) indicated that the forecast skill was consistently higher for all precipitation thresholds during the WV band cases.