Assimilation of Water Vapor and Cloud Sensitive Infrared Brightness Temperatures During High Impact Weather Events

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Data Assimilation System

- Infrared brightness temperature assimilation examined using a regional-scale Observing System Simulation Experiment approach
    - Relative impact of clear and cloudy sky observations
    - Horizontal covariance localization radius employed during the assimilation step
    - Impact of water vapor sensitive infrared bands on precipitation forecasts during a high impact weather event
    - Simultaneous assimilation of radar and satellite observations
- Assimilation experiments were performed using the WRF model and the EnKF algorithm in the DART data assimilation system
- Successive Order of Interaction (SOI) forward radiative transfer model was implemented within the DART framework
    - Simulated fields used by the forward model include T, q_v, T_{skin}, 10-m wind speed, and the mixing ratios and effective diameters for five hydrometeor species (cloud water, rain water, ice, snow, and graupel)

Regional OSSE Advantages

- The GOES-R ABI sensor will provide detailed observations of the atmospheric state over the same geographic domain with very high spatial (< 2 km) and temporal (5 minute) resolution
    - These observations will be very useful for improving the structure of fine-scale features in atmospheric analyses used to initialize high-resolution numerical models
    - Regional-scale OSSEs provide an ideal way to demonstrate the future impact of the ABI sensor since their higher spatial resolution and more frequent updates more closely match its capabilities
- Assess the impact of infrared observations on the cloud field
    - Clouds are poorly sampled by in-situ conventional observations
    - It is very helpful to have an exact measure of the characteristics of the cloud field, such as the cloud distribution and optical depth, from the truth simulation or nature run

Clear vs Cloudy Observation Impact -- OSSE Configuration

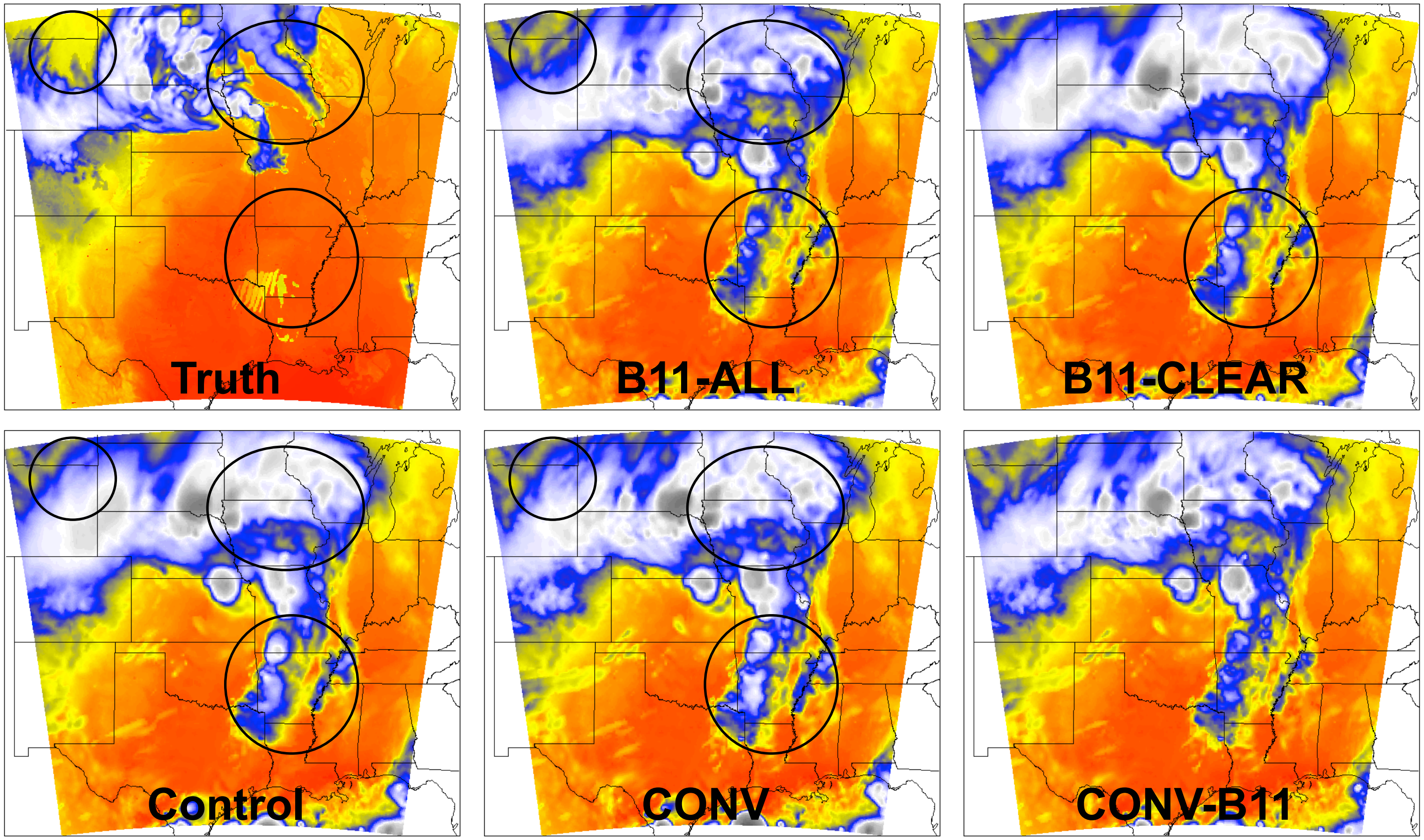
Observations assimilated during each experiment:

- B11-ALL – both clear and cloudy sky ABI 8.5 μm (band 11) T_b
- B11-CLEAR – clear-sky only ABI 8.5 μm T_b
- CONV – conventional observations only
- CONV-B11 – both conventional observations and ABI 8.5 μm T_b
- Control – no observations assimilated

- Assimilation experiments were performed using a 40-member ensemble with 12-km horizontal resolution and 37 vertical levels
- Observations were assimilated once per hour during a 12-hr period

- Otkin, J. A., 2010: Clear and cloudy-sky infrared brightness temperature assimilation using an ensemble Kalman filter. *J. Geophys Res.,* **115, D19207**, *doi:10.1029/2009JD013759.*

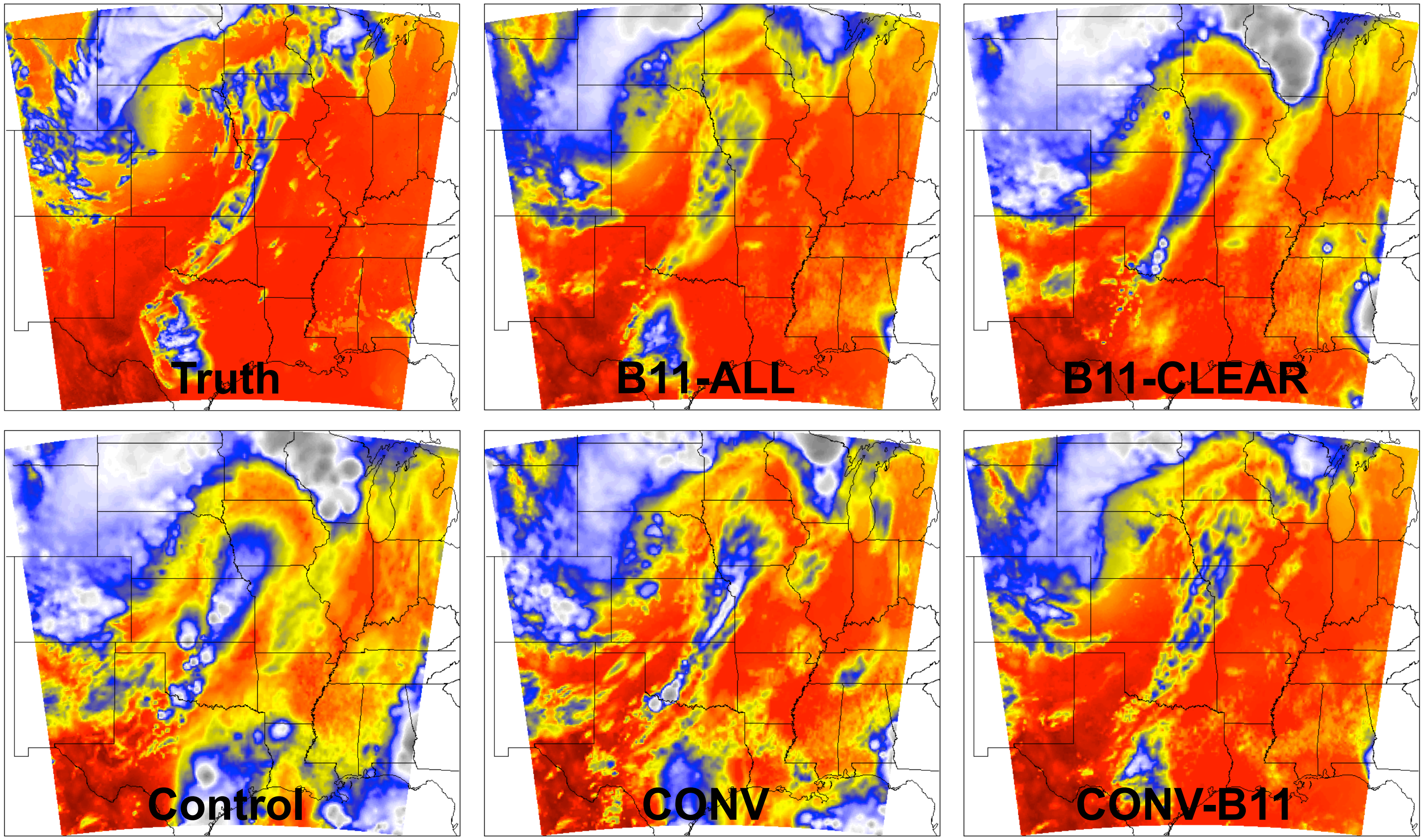
Ensemble-Mean ABI 11.2 μm Brightness Temperatures



Images valid after first data assim-ilation cycle at 12 UTC

• Compared to the conventional-only case, the assimilation of 8.5 μm brightness temperatures had a larger and more immediate impact on the erroneous cloud cover across the southern portion of the domain and also improved the structure of the cloud shield further north

Ensemble-Mean ABI 11.2 μm Brightness Temperatures



Images valid after final data assim-ilation cycle at 00 UTC

- By the end of the assimilation period, the most accurate analysis is achieved when both conventional and 8.5 μm T_b are assimilated
- Comparison of the CONV and B11-ALL images shows that the 8.5 μm Tb have a larger impact than the conventional observations

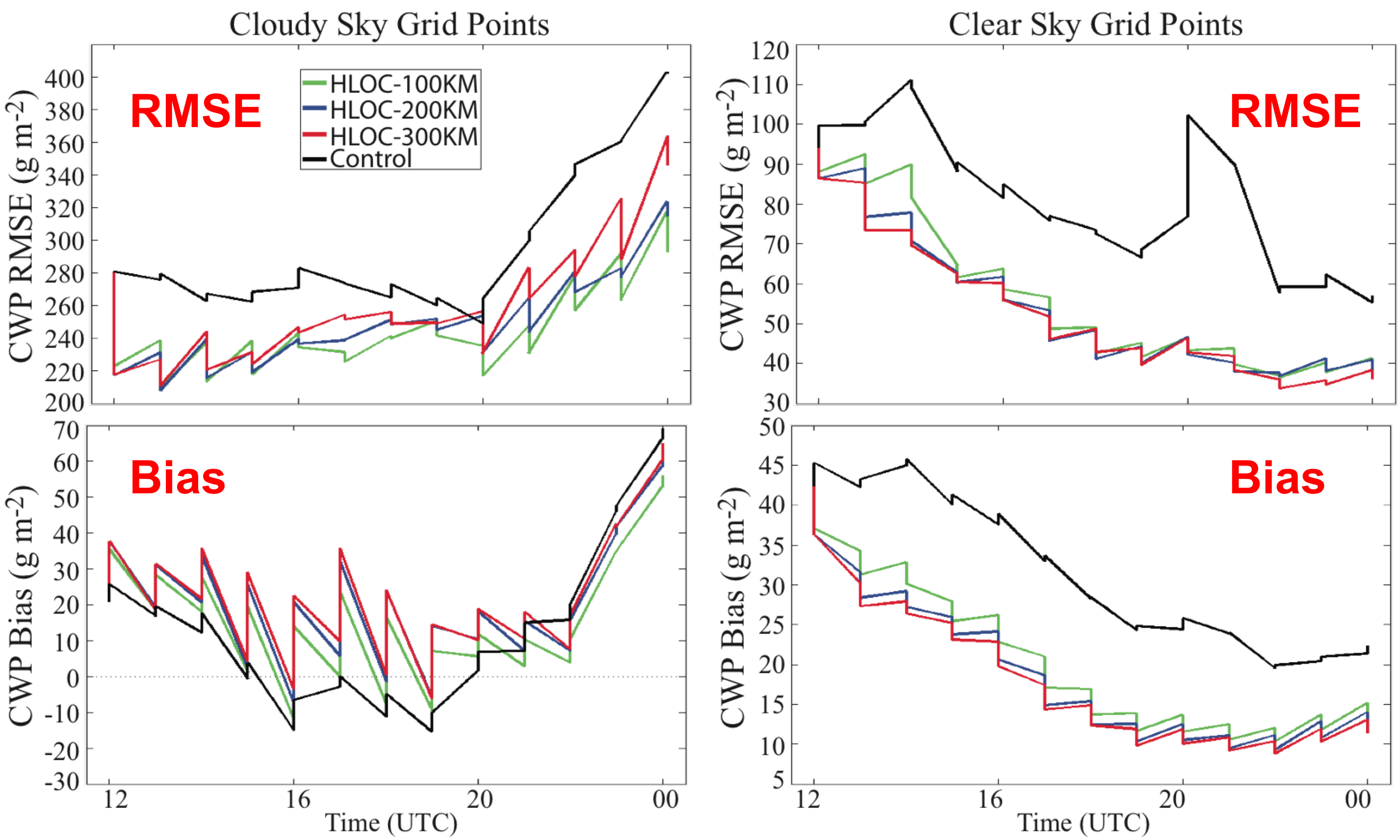
Horizontal Localization Radius Tests -- OSSE Configuration

Four assimilation experiments were performed:

- Control – conventional observations only
- HLOC-100KM – conventional + ABI 8.5 μm T_b (100 km loc. radius)
- HLOC-200KM – conventional + ABI 8.5 μm T_b (200 km loc. radius)
- HLOC-300KM – conventional + ABI 8.5 μm T_b (300 km loc. radius)

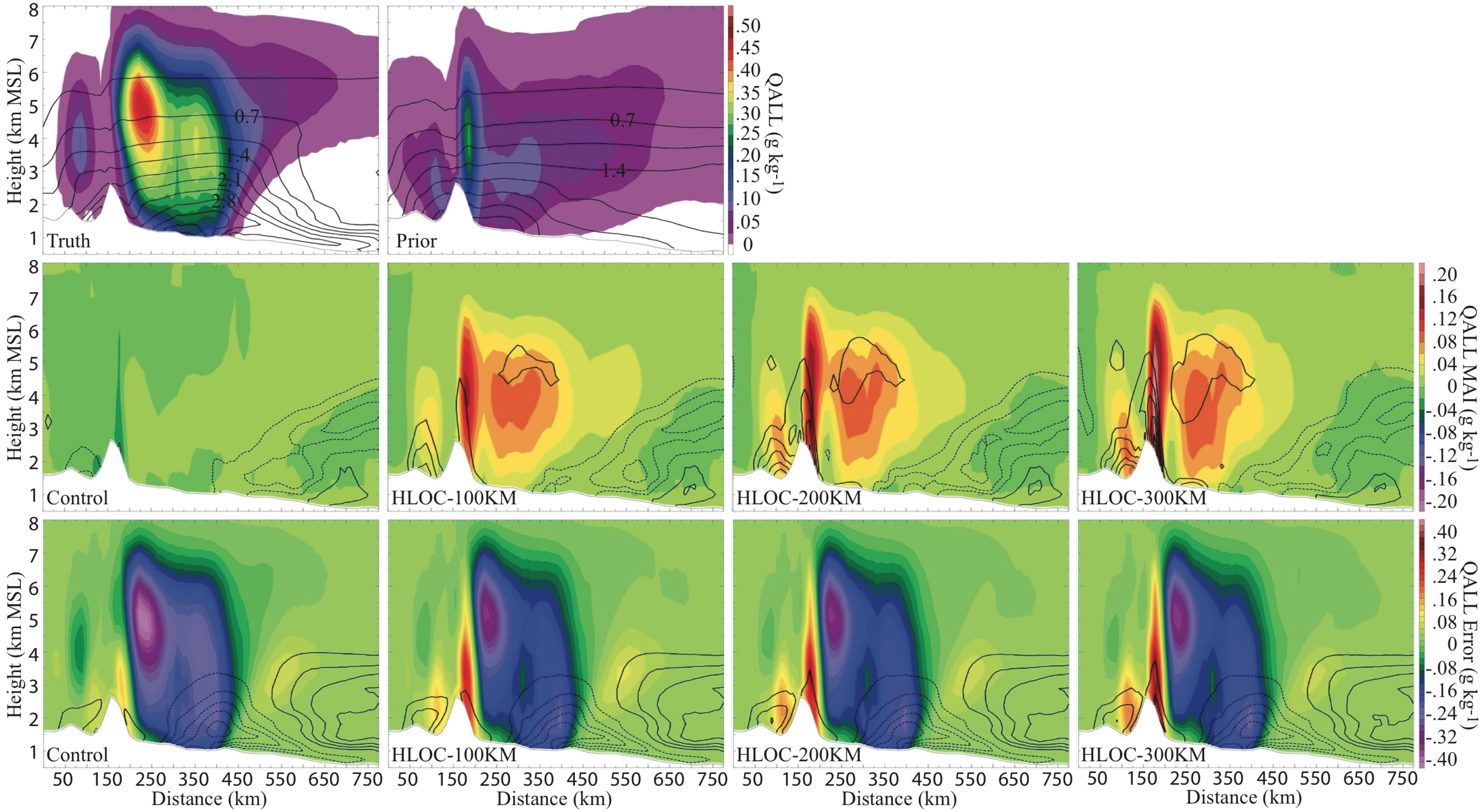
- Assimilation experiments were performed using an 80-member ensemble with 18-km horizontal resolution and 37 vertical levels
- Observations were assimilated once per hour during 12-hr period
- Both clear and cloudy sky ABI 8.5 μm brightness temperatures were assimilated
- Otkin, J. A., 2012: Assessing the impact of the covariance localization radius when assimilating infrared brightness temperature observations using an ensemble Kalman filter. *Mon. Wea. Rev.*, **140**, 543-561.

Cloud Water Path Error Time Series



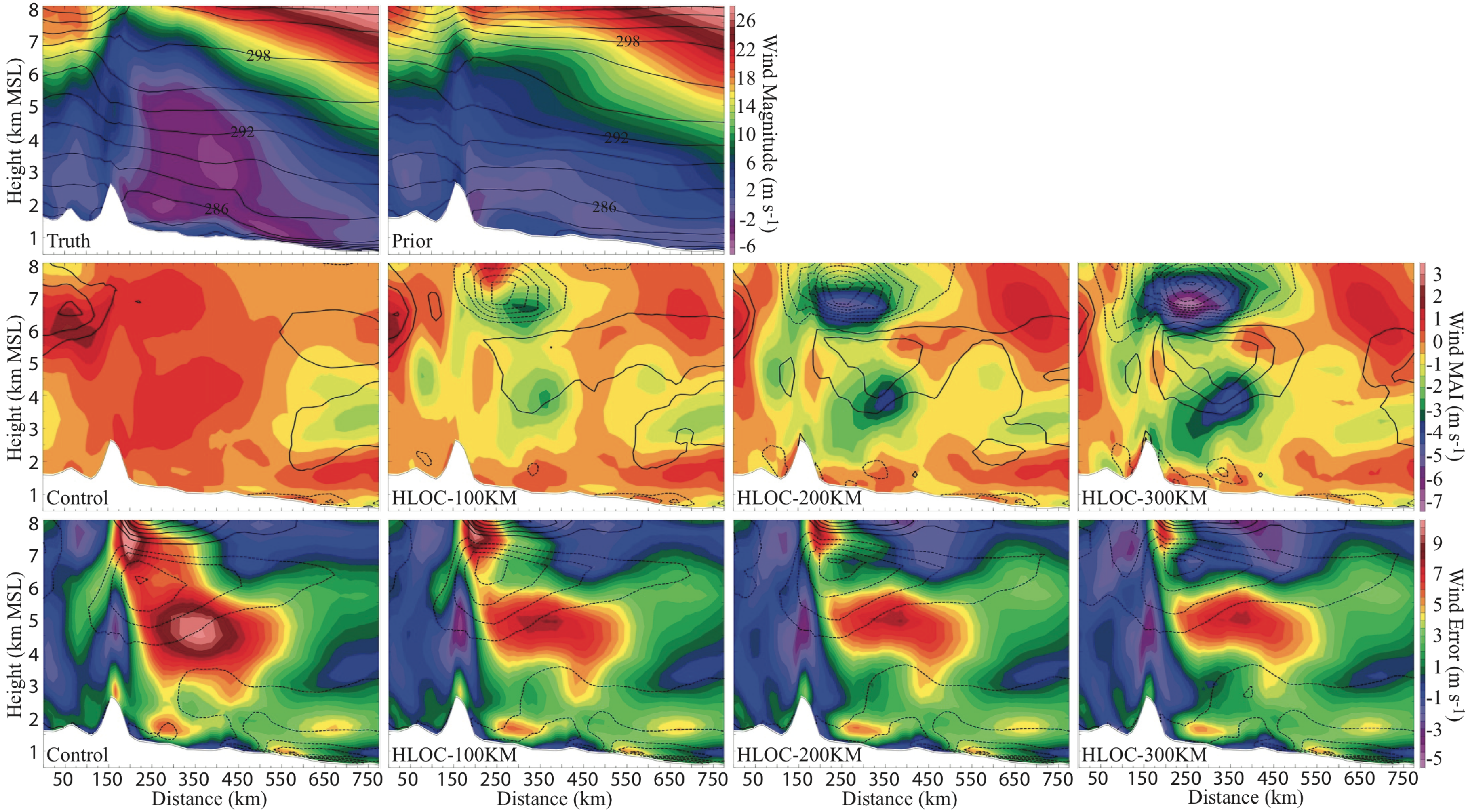
- Different performance for the clear and cloudy grid points
- Larger localization radius generally better for clear grid points but worsens the analysis in cloudy regions

Cloud and Moisture Vertical Cross Sections



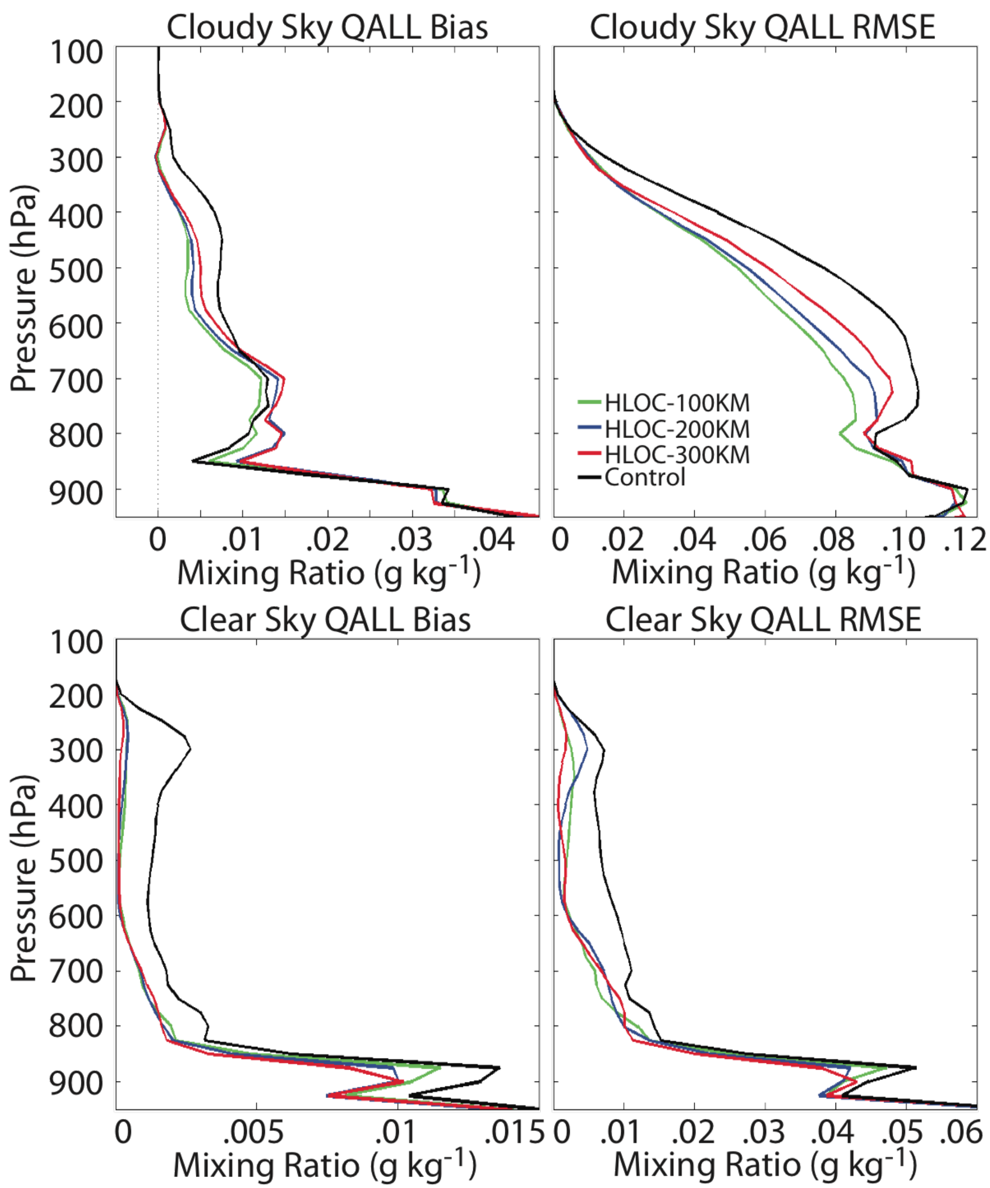
- Cloudy infrared observations had a much larger impact on the cloud field near the mountains; the impact increased with increasing loc. radius
- Infrared observations did not improve the water vapor field

Temperature and Wind Vertical Cross Sections



- Infrared observations had a larger impact than the conventional obs
- Varying the localization radius had minimal impact on shape of MAI, but a large impact on the magnitude of the increments

Cloud Errors After Last Assimilation Cycle



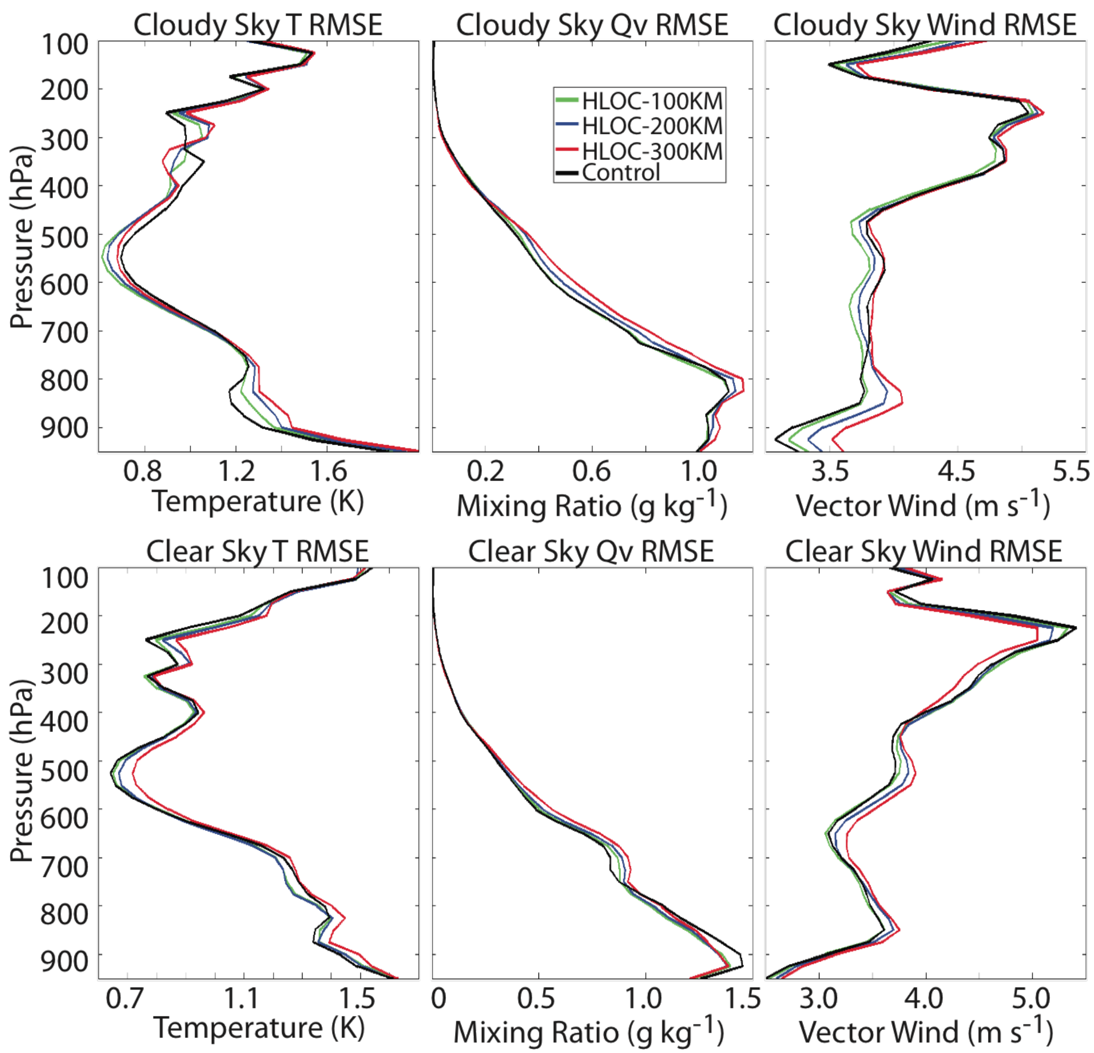
- Total cloud condensate (QALL) errors over the entire model domain after the last assimilation cycle

- Similar errors occurred for the clear sky grid points

- Errors consistently decreased with decreasing localization radius for the cloudy grid points

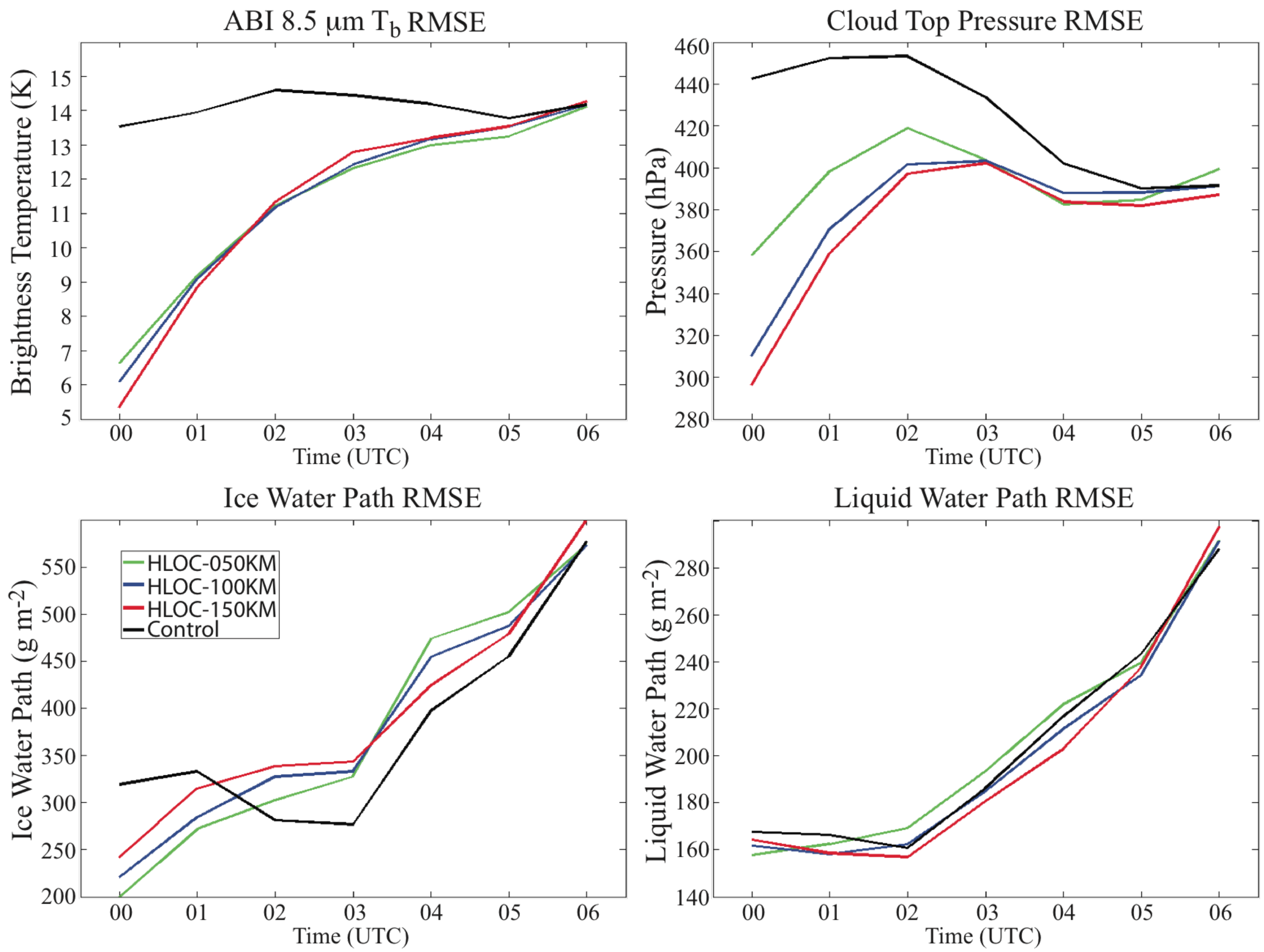
- Suggests different loc. radii should be used for clear and cloudy observations

Thermodynamic Errors After Last Assimilation Cycle



- Thermodynamic and moisture errors after the last assimilation cycle
- Greater degradation tended to occur when a larger radius was used
- These results show that a smaller radius is necessary to maintain accuracy relative to Control case

Short-Range Forecast Impact



- Overall, the initially large positive impact of the infrared observations decreases rapidly with time

- Results show that without improvements in the thermodynamic and moisture fields, it is difficult to preserve initial improvements in the cloud field

Impact of ABI Water Vapor Bands

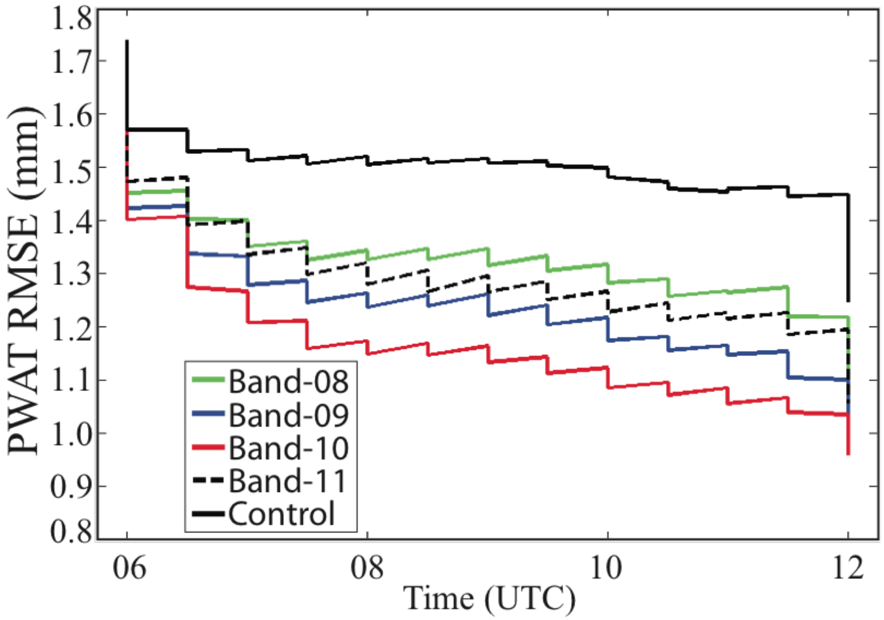
- A regional-scale OSSE was used to evaluate the impact of the water vapor sensitive ABI bands on the analysis and forecast accuracy during a high impact weather event

- Five assimilation experiments were performed:
  - Control – conventional observations only
  - Band-08 -- conventional + ABI 6.19 μm T_b (upper-level WV)
  - Band-09 -- conventional + ABI 6.95 μm T_b (mid-level WV)
  - Band-10 -- conventional + ABI 7.34 μm T_b (lower-level WV)
  - Band-11 -- conventional + ABI 8.5 μm T_b (window)

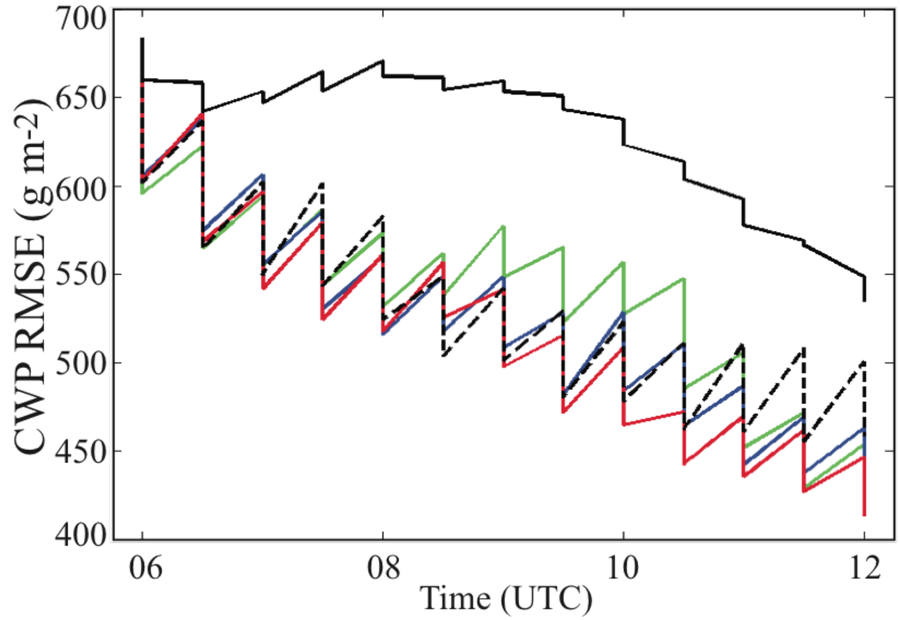
- Assimilation experiments were performed using a 60-member ensemble containing 15-km horizontal resolution and 37 vertical levels
- Observations were assimilated every 30 minutes during a 6-hr period
- Otkin, J. A., 2012: Assimilation of water vapor sensitive infrared brightness temperature observations during a high impact weather event. *J. Geophys. Res.*, **117, D19203**, doi:10.1029/2012JD017568.

Impact of ABI Water Vapor Bands

PWAT Analysis Errors

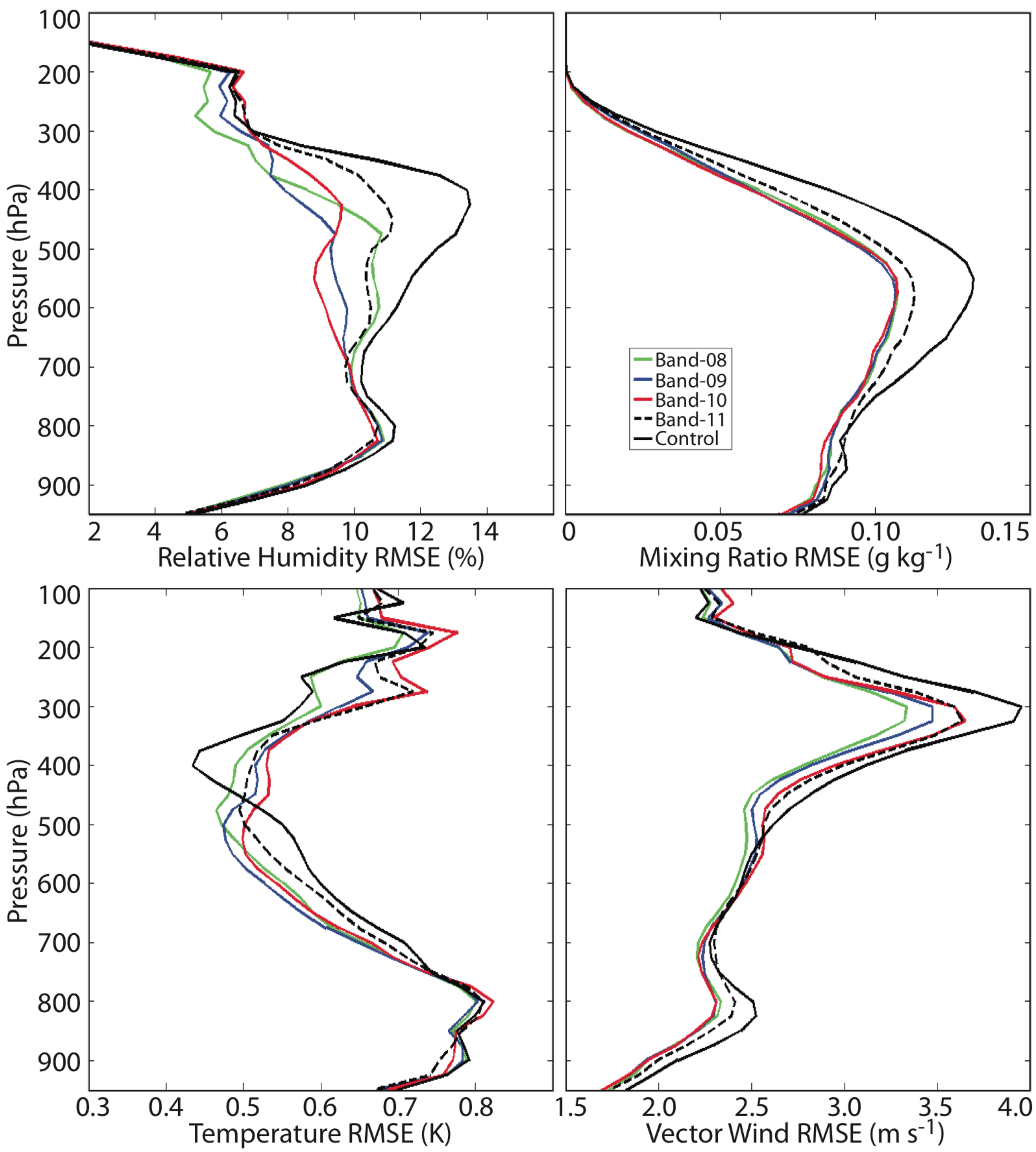


Cloud Analysis Errors



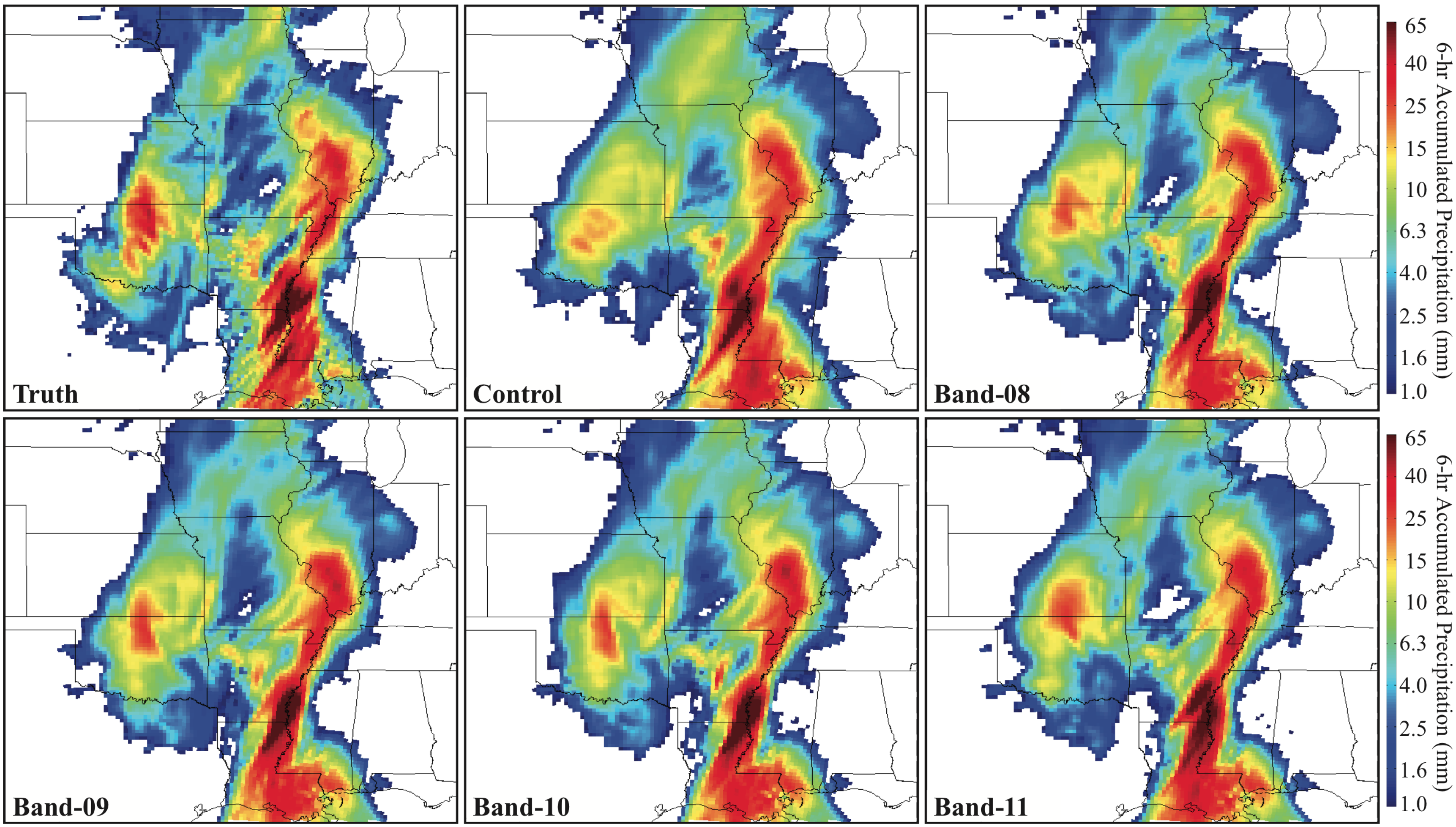
- Large improvements made to the water vapor and cloud analyses after each assimilation cycle regardless of which band was assimilated
- Smallest errors occurred when brightness temperatures from lower-peaking channels were assimilated
- Each of the water vapor band assimilation cases have smaller cloud errors than the Control and window band 11 cases

Impact of ABI Water Vapor Bands



- Thermodynamic and moisture errors after the last assimilation cycle
- Analyses were most improved when WV sensitive brightness temperatures were assimilated
- Temperature and wind errors were smallest during the Band 08 case
- Water vapor and cloud analyses most accurate during the band 09 and 10 cases

6-hr Accumulated Precipitation Forecasts



- Precipitation forecasts were more accurate during the brightness temperature assimilation cases.

Precipitation Forecast Skill

	6-hr Accumulated Precipitation Thresholds (mm)				
EXP	**>0.25**	**>2.54**	**>6.35**	**>12.7**	**>25.4**
Total Events	10,749	5,946	3,152	1,599	580
Control	0.724	0.663	0.573	0.558	0.387
Band-08	**0.758**	**0.702**	0.604	0.575	0.439
Band-09	**0.756**	0.679	0.601	**0.595**	**0.450**
Band-10	0.739	0.667	**0.609**	**0.599**	0.429
Band-11	0.742	0.671	**0.608**	0.552	0.434

- Band 08 (upper level WV) provided best results for lower precipitation thresholds; however, bands 09 (mid level WV) and 10 (low level WV) provided the best results for higher thresholds

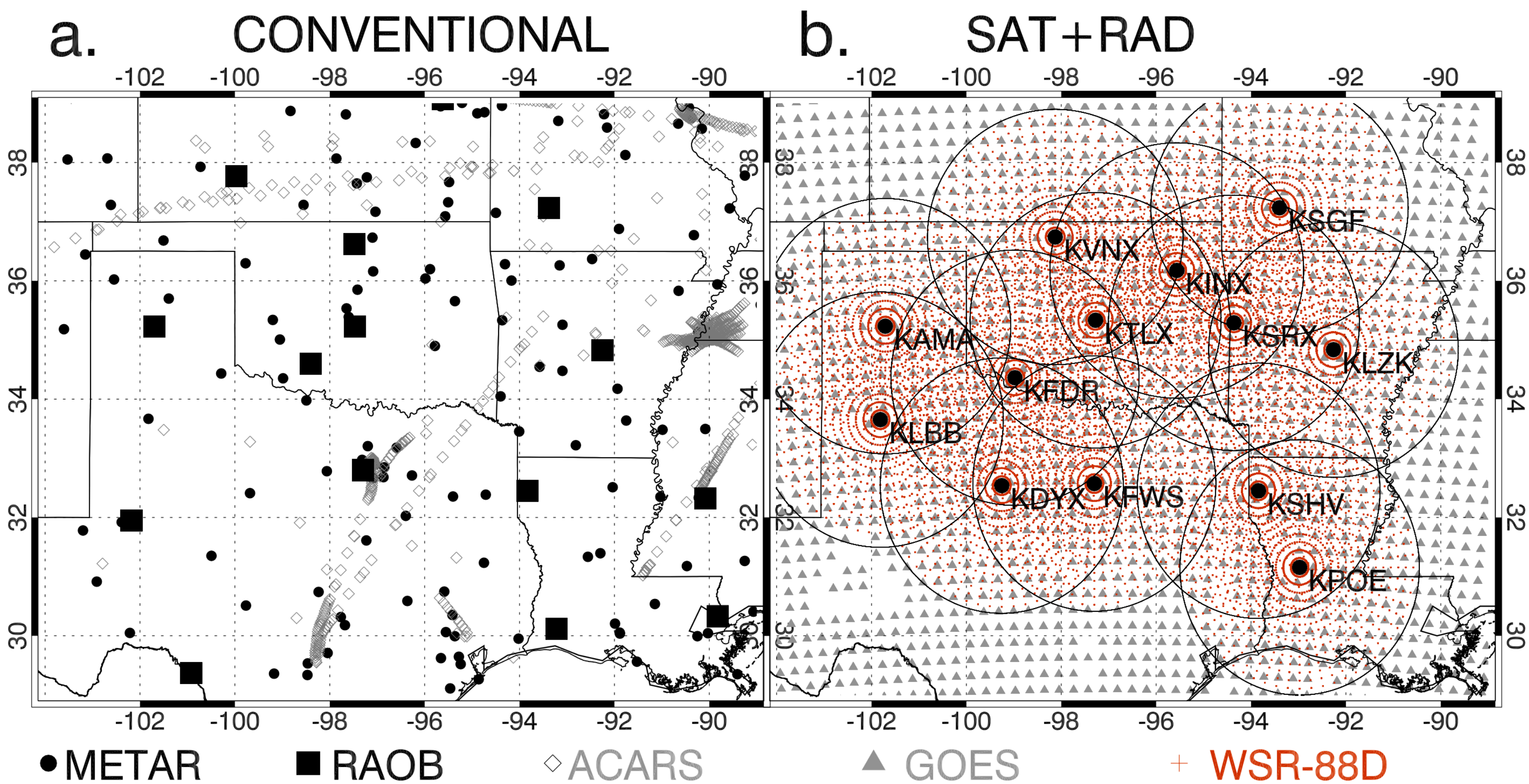
Simultaneous Assimilation of Radar and Satellite Data

- A regional-scale OSSE was used to evaluate how the simultaneous assimilation of radar and satellite observations impacts the analysis and forecast accuracy during a high impact weather event

- Four assimilation experiments were performed:
  - CONV – conventional observations only
  - SAT -- conventional + ABI 6.95 μm T_b (band 9)
  - RAD -- conventional + radar reflectivity and radial velocity
  - RADSAT -- conventional + satellite + radar

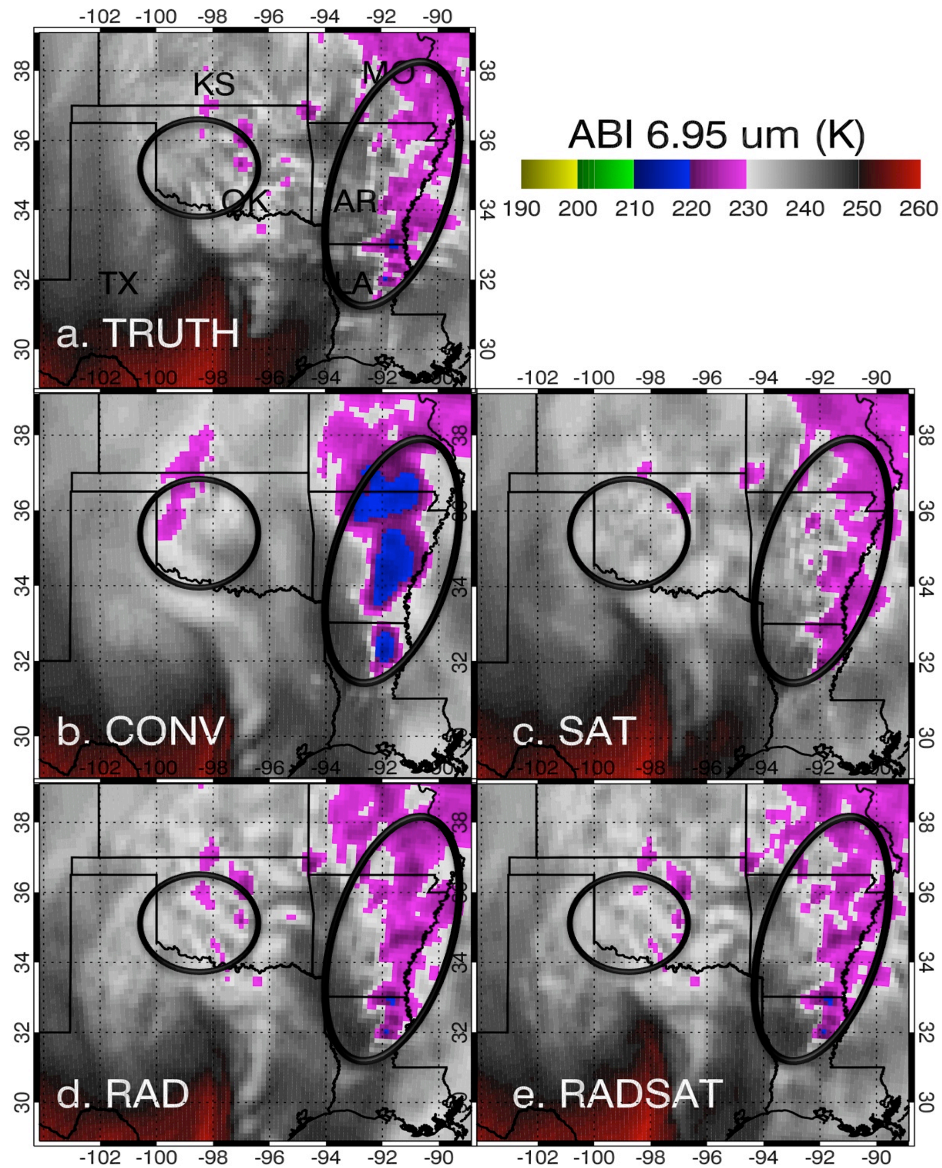
- Assimilation experiments were performed using a 48-member ensemble containing 15-km horizontal resolution and 53 vertical levels
- Observations were assimilated every 5 minutes during a 1-hr period
- Jones, T. A., J. A. Otkin, D. J. Stensrud, and K. Knopfmeier, 2013: Assimilation of simulated GOES-R satellite radiances and WSR-88D Doppler radar reflectivity and velocity using an Observing System Simulation Experiment. *Mon. Wea. Rev.*, **141**, 3273-3299.

Conventional and Radar Observation Locations



- Conventional observations sparse relative to satellite and radar data
- Several overlapping radar observations
  - Also note that radar data is 3-D

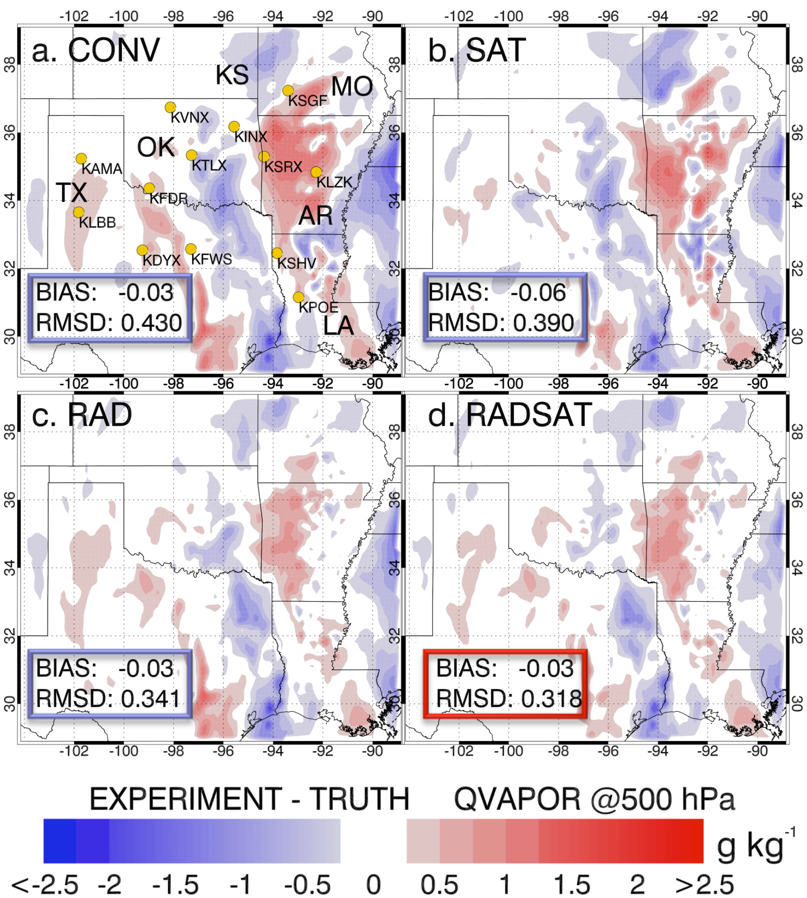
Simulated Satellite Imagery Comparison



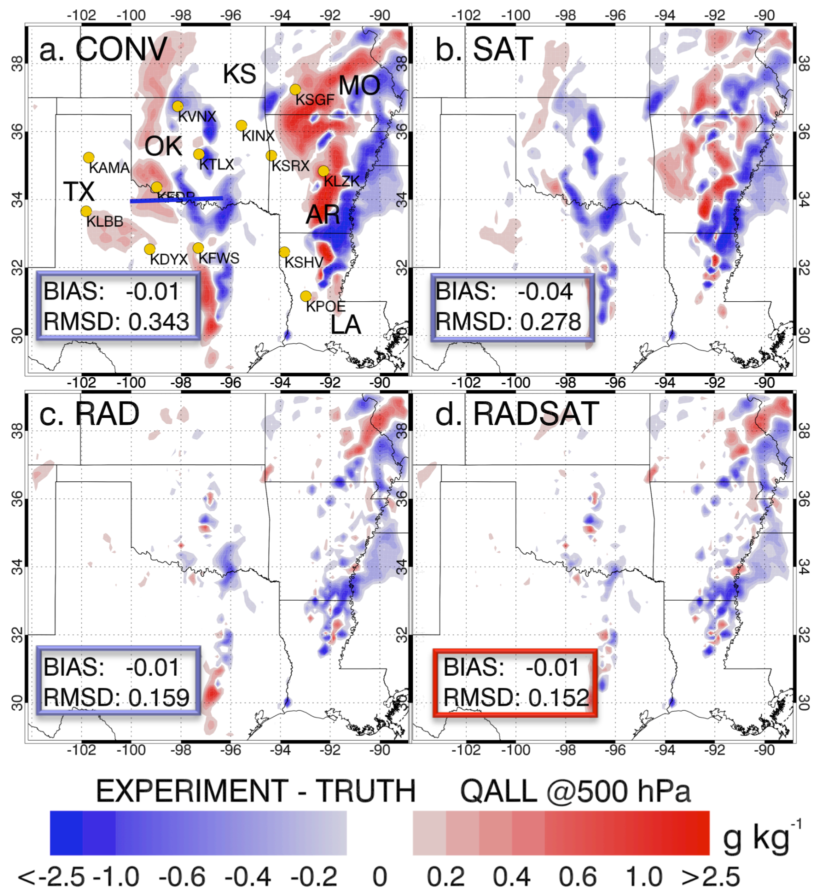
- Simulated 6.95 μm Tb after the last assimilation cycle at 1200 UTC
- CONV case is too cold and does not have fine scale structures
- SAT, RAD & RADSAT cases all improve analysis accuracy relative to Truth
- Satellite data reduces the cold bias, while radar data adds the finer scale structures

Difference Plots (Experiment – Truth)

Water Vapor Mixing Ratio

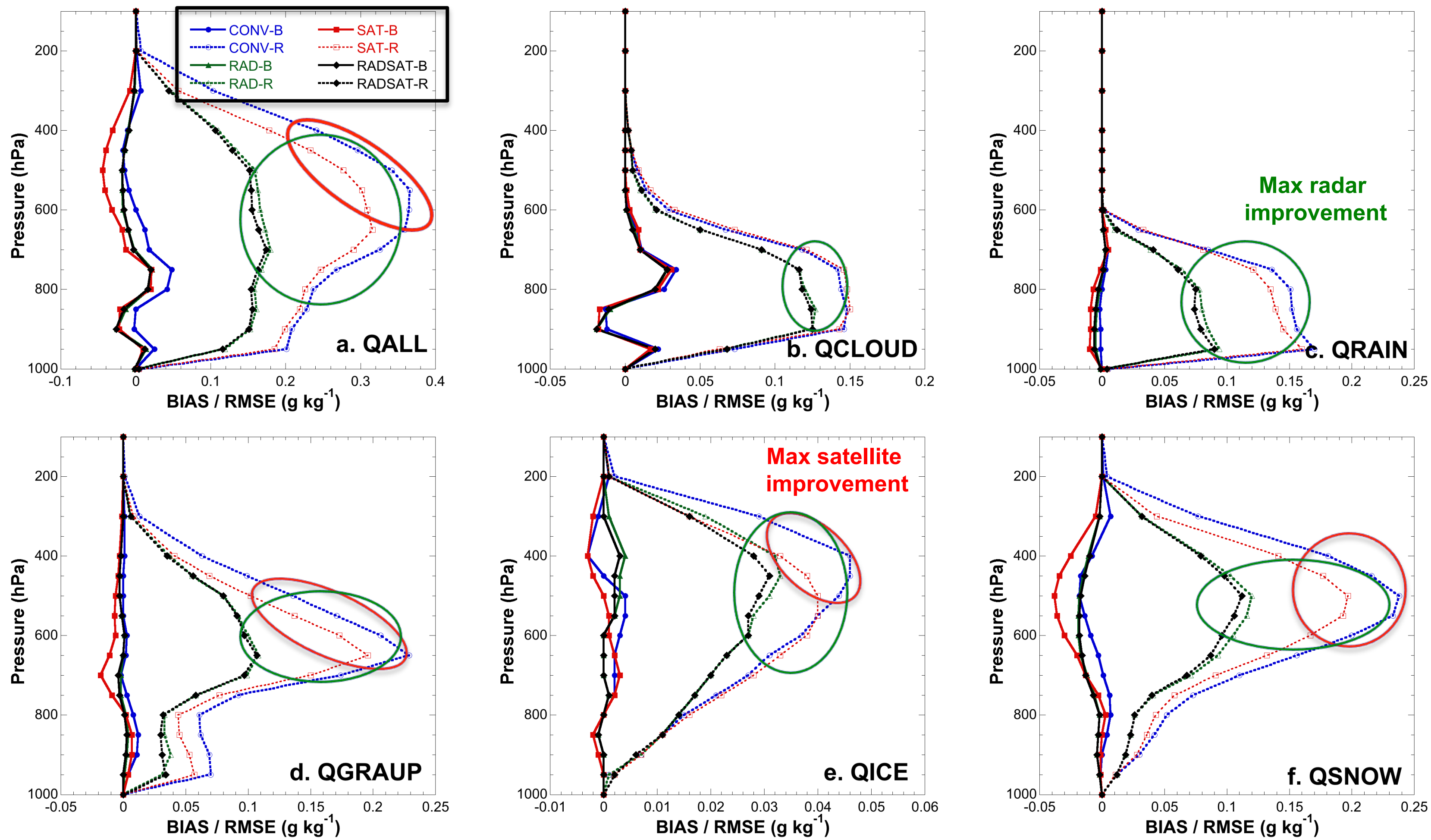


Total Cloud Water Mixing Ratio



- Both SAT and RAD cases contain lower RMSD compared to CONV for the QVAPOR and QALL variables
- RADSAT contains the most accurate analysis overall

Vertical Error Profiles



- Assimilating radar data has large impact on all variables
- Satellite data has positive impact on mid-upper tropospheric frozen hydrometeor variables (*QGRAUP*, *QICE*, *QSNOW*)

Current and Future Plans

- Convective scale OSSE study to examine the impact of satellite and radar observations during an idealized thunderstorm simulation

- Assimilate water vapor sensitive and cloud-affected SEVIRI infrared brightness temperatures in the 2.8-km resolution COSMO model using an ensemble Kalman filter assimilation system

- Perform a detailed analysis of the accuracy of the Community Radiative Transfer Model (CRTM) in cloudy scenes for microwave and infrared channels

- Use satellite observations to examine the ability of different cloud microphysical parameterization schemes to accurately simulate cloud properties