Assimilating simulated radar and satellite data using an OSSE experiment from 24 December 2009

Thomas Jones, Jason Otkin, David Stensrud, Kent Knopfmeier

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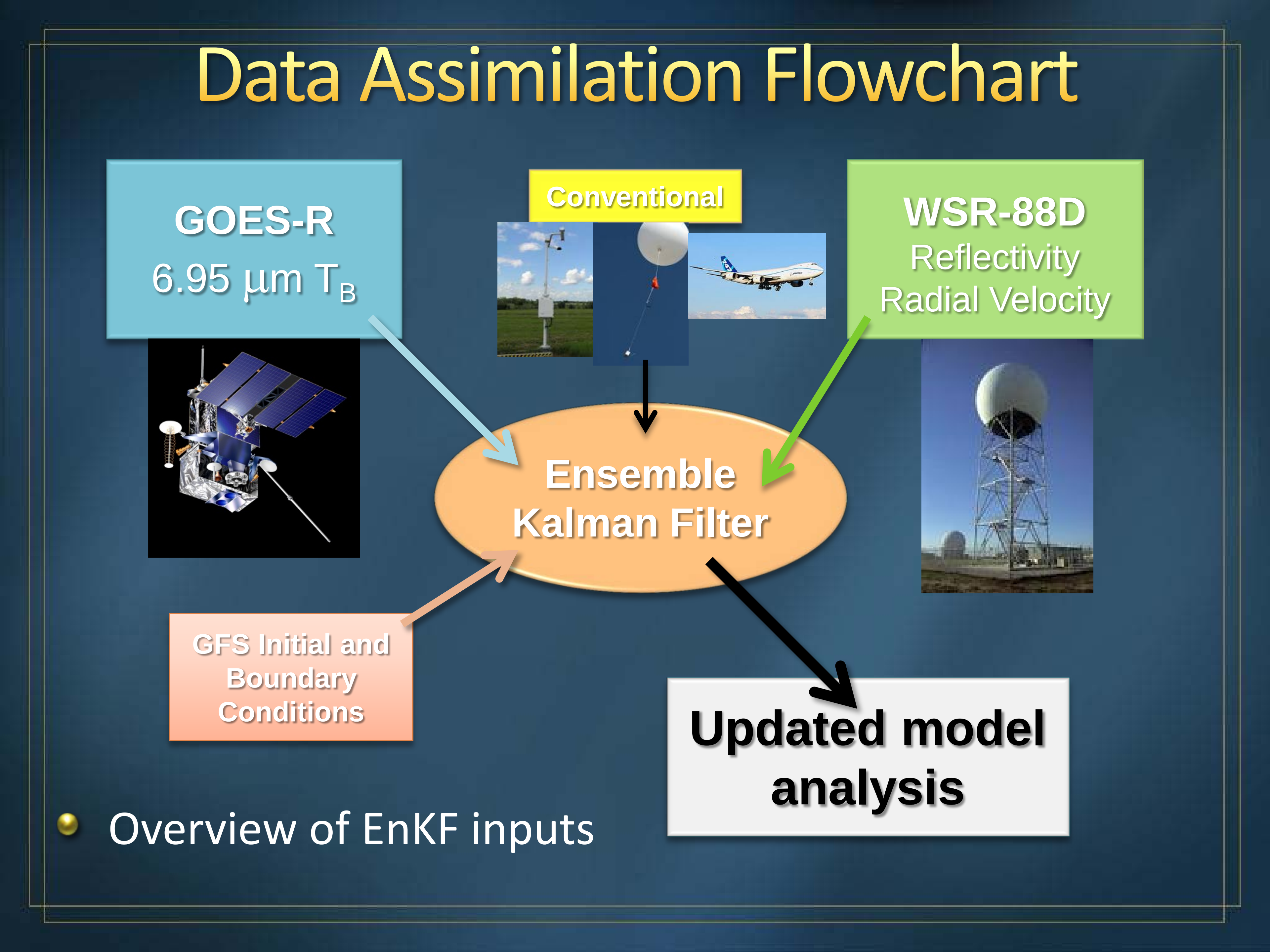
Objectives

- Assess the potential for assimilating remote sensing observations of moisture and cloud properties into a mesoscale NWP model
- Compare the effectiveness of assimilating *both* radar and satellite data
  - Each provides high resolution observations of the atmospheric state
  - Each is sensitive to different atmospheric variables
- Simulate observations using an Observing System Simulation Experiment (OSSE)
- Evaluate assimilation under cold-season conditions occurring on 24 December 2009
  - Focus on Southern and Central Plains

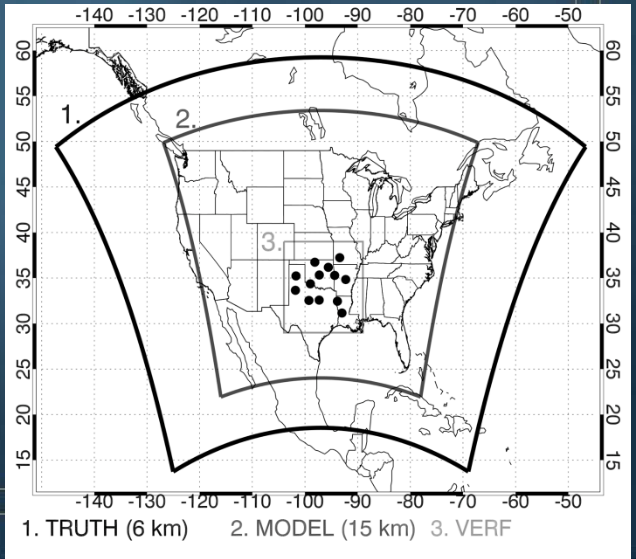

Data Assimilation Flowchart
GOES-R
6.95 µm T_B
Conventional
WSR-88D
Reflectivity
Radial Velocity
Ensemble Kalman Filter
GFS Initial and Boundary Conditions
Updated model analysis
Overview of EnKF inputs

Case Study Characteristics
24 December 2009

- Generated blizzard conditions over much of Central and Southern Plains
  - Over 1 foot of snow fell in many locations causing significant human impacts
- Mid-level trough provided forcing mechanism
- Strong cold air advection coupled with high atmospheric moisture content provided favorable environment for winter weather
- *Skillful forecasts require that these conditions be accurately analyzed*

Truth Simulation

- Generated using the Advanced Weather Research Forecasting (WRF-ARW) model (V3.3)
  - Initial and boundary conditions provided global 0.5° FNL analyses from NCEP
- Domain and Resolution:
  - 1100 x 750 grid points, CONUS domain (*1*)
  - 6 km horizontal resolution with 52 vertical levels
- Schemes:
  - Microphysics: WSM6
  - PBL: Yonsei
  - Land Surface: Noah
  - Cumulus Param: Kain Fritsch



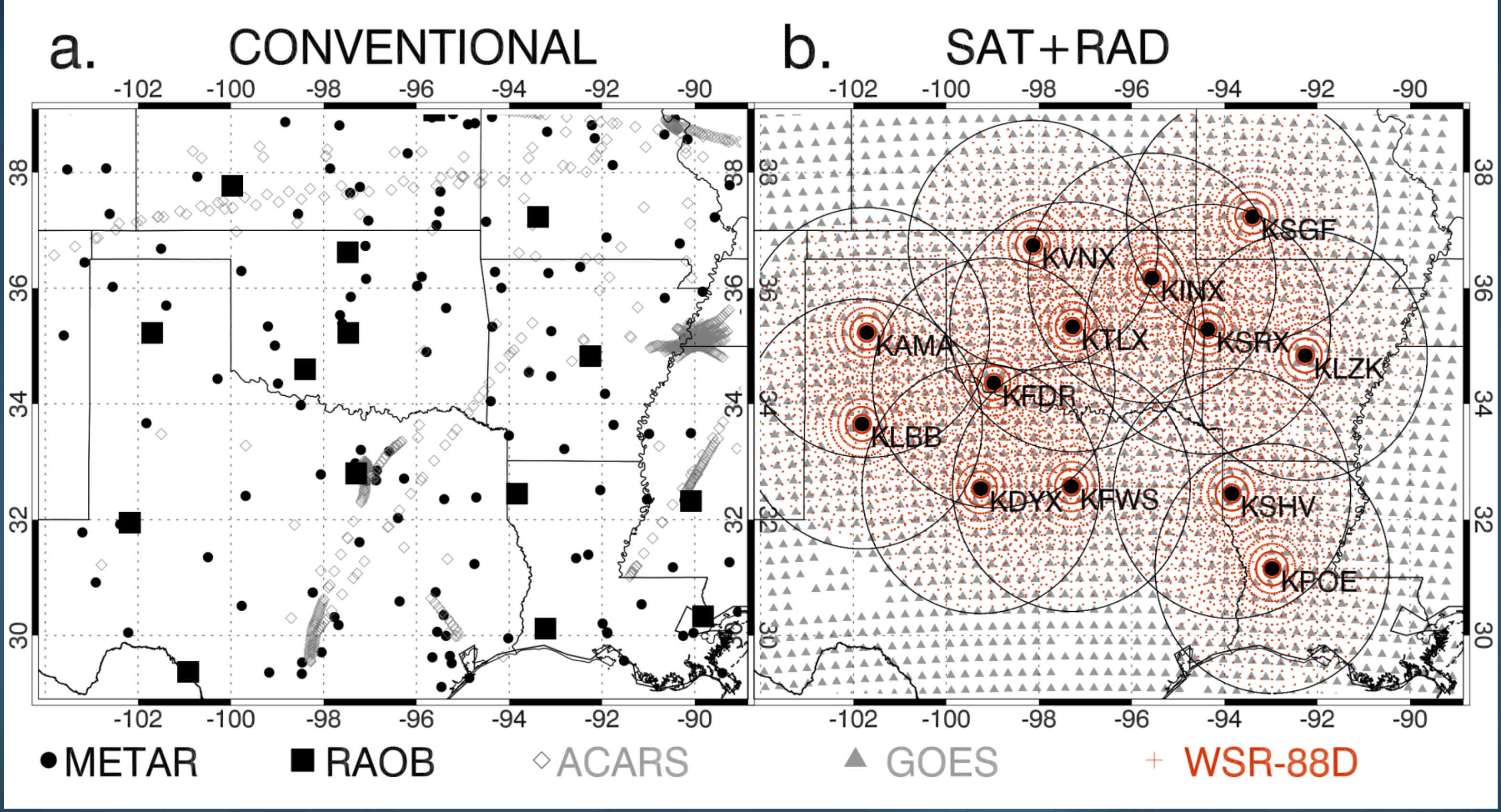
Simulated Observations

3 Sub-types

- **1. Conventional**
  - Temperature, humidity, wind and pressure from ASOS, RAOB, and ACARS
  - Observations are retrieved from actual locations of each sensor
- **2. Satellite**
  - GOES-R ABI 6.95 μm Brightness Temperature (T_B)
  - Sensitive to mid- and upper-tropospheric humidity and cloud cover
  - 30 km resolution
- **3. Radar**
  - WSR-88D Doppler radar reflectivity and radial velocity
  - From 13 Central and Southern Plains radars
  - 15 km gate spacing, 6° Azimuth spacing

Simulated Observations

1100 – 1200 UTC 24 December 2009



- Satellite and radar observations provide much higher resolution than exist for conventional observations
  - Radar is 3-D, and two variables (reflectivity and radial velocity)
  - Satellite is 2-D, and currently a single channel (6.95 μm)

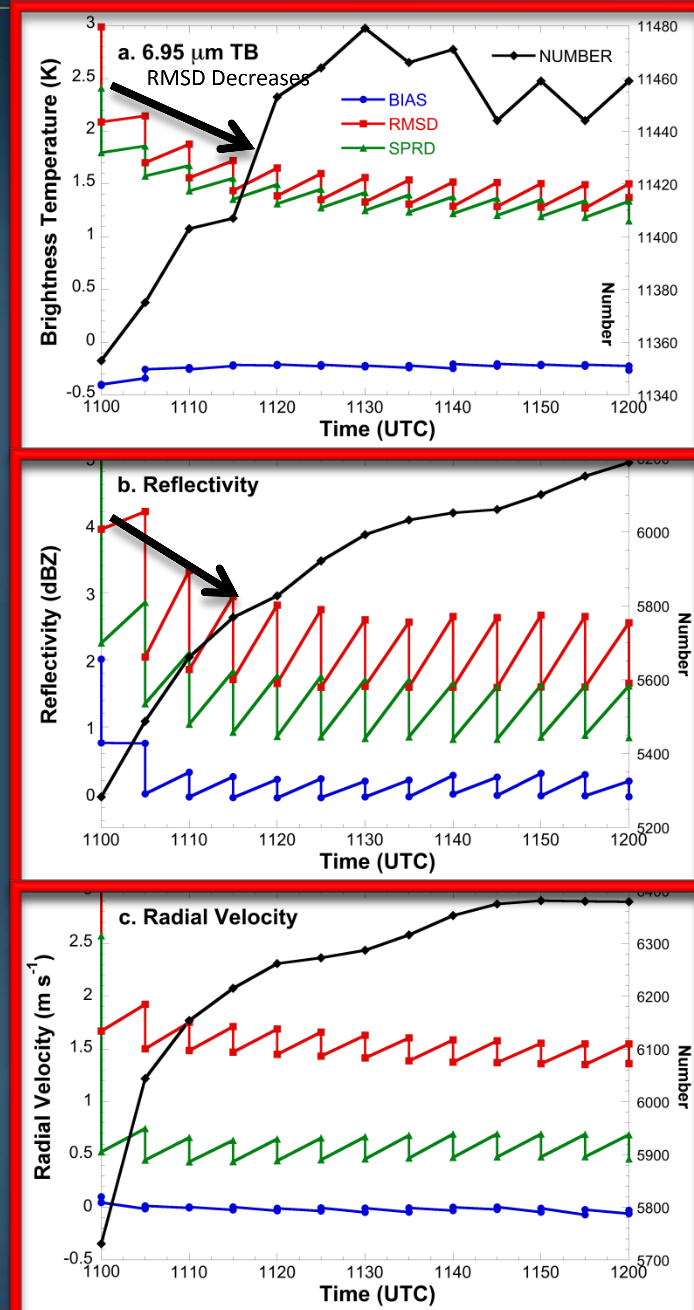
Model Characteristics

- **WRF-ARW (V3.3)**
  - Same physics options as Truth simulation except
  - Smaller mesoscale domain (*2*), 15 km resolution
- **Data Assimilation Research Testbed (DART)**
  - Use Ensemble Kalman Filter approach to assimilate all data types
  - 48 members with adaptive localization applied
- **Assimilation Period**
  - Conventional data from 0900 – 1100 UTC at 5 min intervals
  - Conventional + remote sensing observations from 1100 - 1200 UTC at 5 min intervals
  - Final analysis time occurs at 1200 UTC with forecasts generated thereafter and output at 15 min intervals
- **Assimilation Experiments**
  - 1. **CONV** Conventional observations only
  - 2. **SAT** Conventional + satellite T_B
  - 3. **RAD** Conventional + radar reflectivity and velocity
  - 4. **RADSAT** Conventional + satellite + radar

Observation Diagnostics

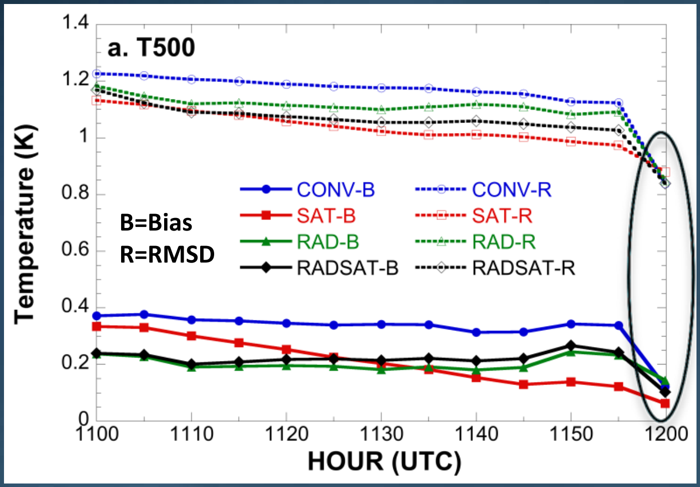
Prior and Posterior fields compared against obs.

- **Satellite 6.95 μm T_B**
  - RMSD decreases after each assimilation cycle between prior and posterior analyses and over time in general
  - Ensemble spread closely follows RMSD
  - Bias is slightly negative, but small in magnitude
- **Radar Reflectivity**
  - Sample size increases as a function of time as fewer outliers are rejected (obs. and analysis come into better agreement)
  - RMSD decreases rapidly over first few cycles, stabilizing at 1.8 dBZ in posterior analysis thereafter
  - Ensemble spread is somewhat lower than RMSD
  - Bias is adjusted to near zero at each assimilation cycle
- **Radar Radial Velocity**
  - Similar characteristics to reflectivity
  - Ensemble spread is lower than RMSD by 1.0 ms^{-1}
  - Bias consistently near 0 ms^{-1}

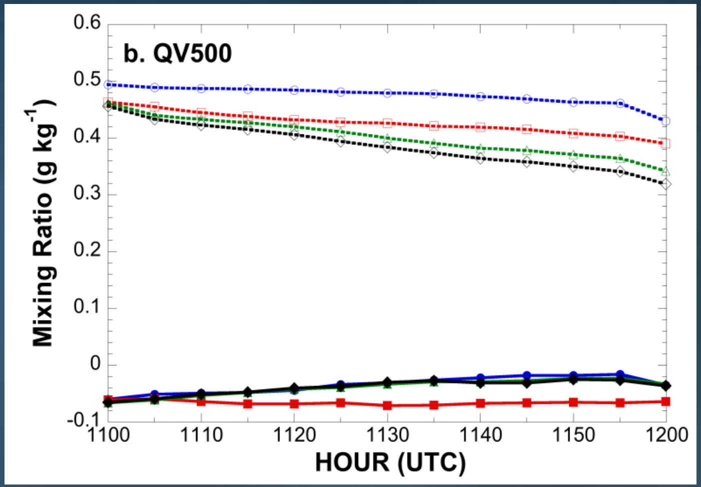


Time-series of bias (**B**) and RMSD (**R**) at 500 hPa

Compared to Truth between 1100 – 1200 UTC, 5 minute cycles

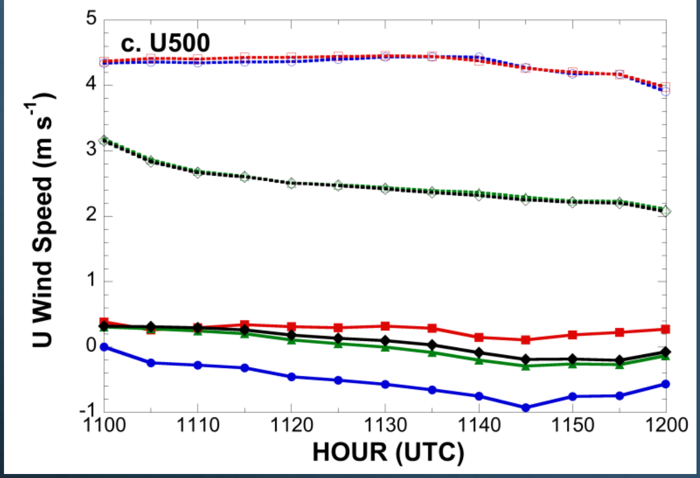


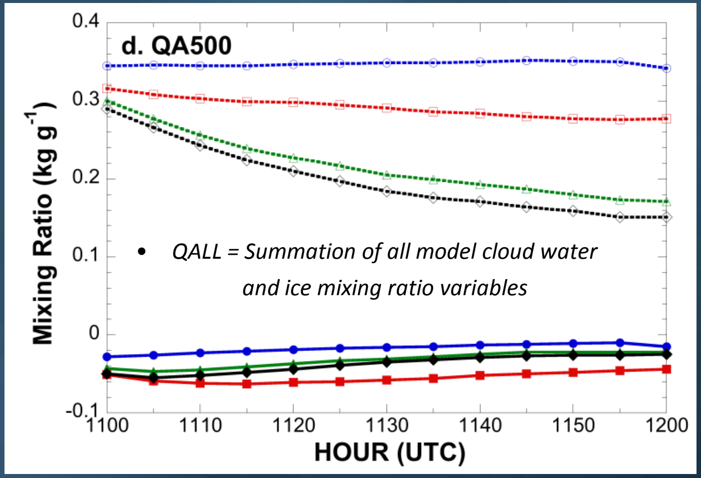
RAOB Assimilation



- **SAT** reduces B & R consistently until 1155 UTC, **RAD** to a lesser degree
- Assimilation of simulated RAOBs makes larger impact at 1200 UTC
- Overwhelms both radar and satellite observations despite limited sample size

- Both **SAT** and **RAD** reduce B & R by similar amounts
- **SAT** retains a slight dry bias com
- Lowest RMSD produced by **RADSAT**



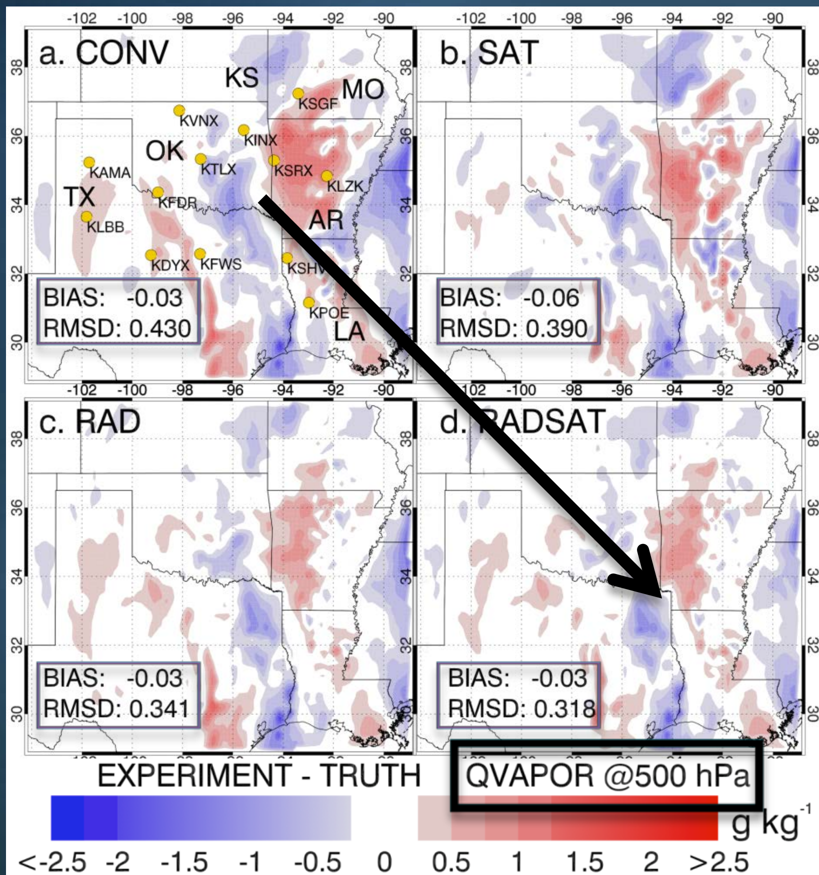


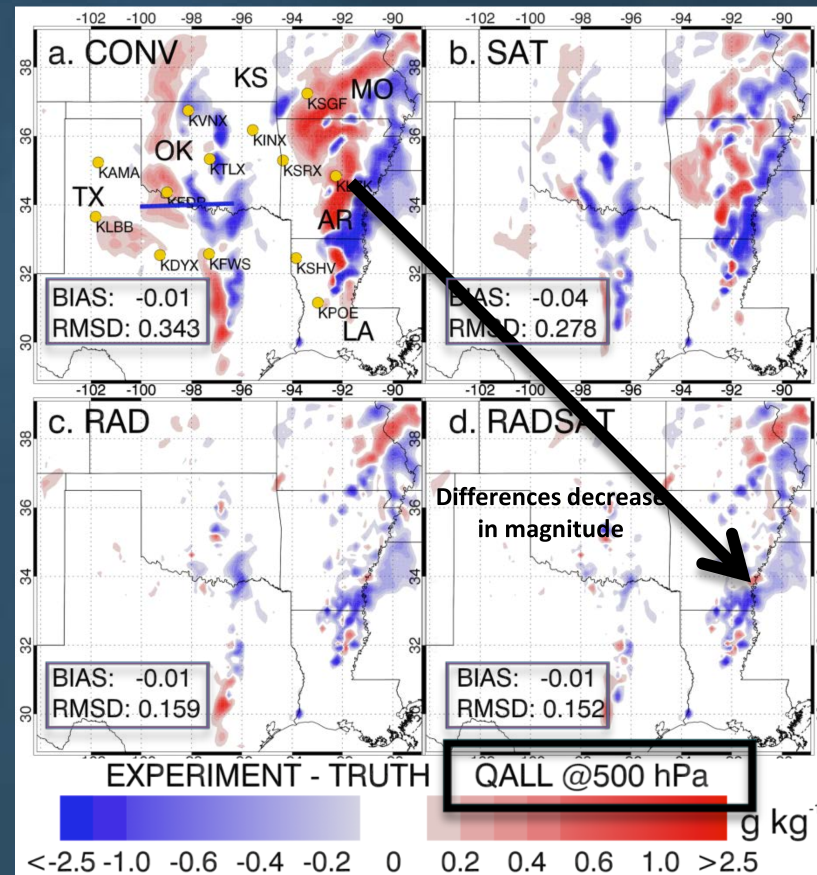
- **SAT** has little impact on RMSD, slight increase in bias
- Assimilating radial velocity data significantly reduces RMSD (**RAD**, **RADSAT**)

- **RAD** consistently reduces RMSD as a function of time
- **SAT** does too, but to a lesser degree
- Combination of radar and satellite D.A. performs best (**RADSAT**)

Difference Plots (Exp. – Truth)

1200 UTC 24 December, 500 hPa

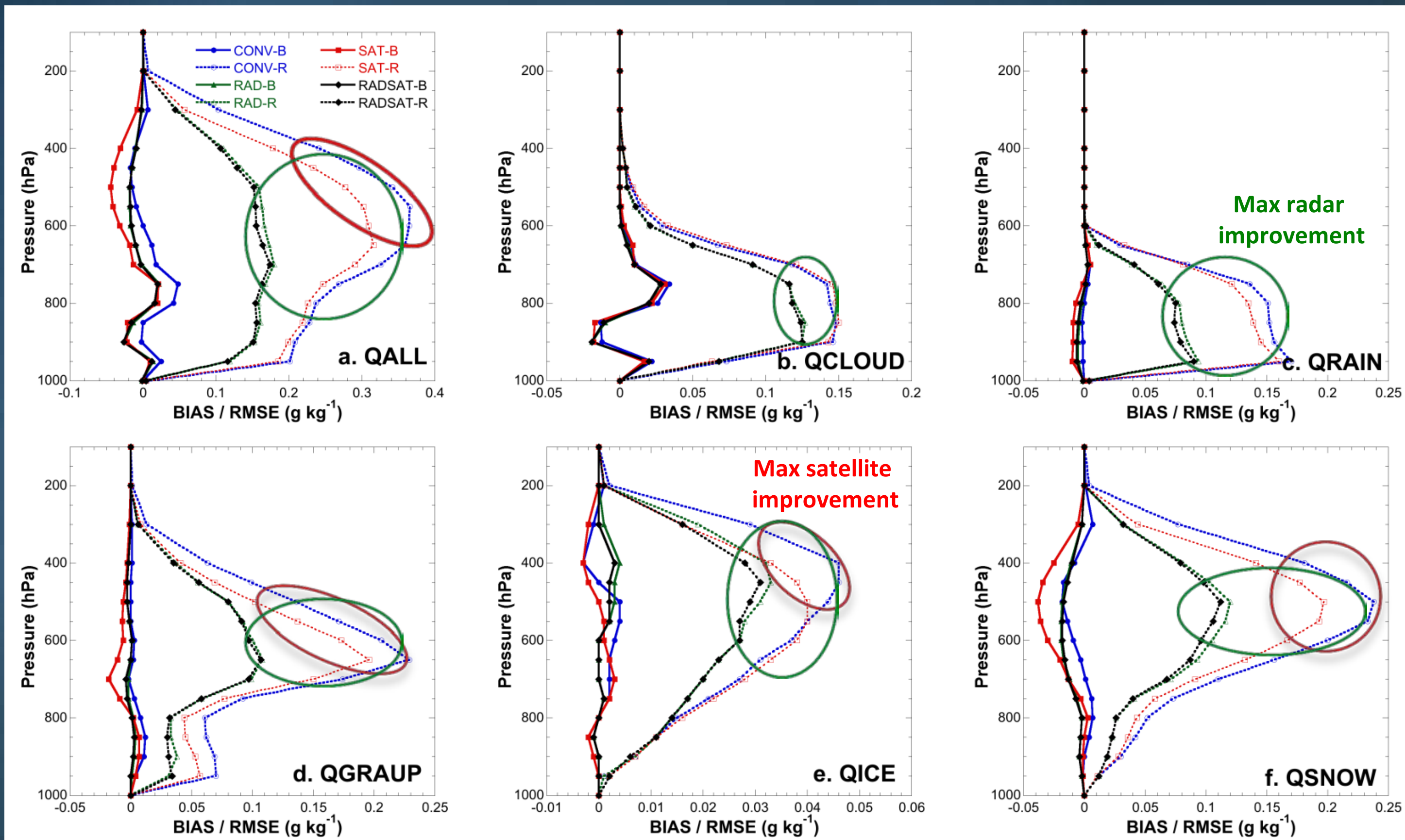




- Both **SAT** and **RAD** experiments lower RMSD compared to **CONV** for *QVAPOR* and *QALL*
- **RADSAT** performs best for both variables

Vertical Profiles

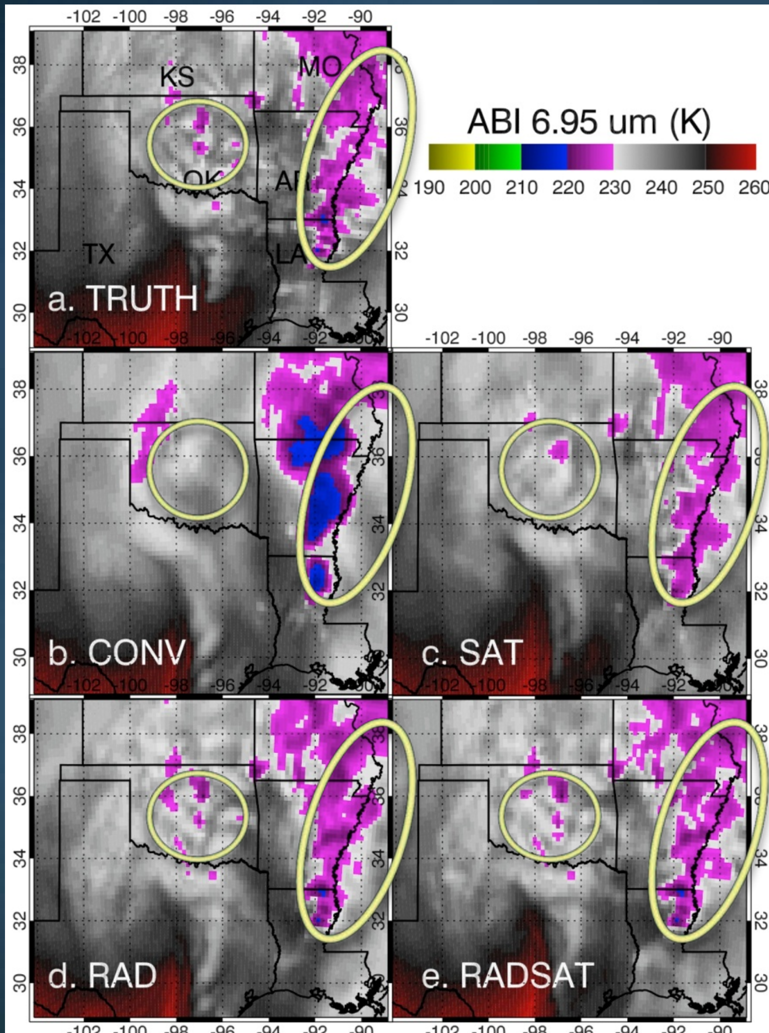
Bias and RMSD for cloud microphysical variables as a function of height

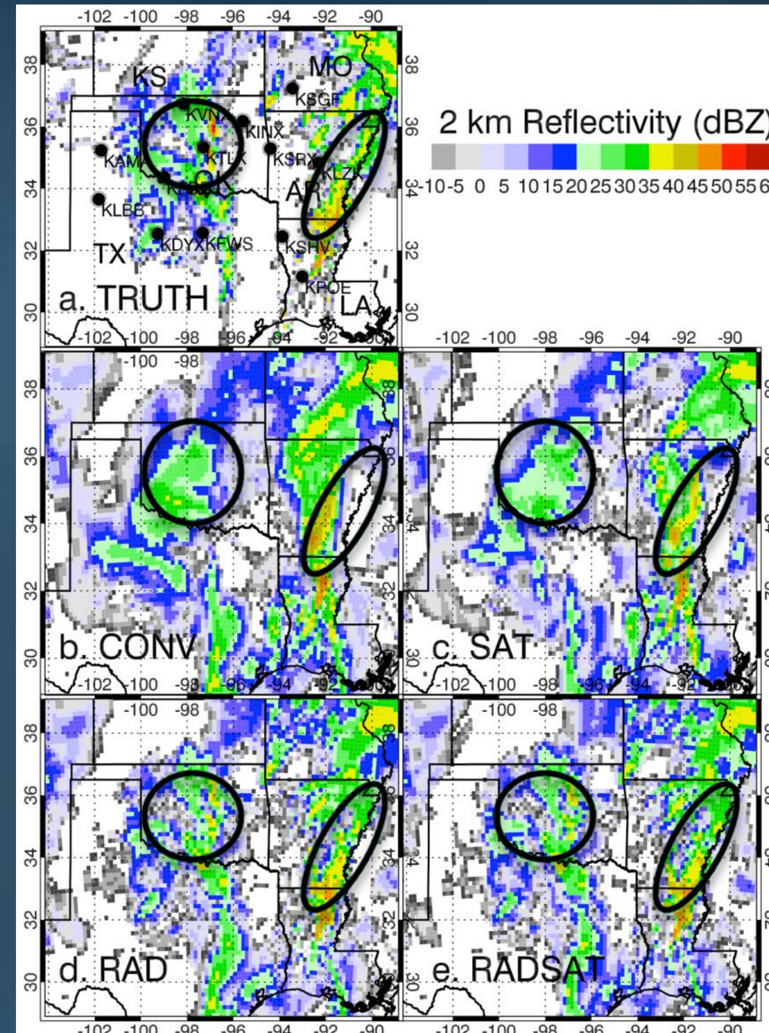


- Assimilating radar data has large impact on all variables
  - Satellite data has positive impact on mid-upper tropospheric frozen hydrometeor variables (*QGRAUP*, *QICE*, *QSNOW*)

Simulated Satellite and Radar Analysis

1200 UTC





- CONV too cold, loses too many fine scale structures
- SAT, RAD, RADSAT all improve analysis relative to Truth
- SAT reduces cold bias, while RAD adds the finer scale structures

- CONV does not capture finer scale features in OK. Also too far west with AR convection
- Radar data has the getter impact on 2 km reflectivity
- Impact of satellite data is larger at higher levels (not shown)

Conclusions

- Both satellite and radar data proved effective at reducing model error compared to a conventional data-only run
  - Reduction in error occurs over multiple assimilation cycles
- **Satellite data impacts:**
  - Mid- and upper- tropospheric humidity
  - Frozen cloud hydrometeors
- **Radar impacts:**
  - Wind fields (radial velocity)
  - Cloud water and cloud ice at all levels
- *Combining radar and satellite data into a single experiment generally produced the most skillful model analysis at 1200 UTC*
- Impacts on downstream forecasts are currently being analyzed

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Questions?

Outline

- Objectives
  - Assimilate *both* satellite and radar data using ensemble Kalman filter approach
- Case Study Characteristics
  - 24 December 2009
- Truth Simulation
- Model & Data Assimilation
- Experiment Differences
  - Conventional, satellite, and radar data
- Conclusions