Simultaneous Assimilation of Polarimetric Radar and All-Sky Satellite Observations for Ensemble Convection Forecasts

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Introduction

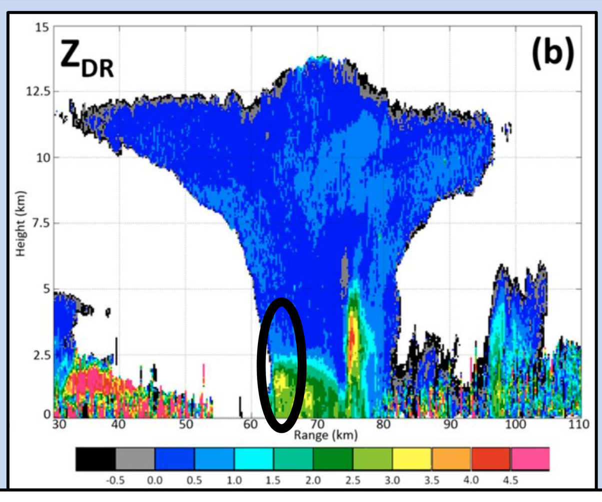
- Increase in ensemble data assimilation (DA) for convective-scale forecasts
- High spatiotemporal resolution of radar and satellite data
- Need to better leverage these data

<u>Polarimetric Radar Data</u>

- Z_{DR} columns – vertical protrusions of positive values of differential reflectivity above the melting level in an updraft
- Improve characterization of updrafts for severe hazards

<u>All-Sky Satellite Data</u>

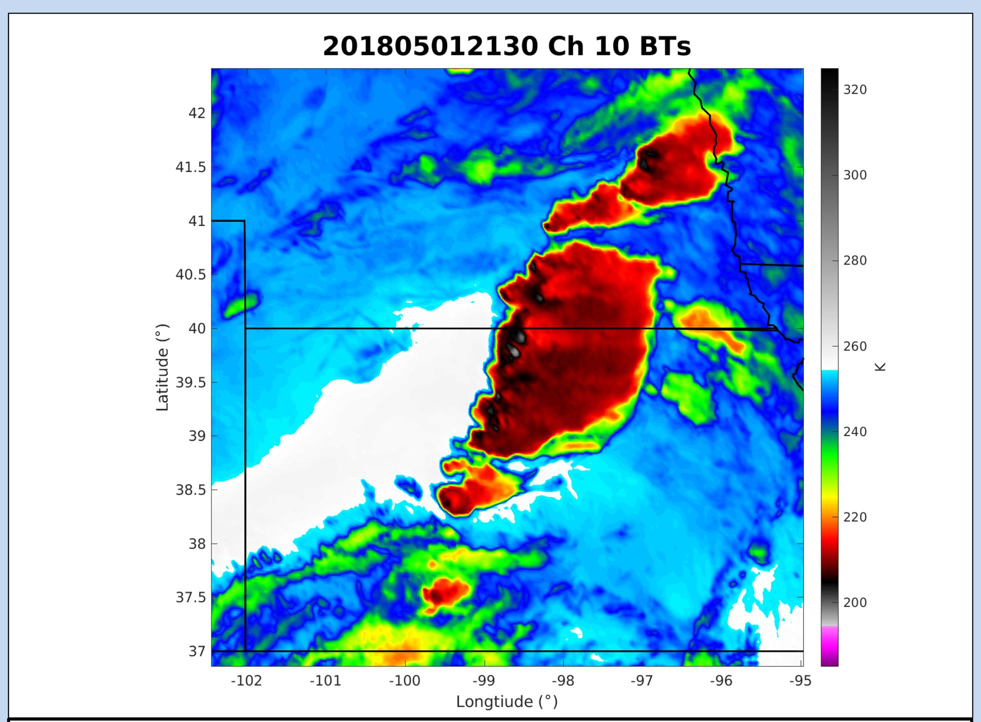
- All-sky = clear and cloudy radiances
- Observe clouds prior to convection
- Improve prediction of ongoing convection
- **How can radar and satellite observations improve convection forecasts when used simultaneously?**



Example of a Z_{DR} column (solid black circle). Courtesy of Kumjian et al. (2014)

Numerical Model and Data Assimilation

- HRRR configuration of WRF-ARW v3.8.1
- National Severe Storms Laboratory (NSSL) double-moment microphysics scheme
- 200 x 200 x 51 levels, 3 km horiz. spacing
- Penn State University (PSU) Ensemble Kalman filter (EnKF)
- 6 hour forecast from **1200-1800** UTC
- **Case Study: 1 May 2018 in Great Plains**
- Data assimilation every 10 minutes from **1800-2200** UTC
- Free forecast from **2200-0000** UTC
- 'CONV' – conventional only
- 'ZDR' – conventional, Z_{DR}
- 'SAT' – conventional, BTs
- 'ALL' – conventional, Z_{DR}, BTs



GOES-16 ABI infrared brightness temperatures. This plot is also the model domain.

Radar Observations

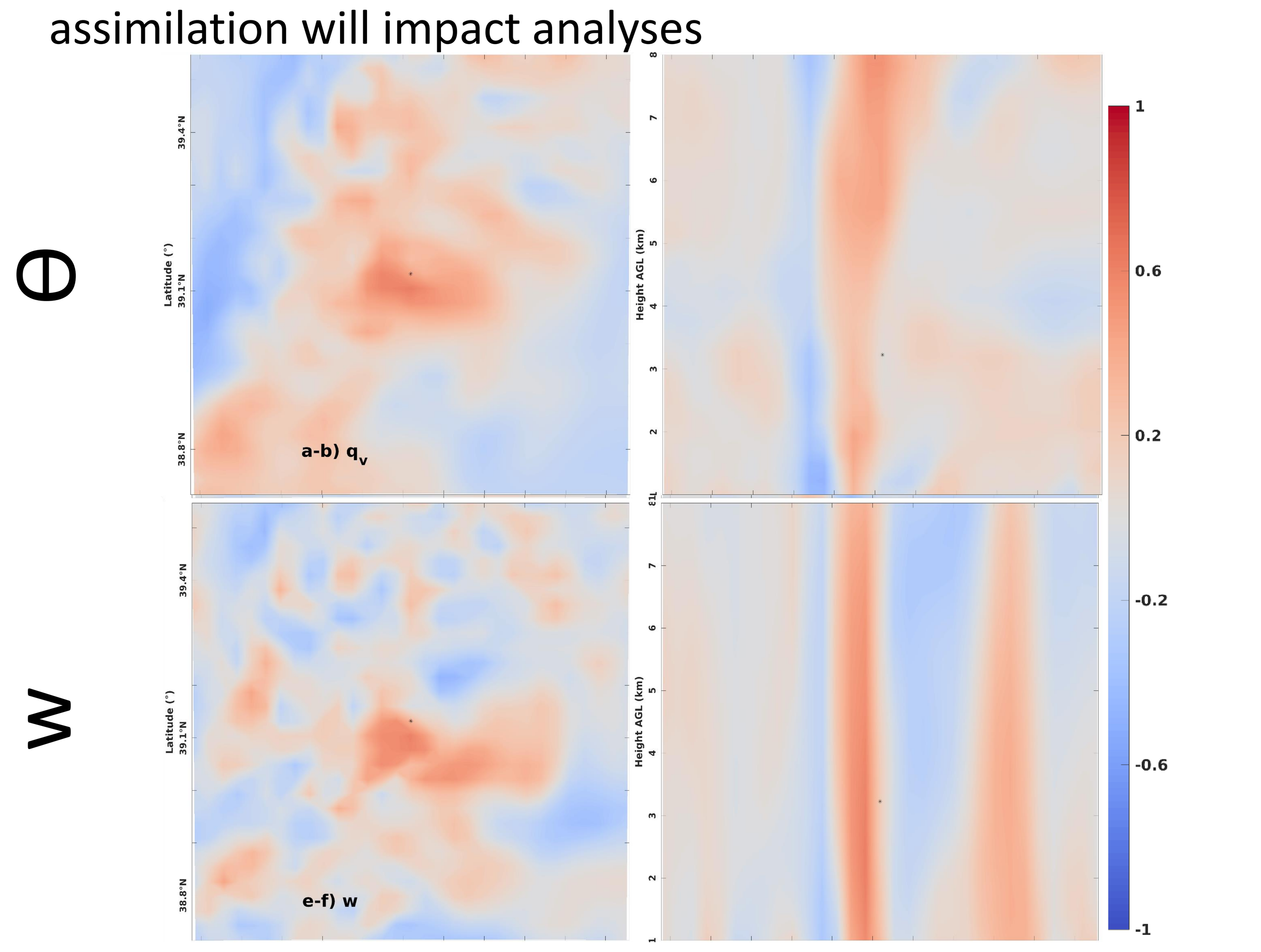
- Superobservations (SO) approach is employed
- Group observations into 10-min bins that are ~6 km apart

<u>Observation Operator</u>

- Zhang et al. (2021) forward operator
- Assumes spherical hydrometeors, accounts for % of melting
- Dependent on fitted coefficients and hydrometeor diameters
- $Z_{dr} \approx 1.019 - 0.143D_m + 0.3165{D_m}^2 + 0.06498{D_m}^3 + 0.004163{D_m}^4$ for rain
- $Z_{dr}(x) \approx a_{d0}(\gamma_x) + a_{d1}(\gamma_x)D_m + a_{d1}(\gamma_x){D_m}^2$ for non-rain

Z_{DR} Correlation Structures

- Z_{DR} at one point and model state variables – shows how EnKF assimilation will impact analyses

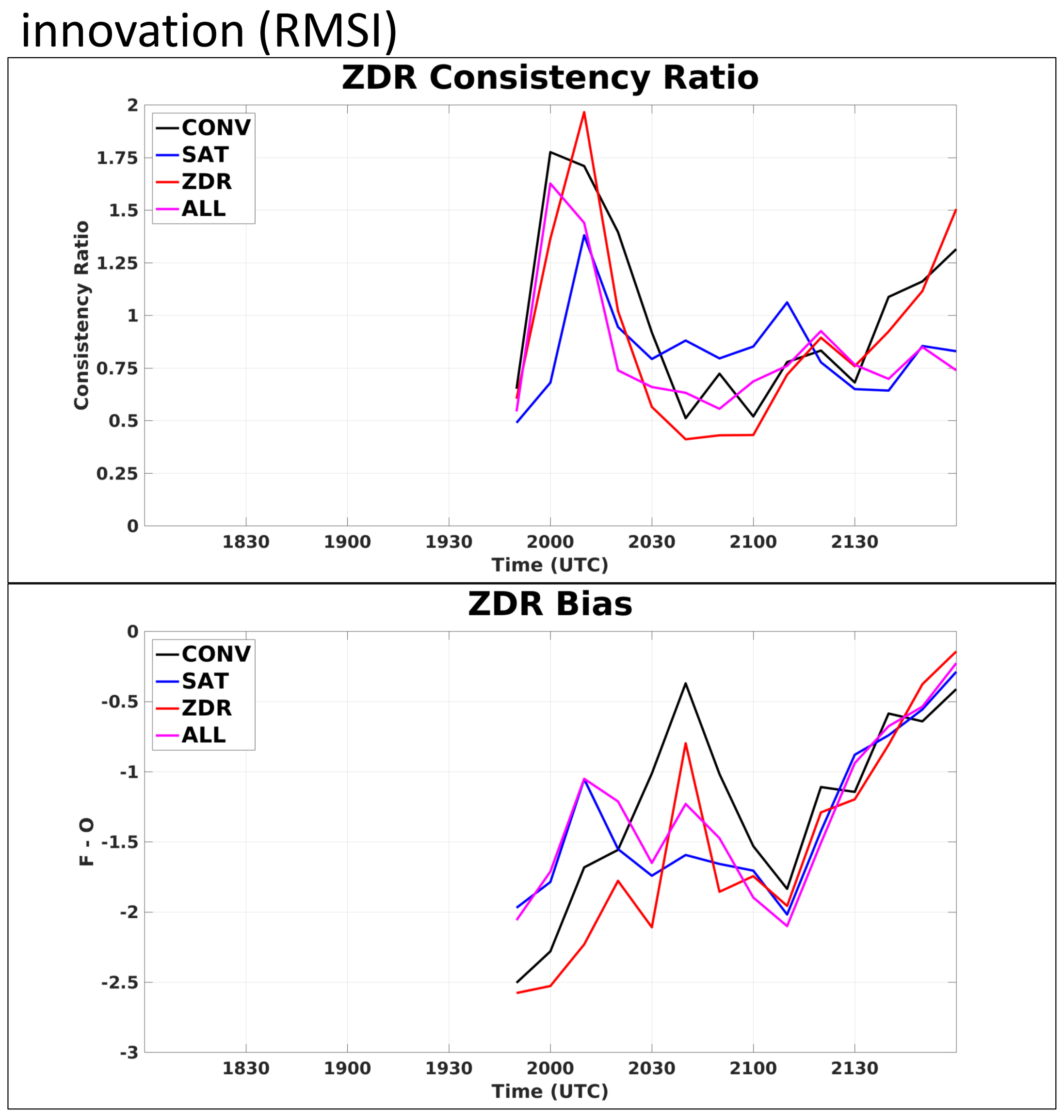


Satellite Observations

- GOES-16 Advanced Baseline Imager (ABI) channel 10 brightness temps – sensitive to low-level water vapor
- Adaptive Background Error Inflation (ABEI) and Adaptive Observation Error Inflation (AOEI) used
- Community Radiative Transfer Model (CRTM) is the forward operator

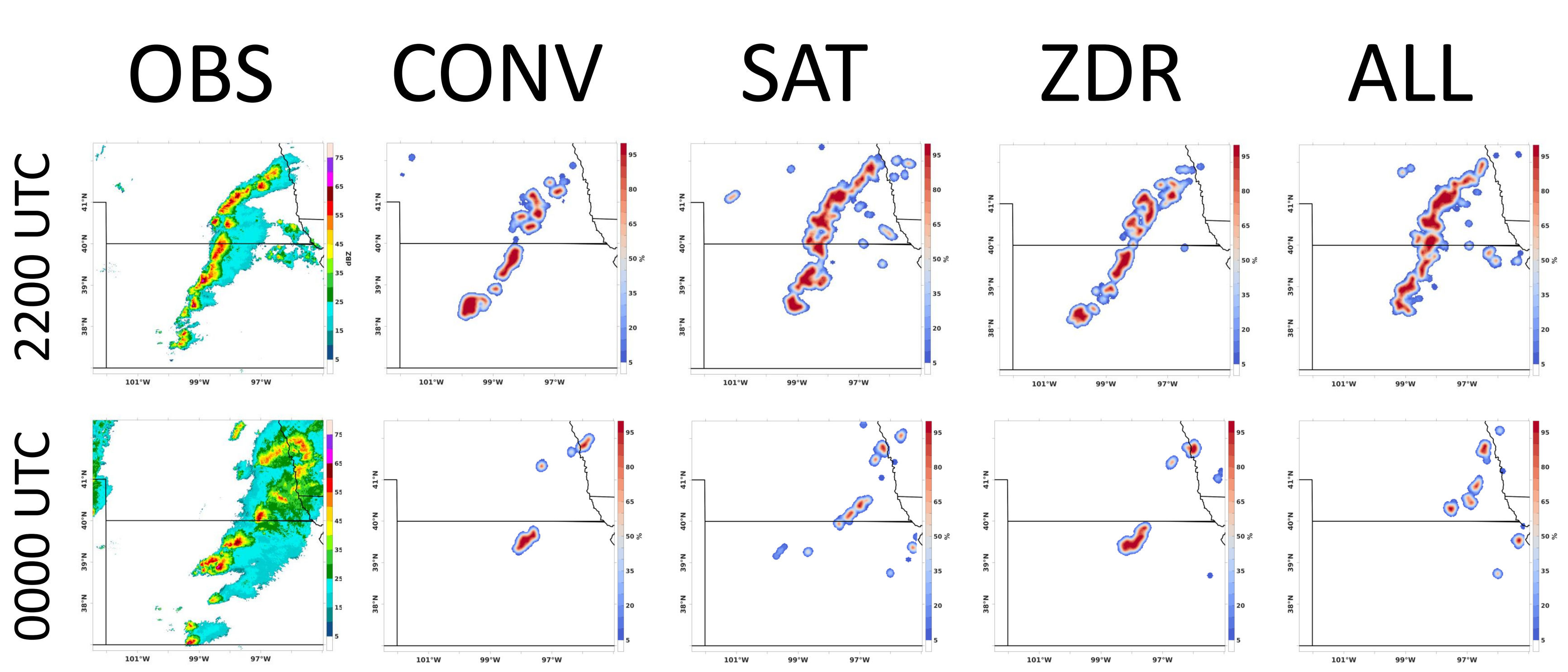
Diagnostics

- Consistency ratio: total spread/root mean square innovation (RMSI)

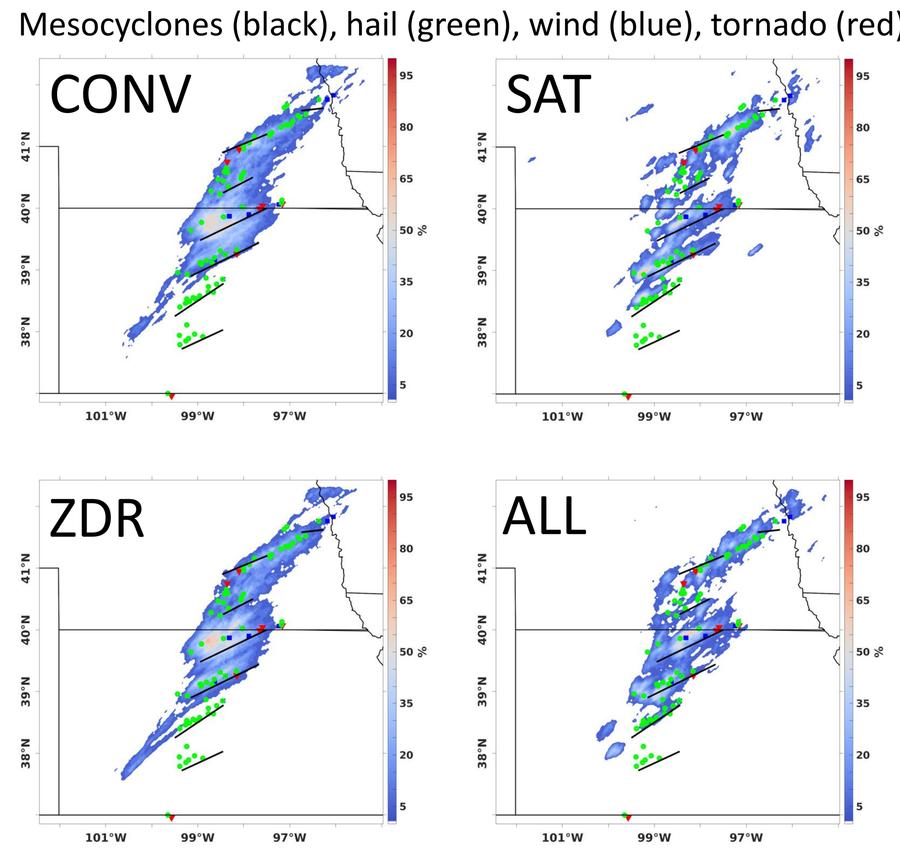


Assimilation and Forecast Verification

- Neighborhood Ensemble Probabilities: 9-km circular neighborhood; probability of reflectivity (Z_H) > 35 dBZ compared against observed reflectivity



- Updraft helicity: product of vertical vorticity and vertical velocity
- 2000-0000 UTC temporal composites of ensemble prob of updraft helicity > 30 m^2s^{-2}
- Mesocyclones (black), hail (green), wind (blue), tornado (red)



Conclusions

- Correlations consistent with stronger updraft features
- Simulated Z_{DR} shows improvement during assimilation period
- ALL performs best for placement of convection and supercells
- Z_{DR} observations improve forecasts in Nebraska after DA
- SAT and ALL show better delineation of updraft helicity tracks
- Satellite data introduces spurious convection
- Southernmost convection challenging in all the experiments

References

Carlin, J. T., J. Gao, J. C. Snyder, and A. V. Ryzhkov, 2017: Assimilation of Z_{DR} columns for improving the spinup and forecast of convective stors in storm-scale models: Proof of concept experiments. *Mon. Wea. Rev.*, **145**, 5033-5057, https://doi.org/10.1175/MWR-D-17-0103.1.

Eure, K. C., and Coauthors, 2023: Simultaneous assimilation of planetary boundary layer observations from radar and all-sky satellite observations to improve forecasts of convection initiation. *Mon. Wea. Rev.*, **151,** 795-813, https://doi.org/10.1175/MWR-D-22-0188.1.

Evensen, G., 1994: Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte Carlo methods to forecast error statistics. *J. Geophys. Res.*, **99**, 10143-10162, https://doi.org/10.1029/94JC00572.

Kumjian, M. R., 2014: The anatomy and physics of Z_{DR} columns: Investigating a polarimetric radar signature with a spectral bin microphysical model. *J. Appl. Meteorol. Climatol.*, **53**, 1820-1843, https://doi.org/10.1175/JAMC-D-13-0354.1.

Putnam, B., M. Xue, Y. Jung, N. Smook, and G. Zhang, 2019: Ensemble Kalman filter assimilation of polarimetric radar observations for the 20 May 2013 Oklahoma tornadic supercell case. *Mon. Wea. Rev.*, **147**, 2511-2533, https://doi.org/10.1175/MWR-D-18-0251.1.

Zhang, F., Y. Weng, J. A. Sippel, Z. Meng, and C. H. Bishop, 2009: Cloud-resolving hurricane initialization and prediction through assimilation of Doppler radar observations with an ensemble Kalman filter. *Mon. Wea. Rev.*, **137**, 2105-2125, https://doi.org/10.1175/2009MWR2645.1.

Zhang, Y., F. Zhang, and D. J. Stensrud, 2019: Simultaneous assimilation of radar and all-sky satellite infrared radiance observations for convection-allowing ensemble analysis and prediction of severe thunderstorms. *Mon. Wea. Rev.*, **147**, 4389-4409, https://doi.org/10.1175/MWR-D-19-0163.1.

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