Development and research of assimilating GOES-16 ABI all-sky radiance observations in FV3-LAM using hybrid EnVar

Samuel K. Degelia and Xuguang Wang

Mesoscale data Assimilation and Predictability (MAP) Laboratory
University of Oklahoma, Norman, OK

Acknowledgements: Yongming Wang, Nicholas Gasperoni, Xu Lu, and Aaron Johnson

Unifying Innovations in Forecast Capabilities Workshop
UFS Application Team - Short Range Weather
Wednesday, 20 July 2022

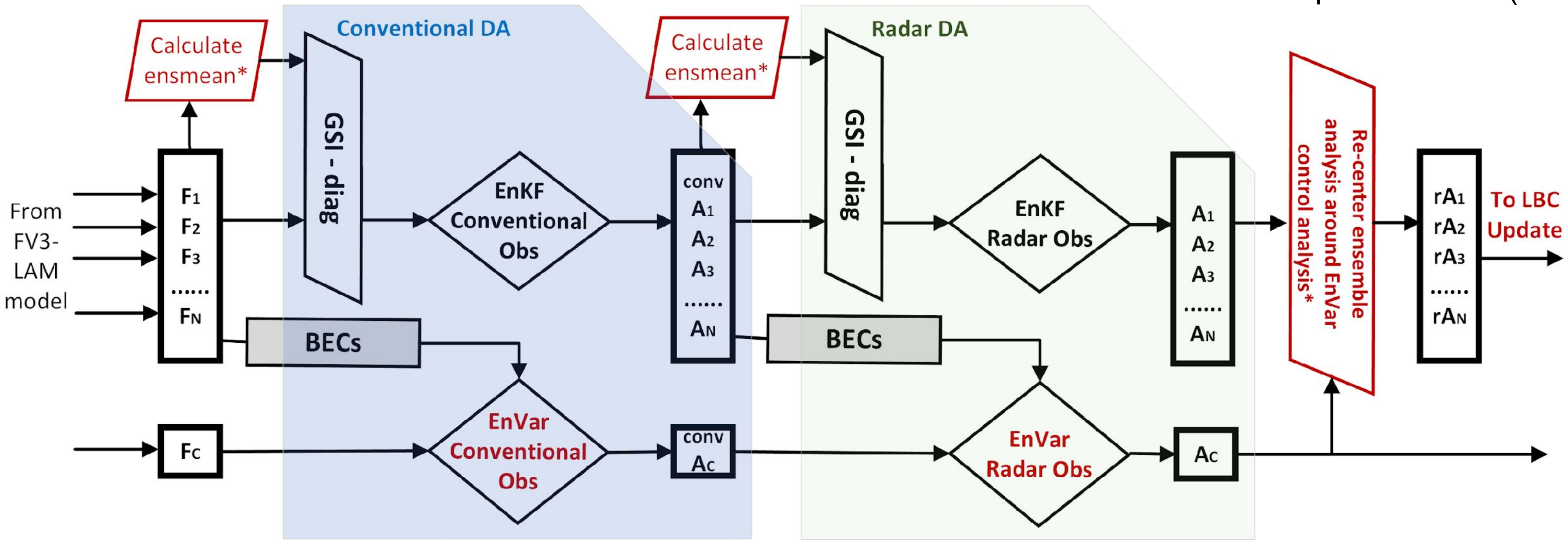
Background and objectives

- All-sky infrared radiance observations from the GOES-16 Advanced Baseline Imager (ABI) provide high-resolution information about water vapor and cloud hydrometeors
- These observations are complementary to radar reflectivity such that they can provide information in non-precipitating regions
- Additional development and research of assimilating ABI all-sky radiances are needed in convection-allowing models for operational RRFS implementation
- **The primary goal of this UFS-R2O project is to develop and test the GOES ABI all-sky radiance data assimilation for FV3-LAM hybrid EnVar data assimilation system toward improving Rapid Refresh Forecast System (RRFS) analyses and forecasts**
- Specific objectives include:
  - Part I: Develop and test ABI all-sky radiance DA capabilities in the RRFS hybrid EnVar system
  - Part II: Evaluate the impact of assimilating ABI all-sky radiances for multiple severe weather events

Part I: Development and testing of GOES16 ABI all-sky radiance DA capabilities in the RRFS hybrid EnVar system

Fully-cycled EnVar system for FV3-LAM (see talk by Tsunghan Li* from OU MAP in the same session)

From Gasperoni* et al. (2022)

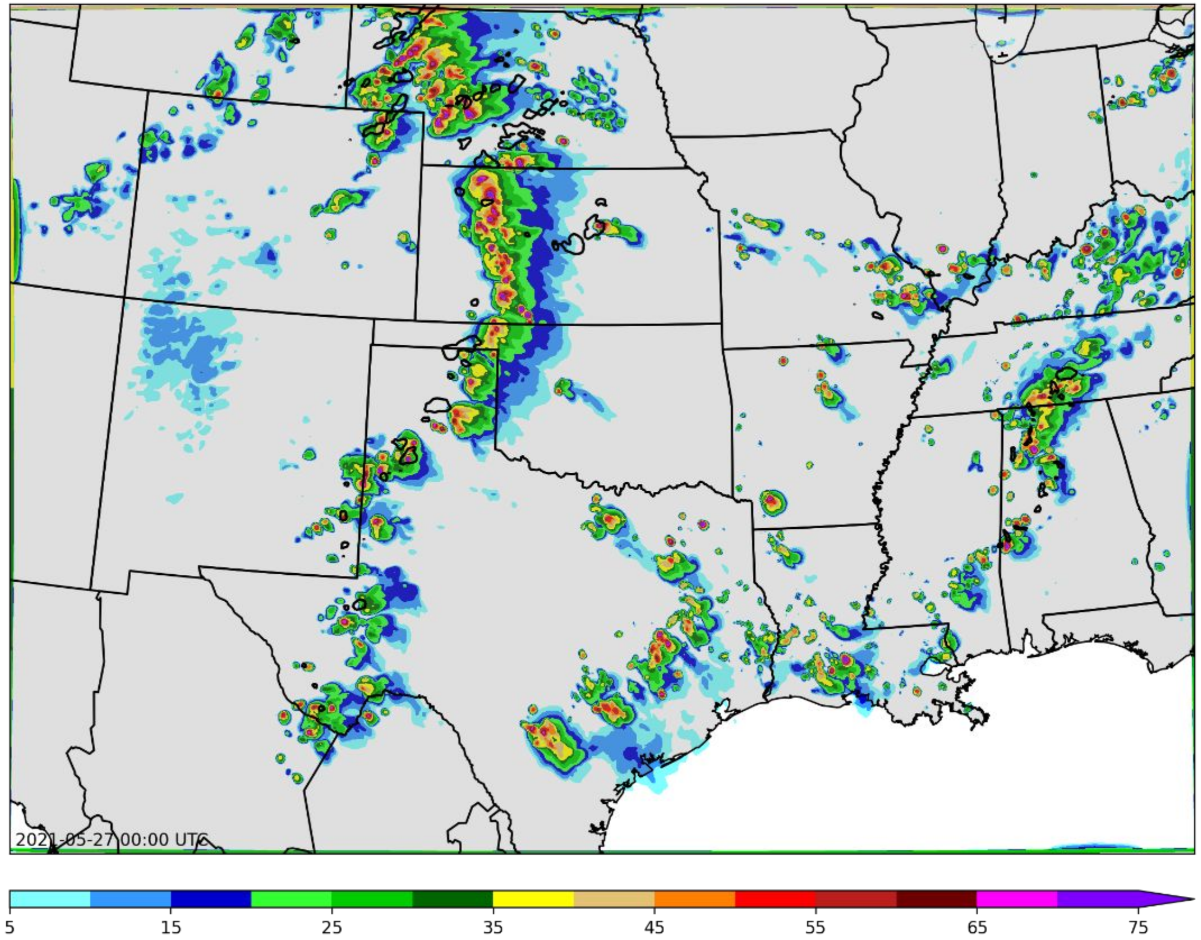


- First attempt for cycled assimilation of both synoptic/mesoscale and storm-scale observations with EnVar for FV3-LAM (Gasperoni* et al. 2022)
- Direct radar reflectivity assimilation follows the approach of Wang* and Wang (2017) and Wang* and Wang (2021) from OU MAP

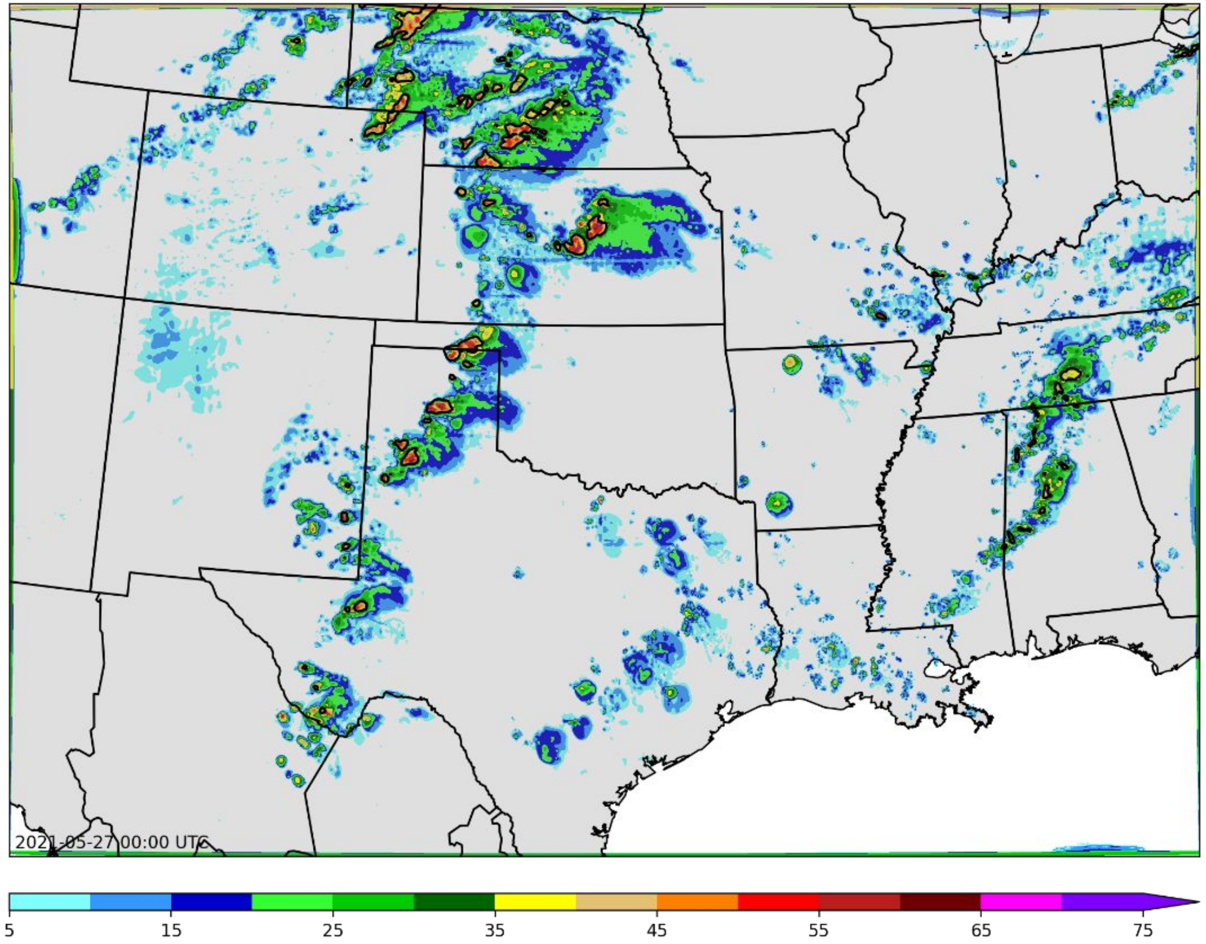
*denote OU MAP student or early career scientist

Testing of the newly developed cycled hybrid EnVar FV3-LAM DA system for direct assimilation of radar observations

NORADAR



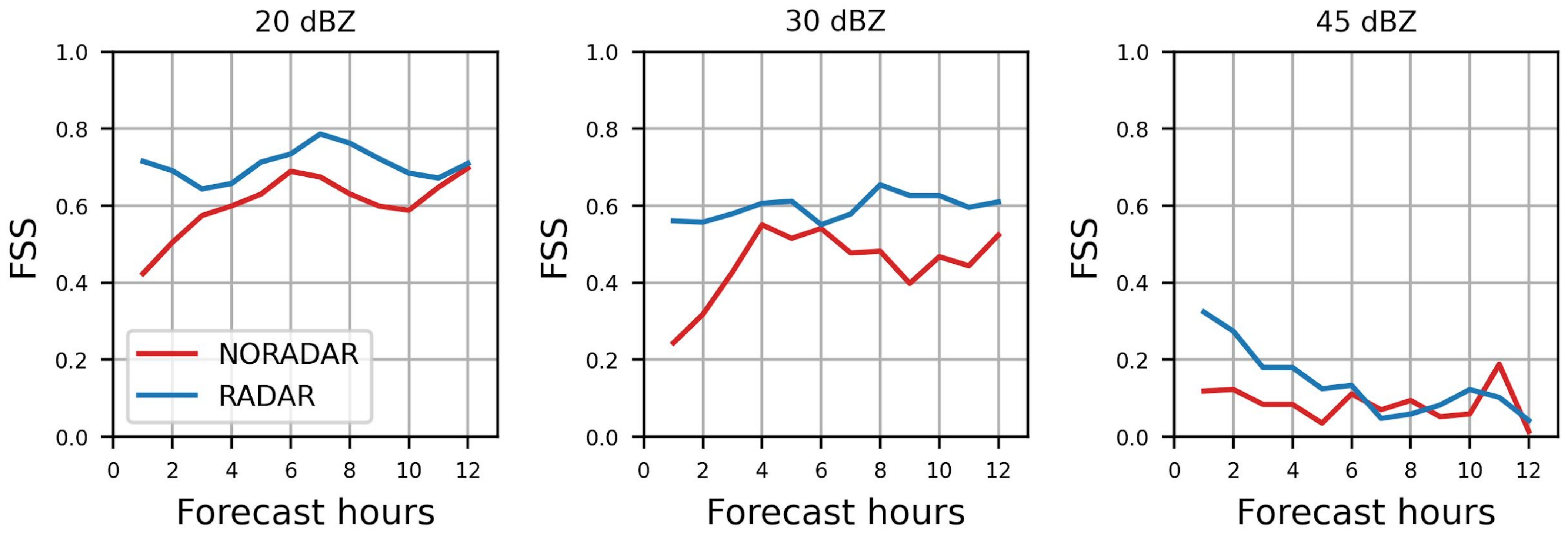
RADAR



00 UTC (analysis) for 27 May 2021

Testing of the newly developed cycled hybrid EnVar FV3-LAM DA system for direct assimilation of radar observations

27 May 2021 case



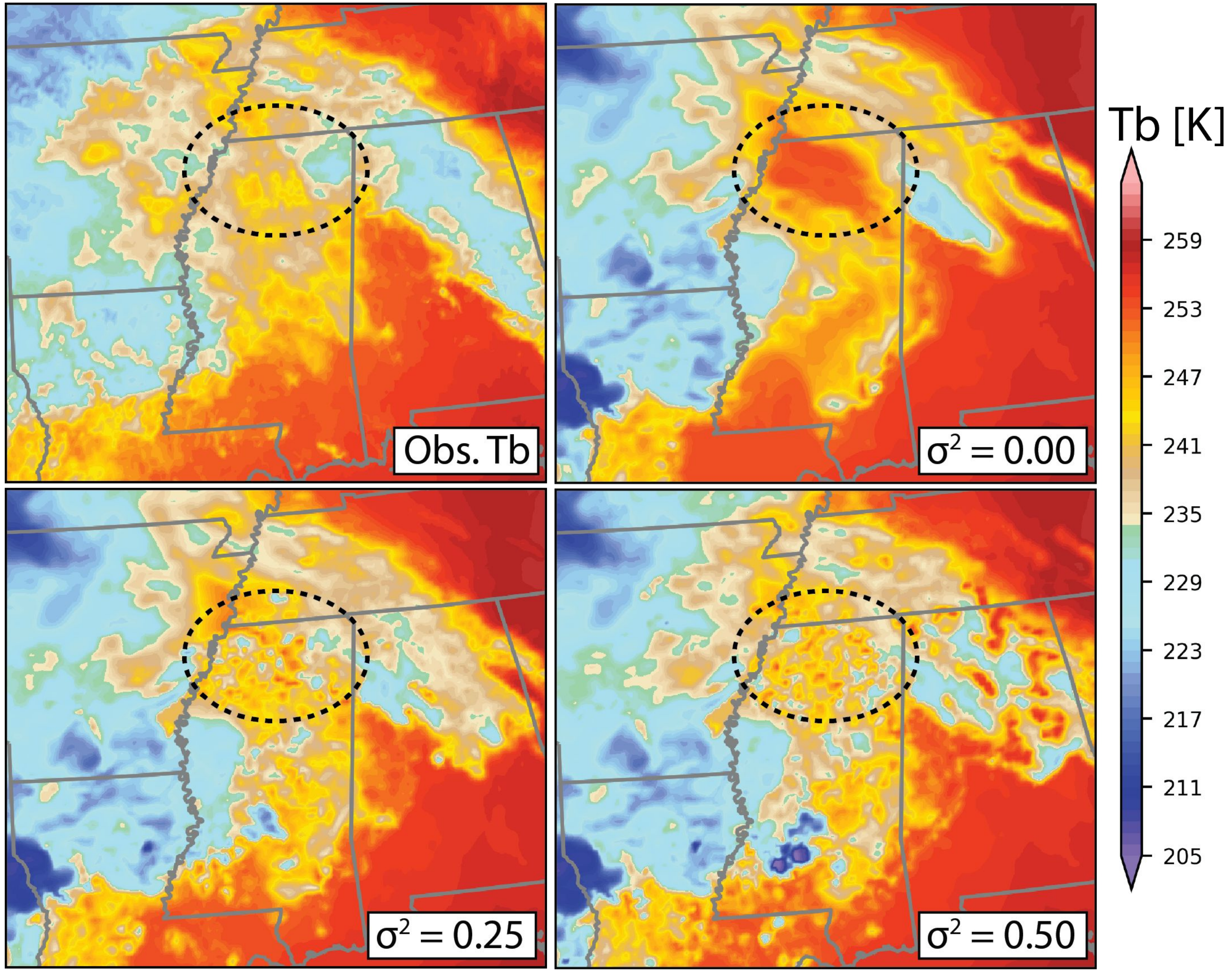
DA system development for ABI assimilation: additional developments

- We have made many development to the fully-cycled EnVar system to support the assimilation of ABI all-sky radiance observations, including:
  - Inflation:
    - **Additive noise for cloud affected obs. that are clear sky in the model (Johnson* et al. 2022)**
    - **Adaptive RTPS inflation**
  - Forward operator
    - Calculation for effective radii in CRTM following Thompson microphysics scheme
  - Obs. bias correction, error estimation and pre-processing
    - Online, nonlinear bias correction using radar anchoring (Chandramouli* et al. 2022)
  - Adaptive observation error (Johnson* et al. 2022)
  - Adaptive thinning for ABI observations
  - Remove partly cloudy pixels (Saunders and Kriebel (1988))
  - EnVar solver improvement
    - **Addition of T_b as a control variable to improve convergence (following Wang and Wang 2017)**

DA system development for ABI assimilation: additive noise

22 UTC 27 April 2021

- Follows Johnson* et al. (2022)
- Adding perturbations to *T*, *q*, *u*, and *v* at locations where obs. are cloudy (C_o > 2 K) but background is clear (C_f < 2 K)
- Appropriately selected inflation helps spin-up shallow clouds



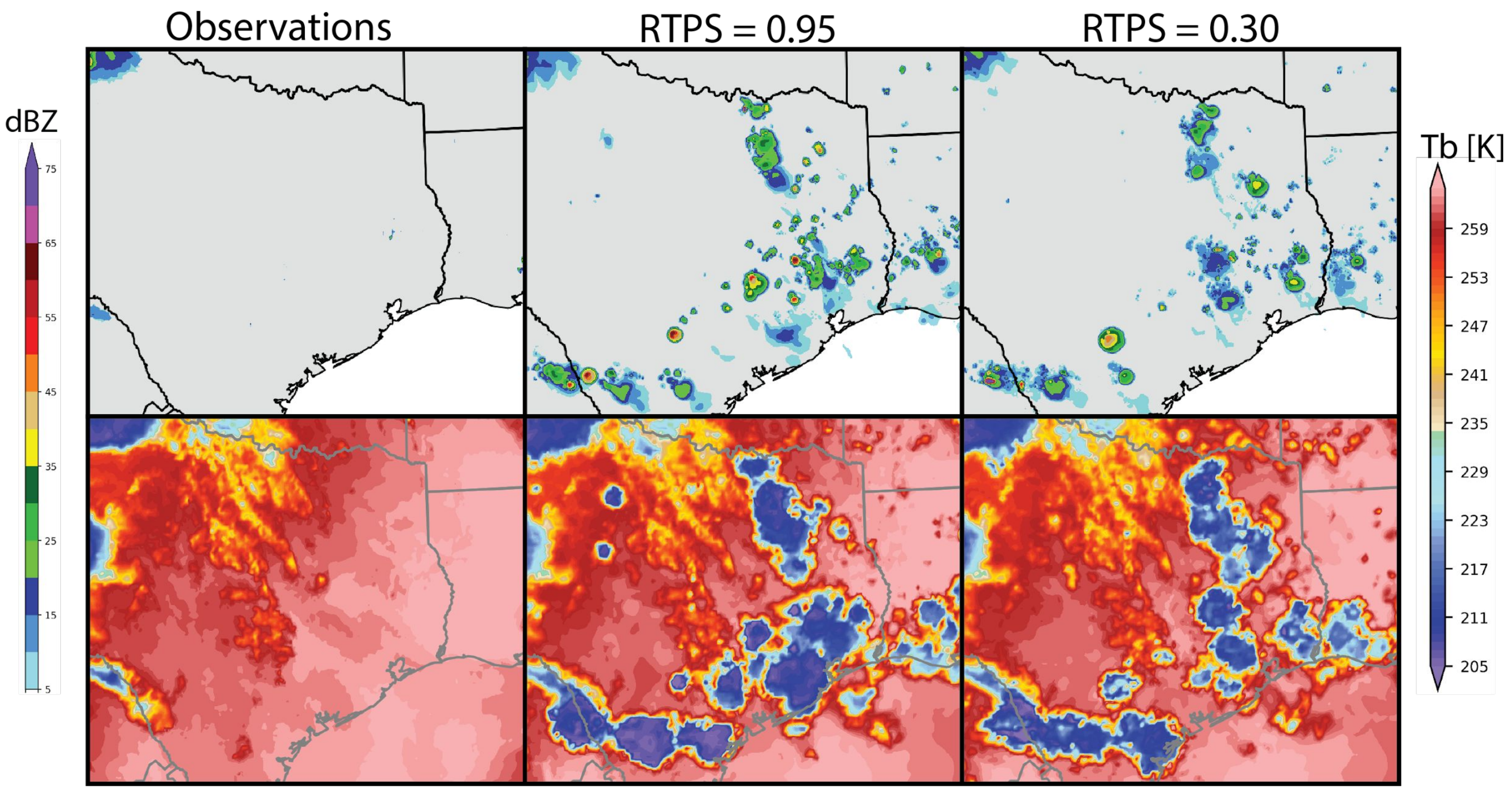
DA system development for ABI assimilation: adaptive RTPS

20 UTC 26 May 2021
EnVar Control Member

- Relaxation to prior spread (RTPS) inflates the analysis ensemble back to some percentage of the prior spread (Whitaker and Hamill 2012)

$$\mathbf{x}_i'^a \leftarrow \mathbf{x}_i'^a\left(\alpha\frac{\sigma^b - \sigma^a}{\sigma^a} + 1\right)$$

- RTPS needs to be adaptively tuned for FV3-LAM given its over convection



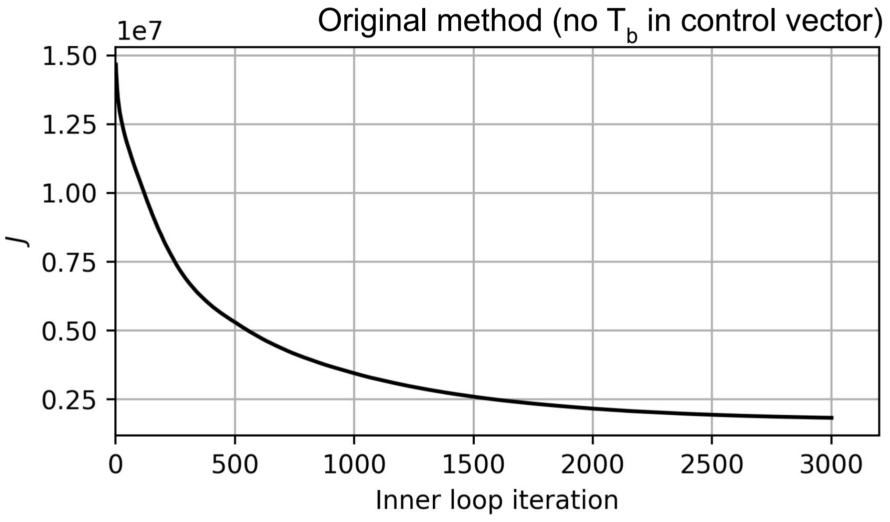
- Appropriately selected RTPS inflation reduce spurious precip., increase spread of T_b, and improve suppression of spurious clouds and convection

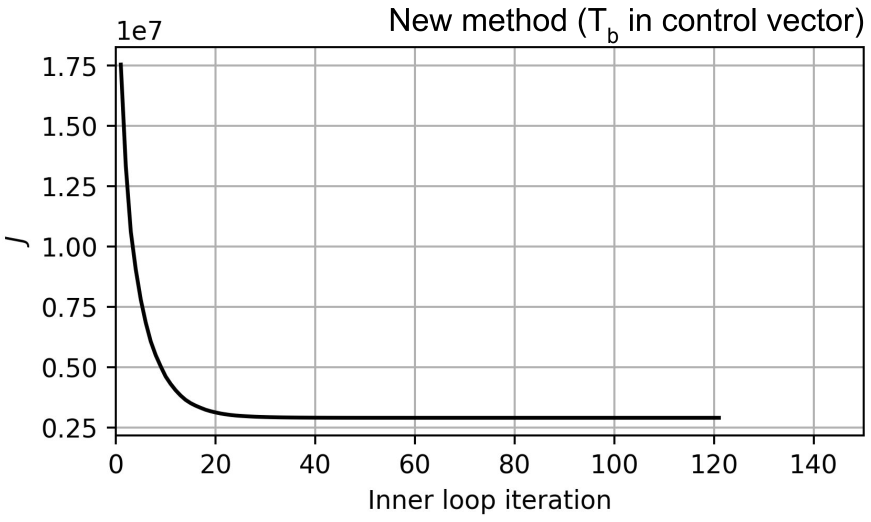
DA system development for ABI assimilation: addition of T_b as a control variable to improve EnVar convergence

- We find that assimilating all-sky radiances often leads to an imbalance in the gradient of the cost function caused by the tangent linear ($\mathbf{H}$) being much larger for some cloud hydrometeors, which therefore prevents efficient convergence

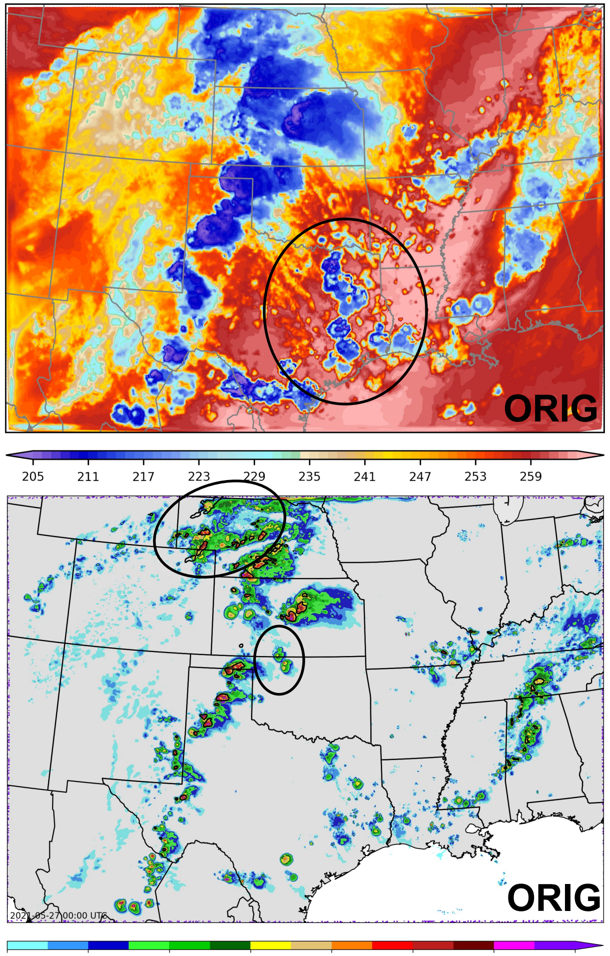
$$\nabla_{\mathbf{a}} J = \mathbf{A}^{-1}\mathbf{a} + \mathbf{D}^{\mathrm{T}}\mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}^{o'})$$

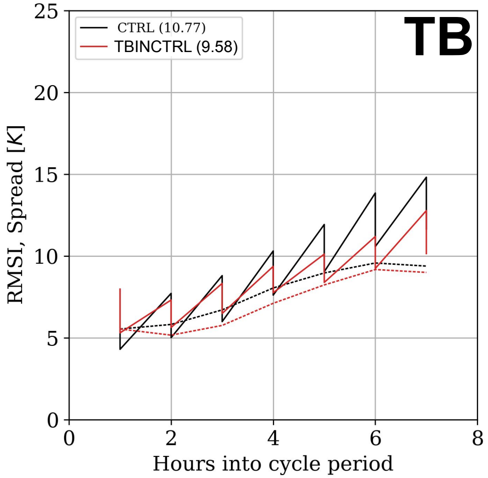
- We propose an alternative method following Wang* and Wang (2017) wherein T_b is added as a control variable, which leads to a more efficient convergence

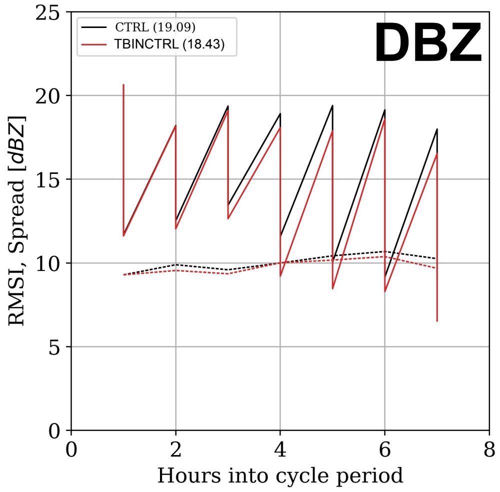




DA system development for ABI assimilation: addition of T_b as a control variable to improve EnVar convergence





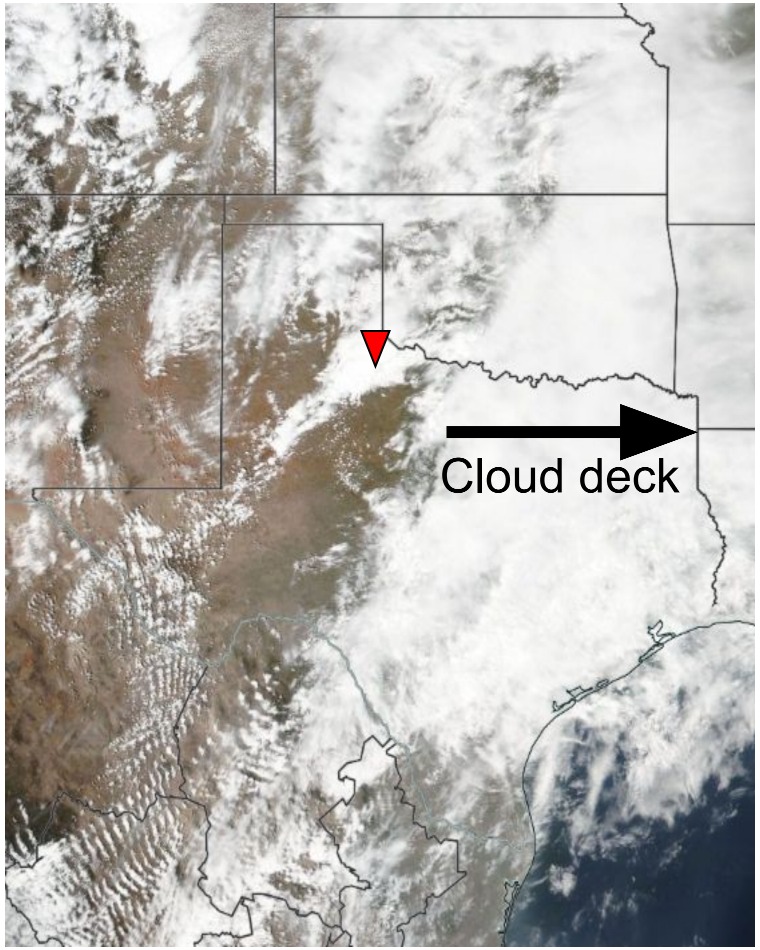


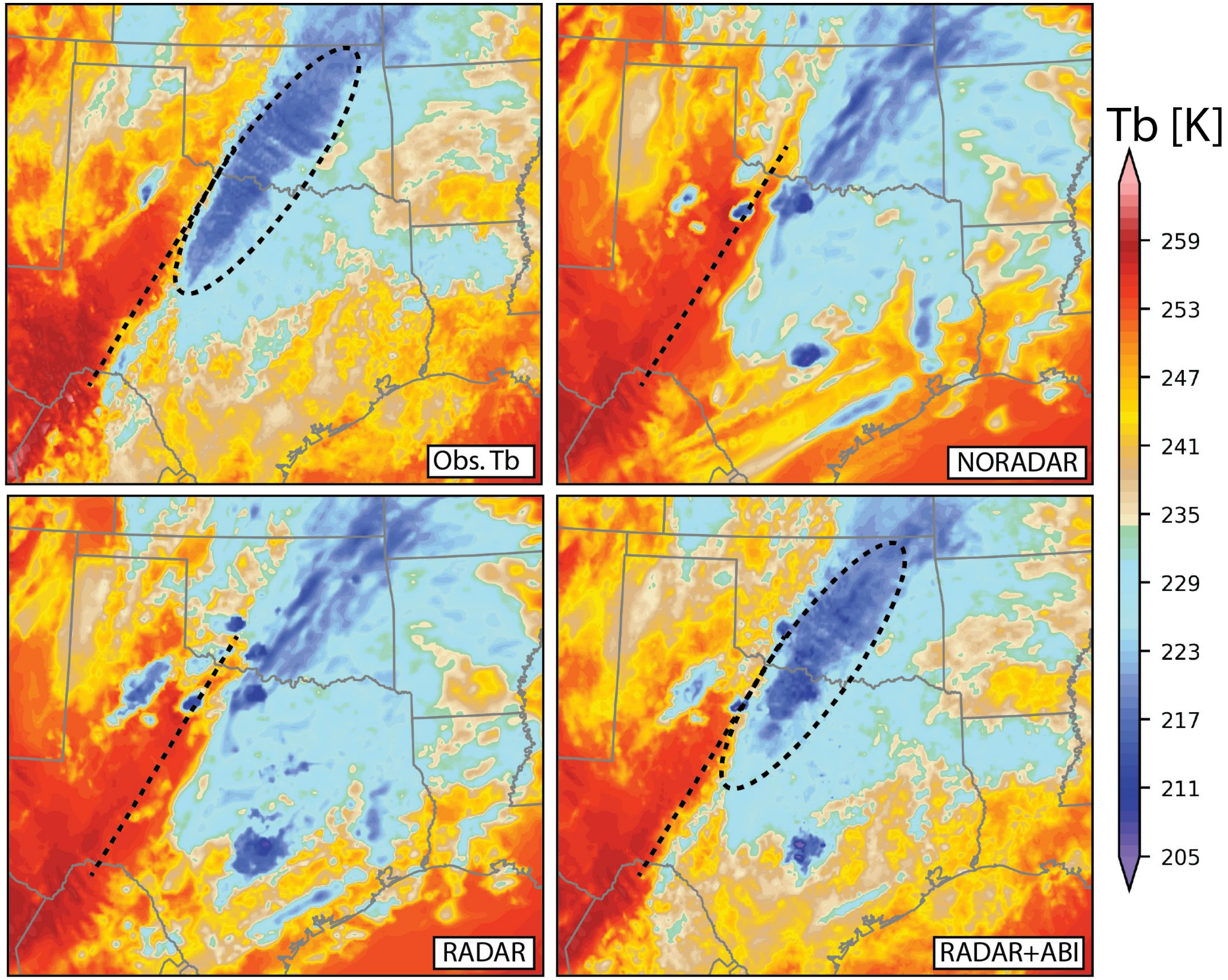
- The new approach improves increments to T_b and dBZ, especially in regions of spurious convection and cloud cover
- These benefits grow throughout the DA period and are maintained throughout the entire forecast period

Part II: Evaluating the impact of assimilating ABI all-sky radiances for multiple severe weather events

Benefits of assimilating ABI observations: synoptic-scale cloud features

20 UTC 27 April 2021

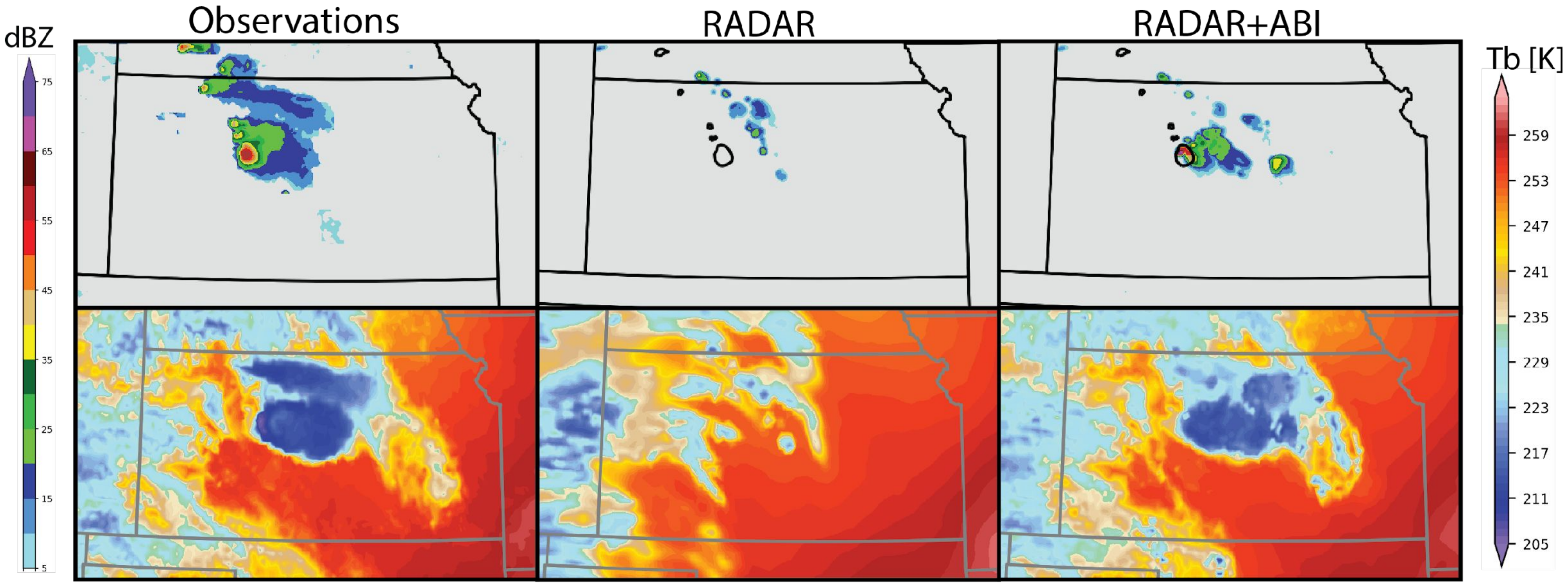




- Assimilating ABI obs. better analyzes location and temp. of cloud tops in the stratus deck

Benefits of assimilating ABI observations: faster spin-up of ongoing supercell

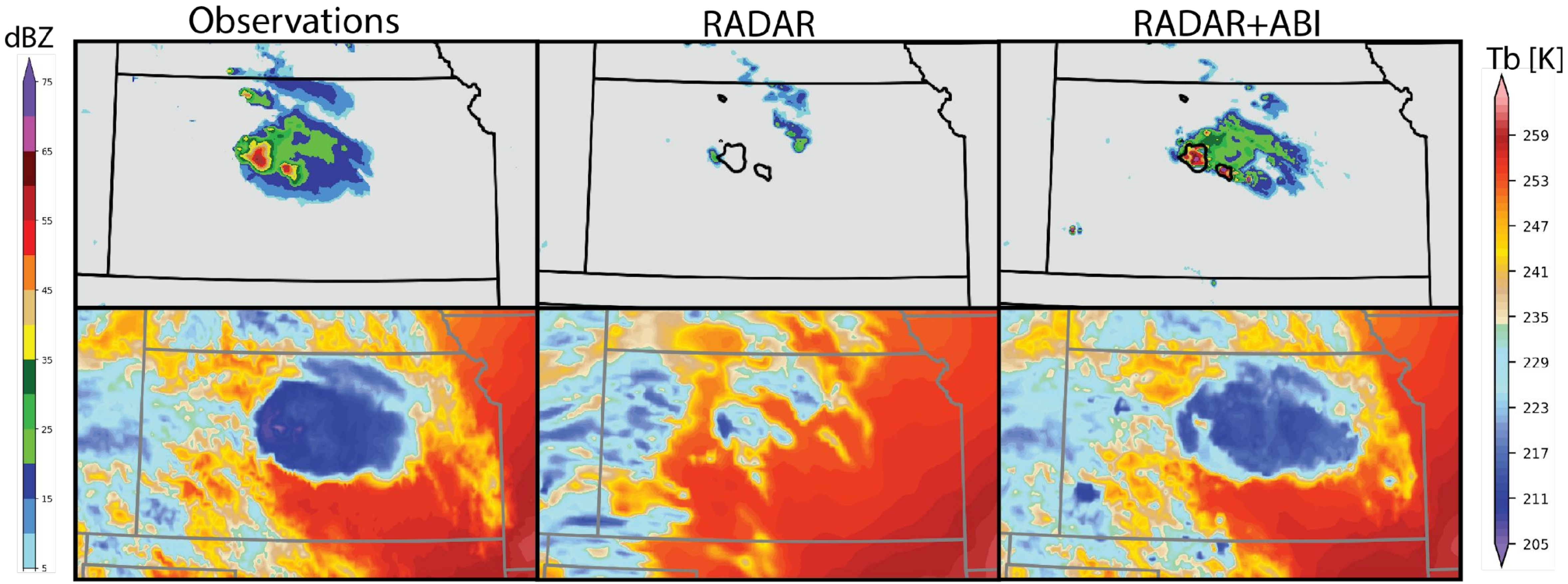
19 UTC 26 May 2021



- RADAR+ABI experiment spins up KS supercell ~ 2 h sooner than RADAR experiment

Benefits of assimilating ABI observations: faster spin-up of ongoing supercell

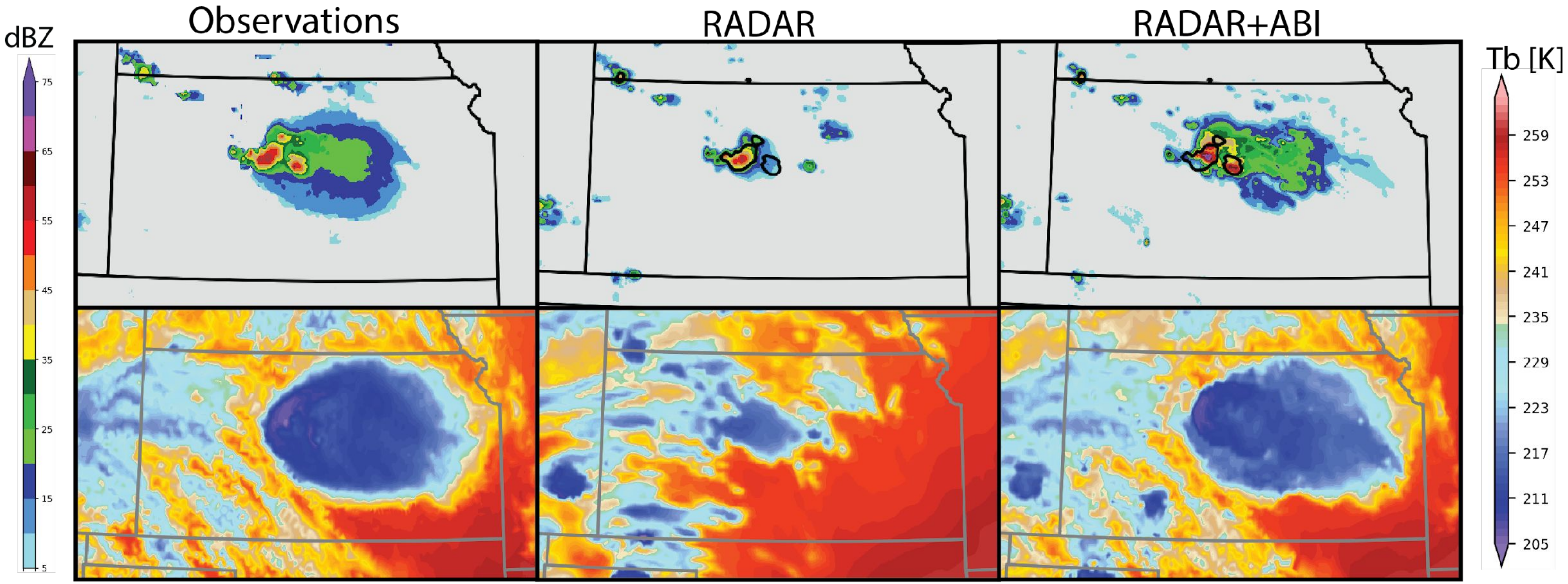
20 UTC 26 May 2021



- RADAR+ABI experiment spins up KS supercell ~ 2 h sooner than RADAR experiment

Benefits of assimilating ABI observations: faster spin-up of ongoing supercell

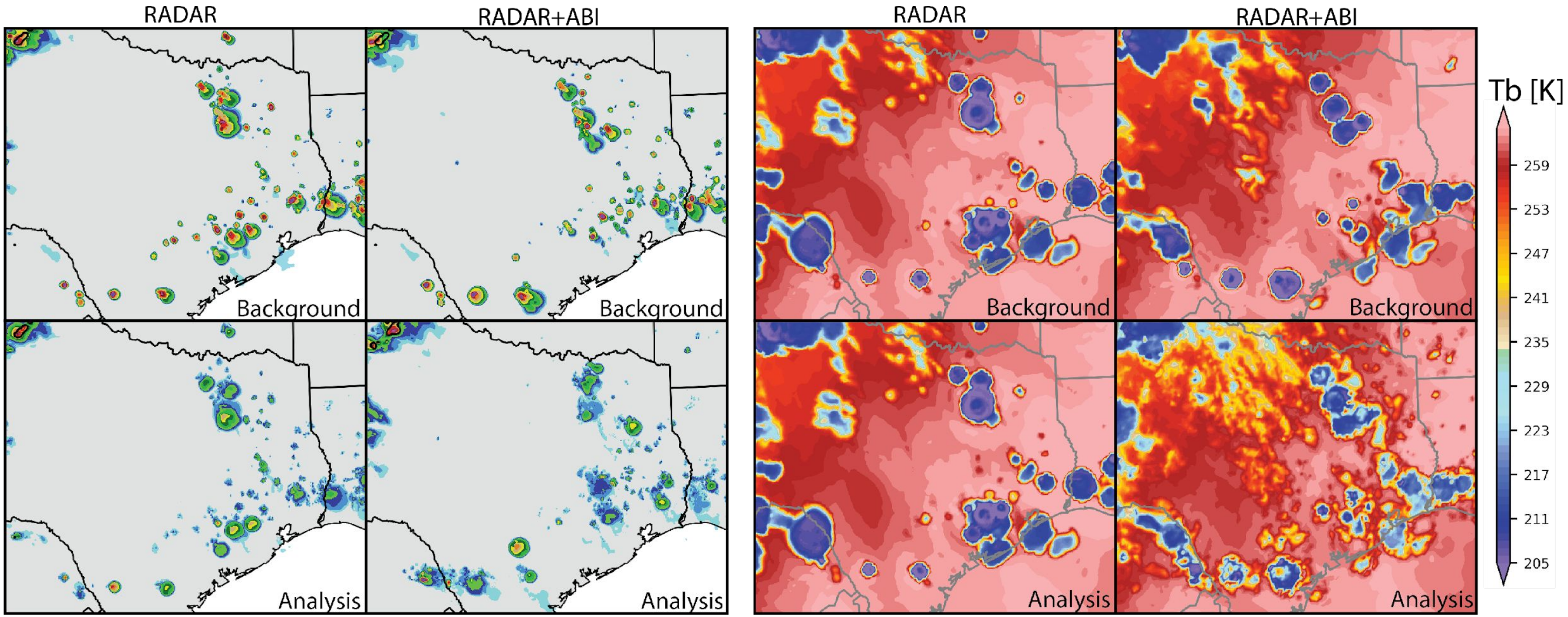
21 UTC 26 May 2021



- RADAR+ABI experiment spins up KS supercell ~ 2 h sooner than RADAR experiment

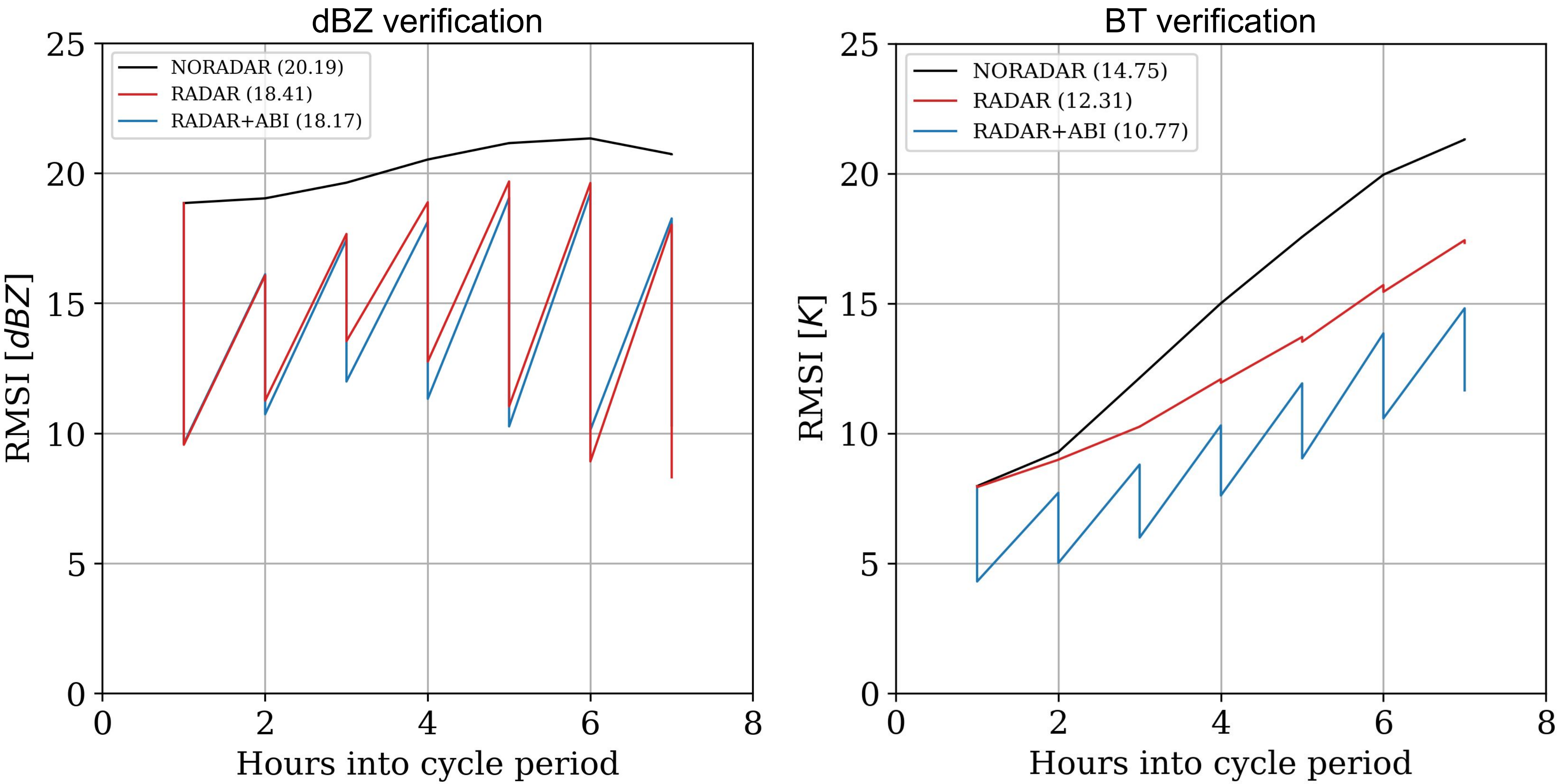
Benefits of assimilating ABI observations: top-down suppression of spurious convection

23 UTC 26 May 2021



- Assimilating radar observations does not remove hydrometeors in anvil associated with spurious convection
- Including the ABI observations during DA better removes these spurious anvil clouds (though not entirely)

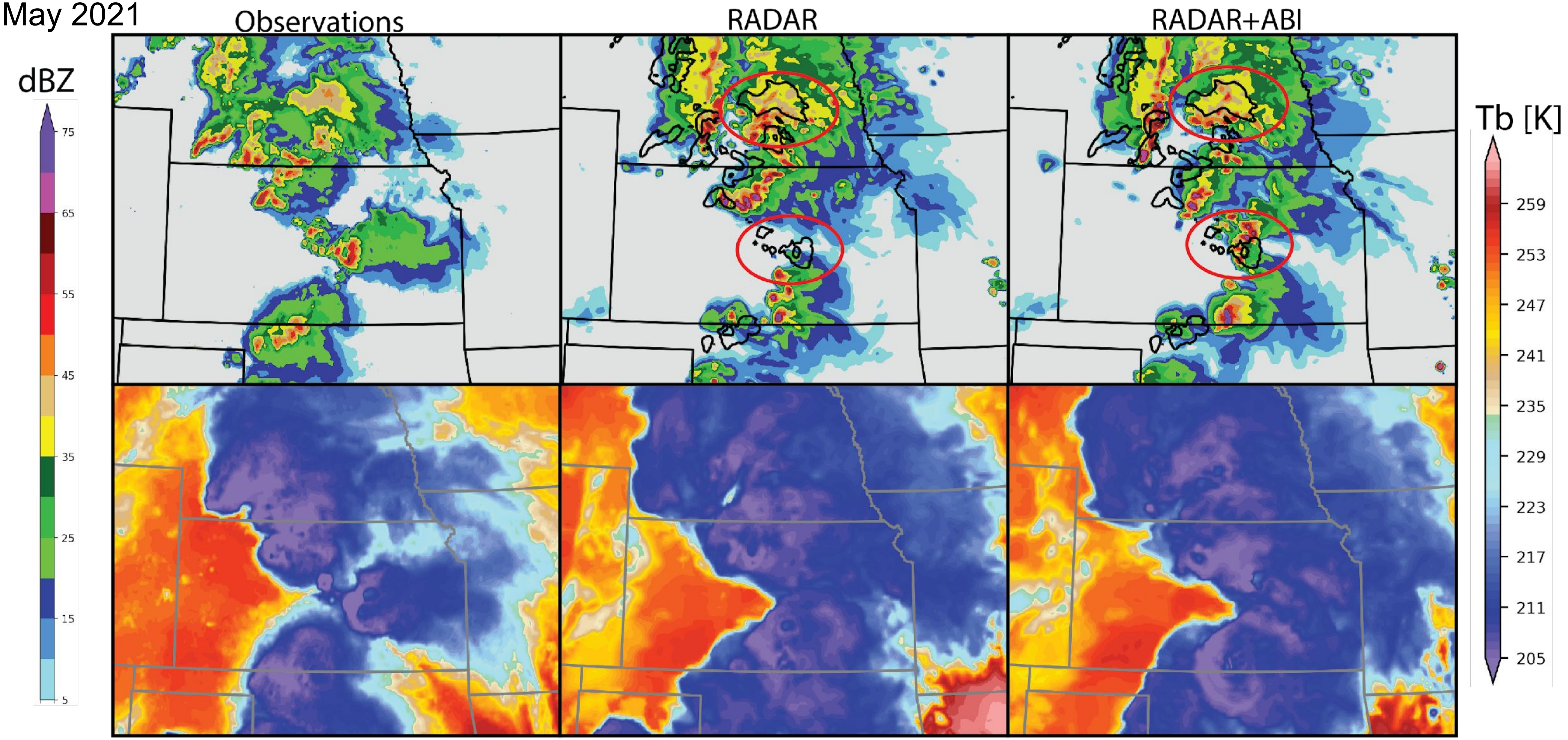
Cycled DA impacts of assimilating radar and ABI observations in FV3-LAM



- Assimilating ABI observations improves fit to dBZ observations during earlier cycles due to better spin-up of convection
- Assimilating ABI observations significantly improve background fit to ABI observations

Forecast impacts of assimilating ABI obs.

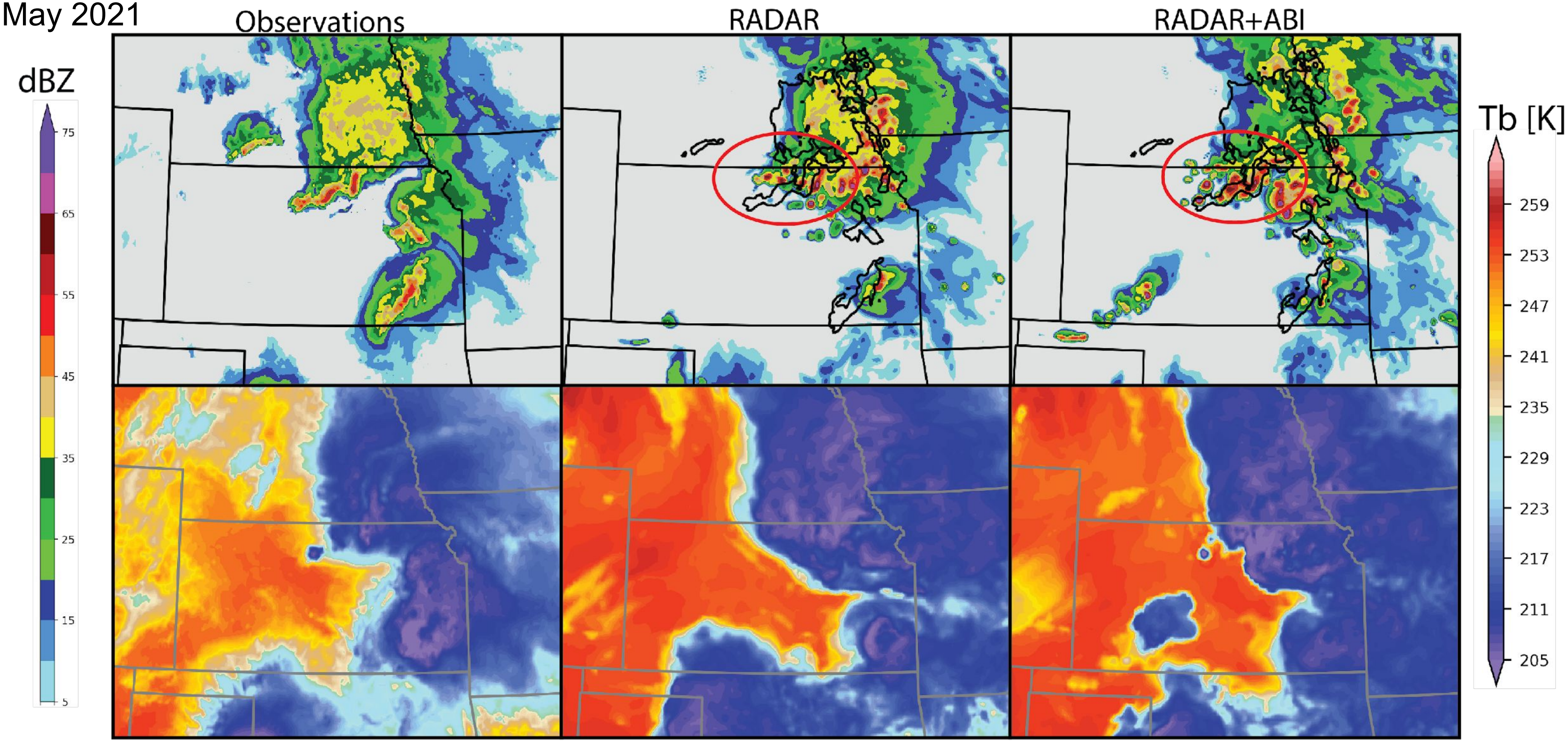
03 UTC 27 May 2021



- Some benefits from assimilating ABI observations continue into the forecast period, especially for localized convection
- Forecast impacts are smaller for T_b as all experiments produce too cold anvils that are larger than the observed system

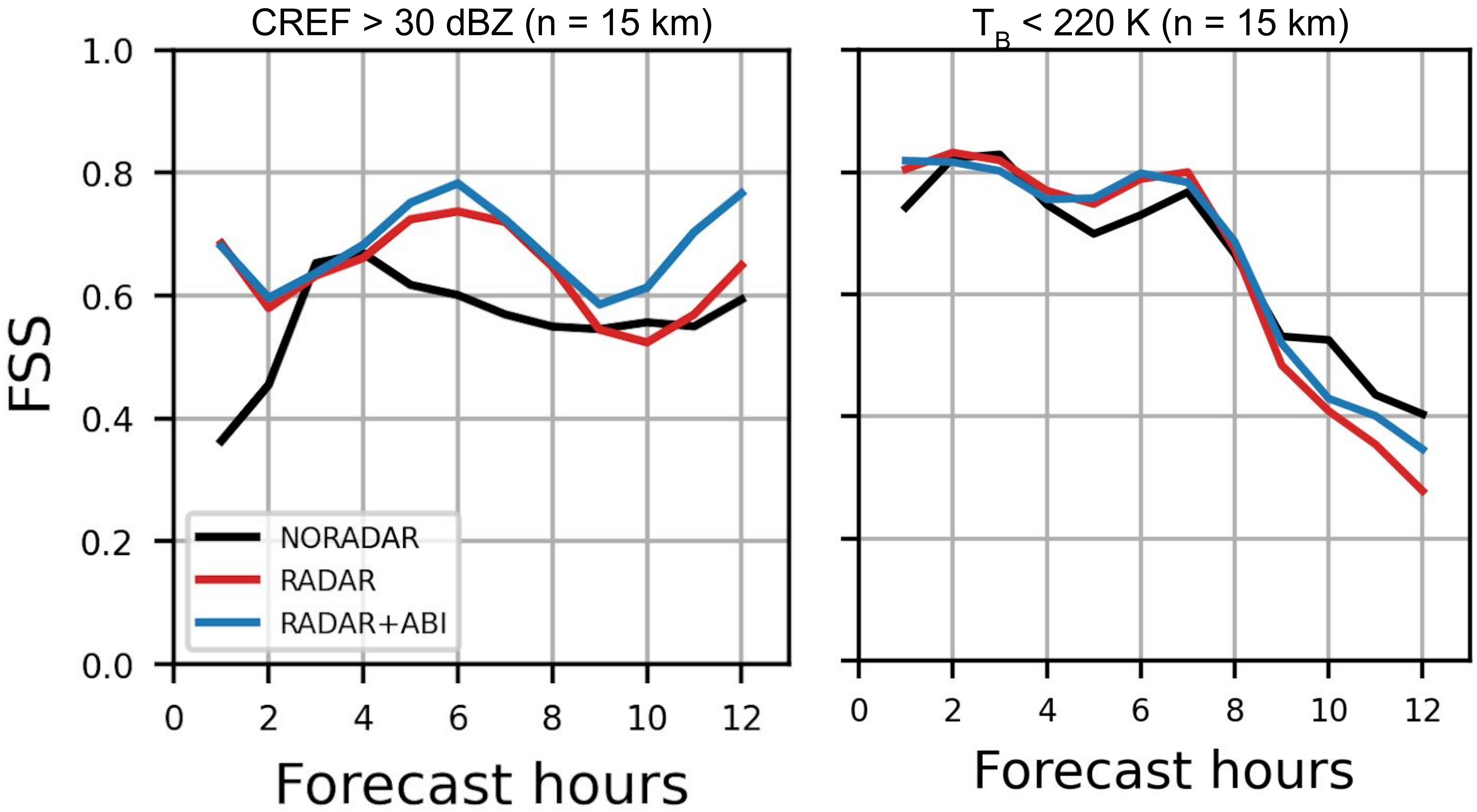
Forecast impacts of assimilating ABI obs.

07 UTC 27 May 2021



- Some benefits from assimilating ABI observations continue into the forecast period, especially for localized convection
- Forecast impacts are smaller for T_b as all experiments produce too cold anvils that are larger than the observed system

Forecast impacts of assimilating ABI obs.



- Some benefits from assimilating ABI observations continue into the forecast period, especially for localized convection
- Forecast impacts are smaller for T_b as all experiments produce too cold anvils that are larger than the observed system (FV3-LAM model bias issue)

Summary

- GOES16 ABI all sky radiance DA capabilities are developed for FV3-LAM for RRFS implementation
- Assimilation of ABI all sky radiance on top of the radar observations improves the synoptic scale cloud features, facilitates the spin up of the ongoing convection, and assists suppressing spurious convection during the analysis.
- Benefits of assimilating ABI all sky radiance are carried over to the forecast period, especially for localized convection
- Benefits for brightness temperature (T_b) forecasts are smaller than for radar reflectivity likely due to FV3-LAM model biases
- Spurious convection in FV3-LAM can greatly reduce analysis increments for T_b due to large anvil clouds reducing ensemble spread
- Ongoing work will continue R&D and work with NOAA to incorporate ABI all sky radiance DA for future RRFS implementation