# SATELLITE DATA ASSIMILATION AND MICROPHYSICS AND OTHER THINGS

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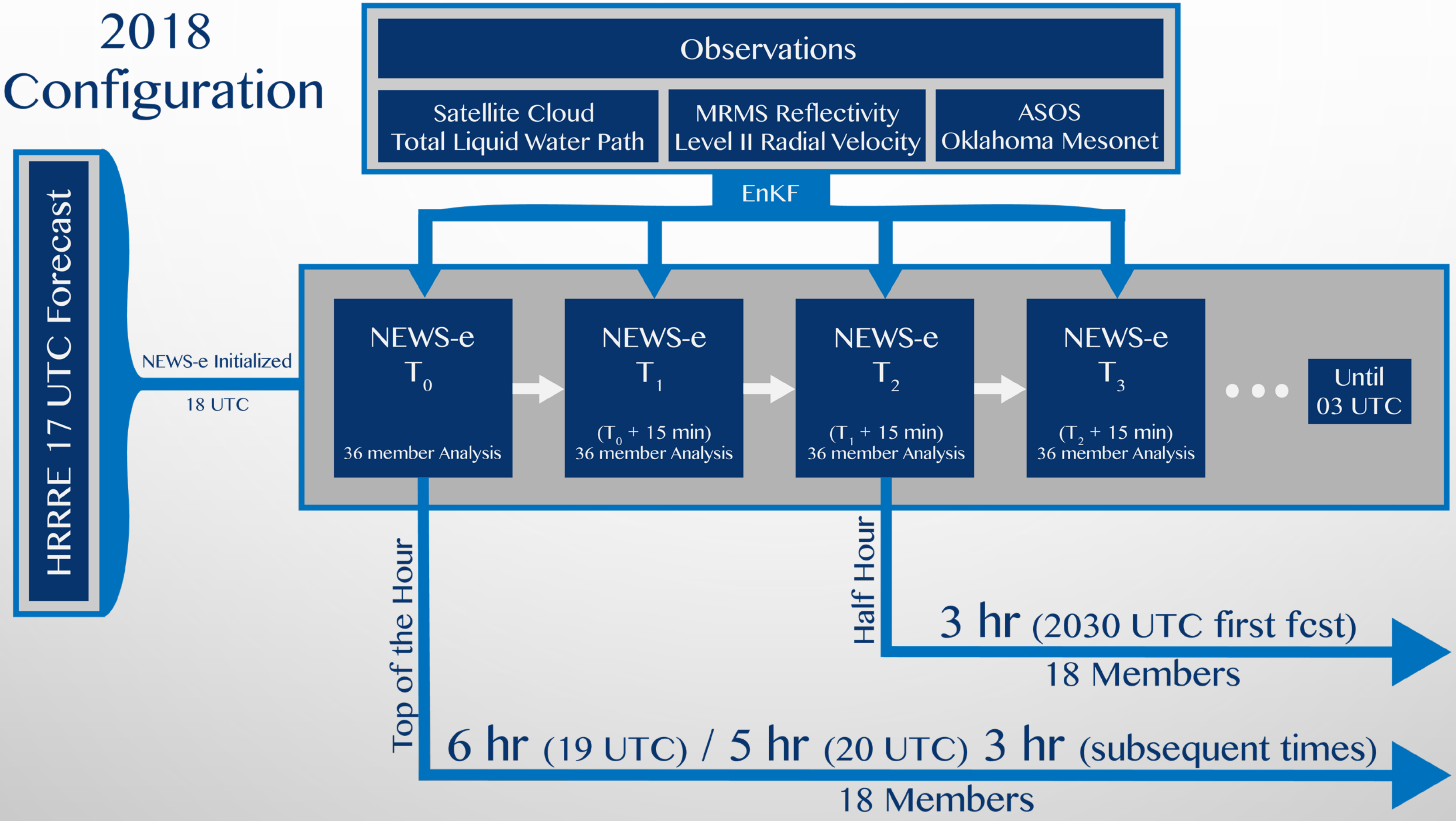
**UNCERTAINTY IN RADAR RETRIEVALS, MODEL PARAMETERIZATIONS, ASSIMILATED DATA AND IN-SITU OBSERVATIONS: IMPLICATIONS FOR THE PREDICTABILITY OF WEATHER**

*OCTOBER 31, 2018*

# Warn-on-Forecast System

- **The Warn-on-Forecast (WoF) project has the primary goal of improving short-term (0-3 h) forecasts of high impact weather events using NWP**
  - High impact weather include tornados, severe winds, flash flooding, and even hurricanes.
- **The NSSL Experimental Warn-on-Forecast System for ensembles (NEWS-e) was developed to address this goal**
  - https://www.nssl.noaa.gov/projects/wof/news-e/realtime/
- **Summary**
  - 36 member ensemble cycled at 15 minute intervals using an ensemble Kalman filter initialized at 1600 or 1800 UTC daily
  - Initial and boundary conditions derived from an experimental HRRR ensemble
  - Horizontal grid spacing: 3 km; regional domain (up to 300 x 300 grid points)
  - 51 vertical levels from the surface to ~10 hPa
  - Currently assimilates conventional synoptic observations, Oklahoma mesonet surface observations, WSR-88D radar reflectivity and radial velocity observations, and GOES-16 cloud water path retrievals within each domain
- **Future (2019)**
  - Additional GOES-16 data in the form of clear-sky water vapor radiances and high resolution atmospheric motion vectors (AMVs) will be assimilated
  - Higher horizontal and vertical resolutions will be tested.

# Warn-on-Forecast System




- Variations in start time, number and length of forecasts exist for different applications

# Current Satellite Data Assimilation in Warn-on-Forecast

- **1. Cloud Water Path (CWP):** Integrated cloud water retrieved from GOES-16 visible and infrared observations (Jones et al. 2016).
  - Assimilated into NEWS-e starting in 2016 and has proved effective in improving cloud analyses, convective initiation, and the thermodynamic environment.
  - Observations objectively analyzed to a 5 km grid and parallax correction applied
- **2. Clear-sky water vapor channel (6.2, 6.9, 7.3 μm) radiances:** Sensitive to the mid and upper-tropospheric atmospheric moisture content (Jones et al. 2018).
  - Assimilation of the 6.2 μm channel was tested during FFAIR experiment this (2018) summer and no adverse impacts were observed.
  - Retrospective testing of multiple severe weather cases from the spring and summer experiments assimilating the 6.2 and 7.3 μm channels is underway.
- **3. Atmospheric Motion Vectors (AMVs):** Wind speed and direction derived from cloud and water vapor objects over a series of images
  - GOES-16 AMV retrievals are generated at high enough spatial and temporal resolution to be useful by NEWS-e. Visible retrievals being the most numerous.
  - Retrospective testing underway, with plans to implement in 2019 NEWS-e

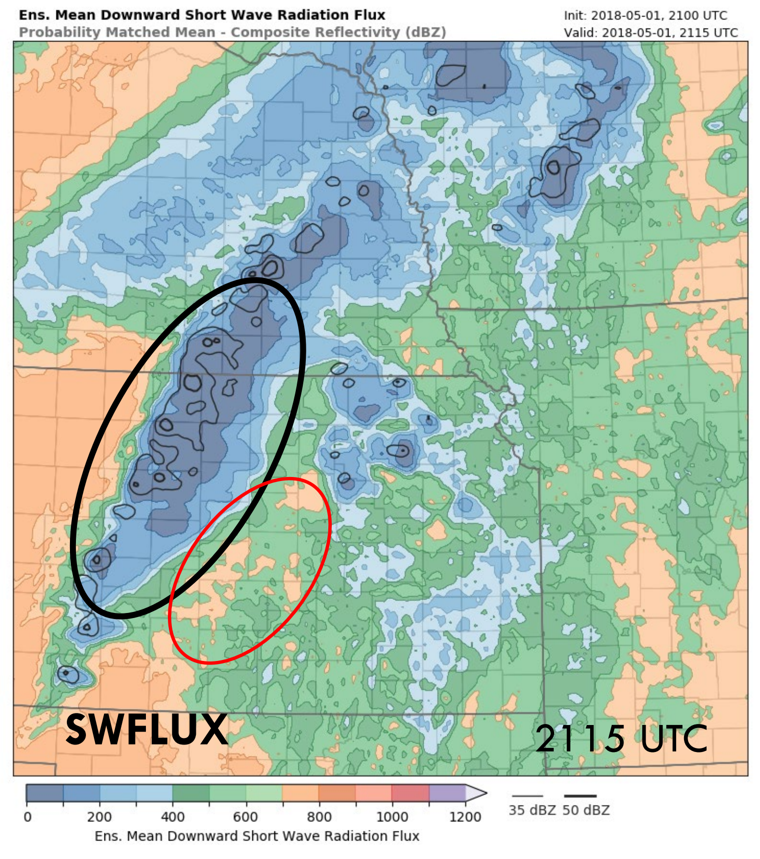
# Challenges

- **Satellite data assimilation into a WoF system has many significant challenges**
- **1.** What is the most effective satellite observation type to assimilate?:
  - Does improving the cloud analysis or overall near-storm environments (moisture, winds) provide the greatest overall impact to the model?
- **2.** How does satellite data assimilation impact current radar data assimilation?
  - Satellite and radar observations must have consistent geo-location so that small-scale features are assimilated at the right place and time
  - Is assimilating cloud information in high precipitation detrimental to radar-only DA?
- **3.** Satellite DA ***must*** be able to show skill in high impact weather forecasting compared to radar-only DA methods
  - *Question to answer*: Does satellite data help forecast if a tornado is going pass by my house in an hour
- **4.** Assimilating satellite and radar data simultaneously is difficult

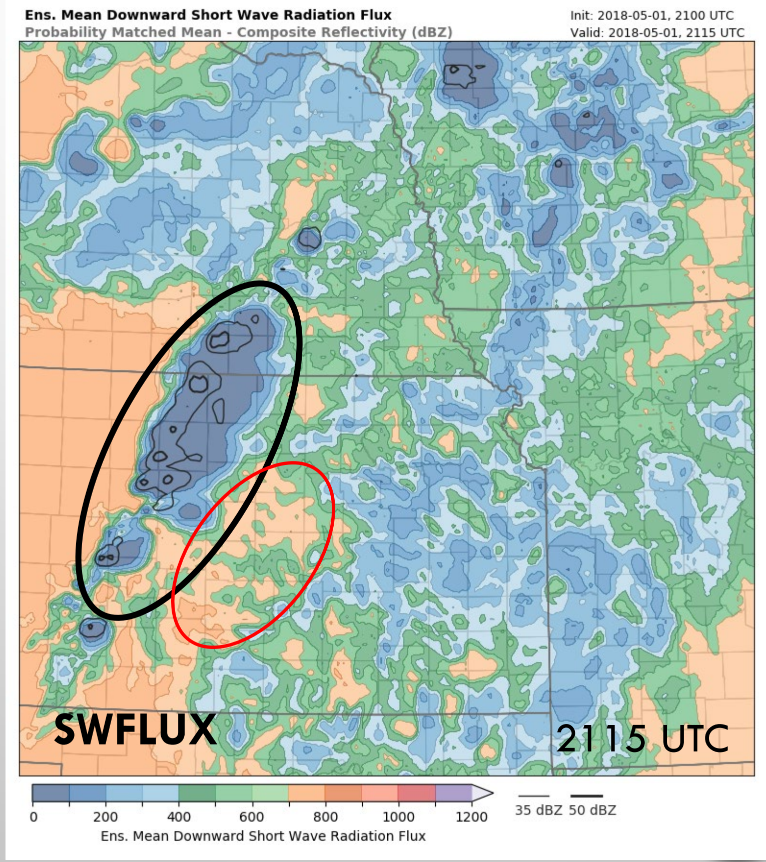
# Cloud water path (CWP) impact on Cloud Analysis

- Two experiments from May 1 2018 are compared:
  - 1. **NOCWP**: Assimilates all available conventional and radar observations
  - 2. **CWP**: Assimilated conventional, radar, and GOES-16 CWP retrievals

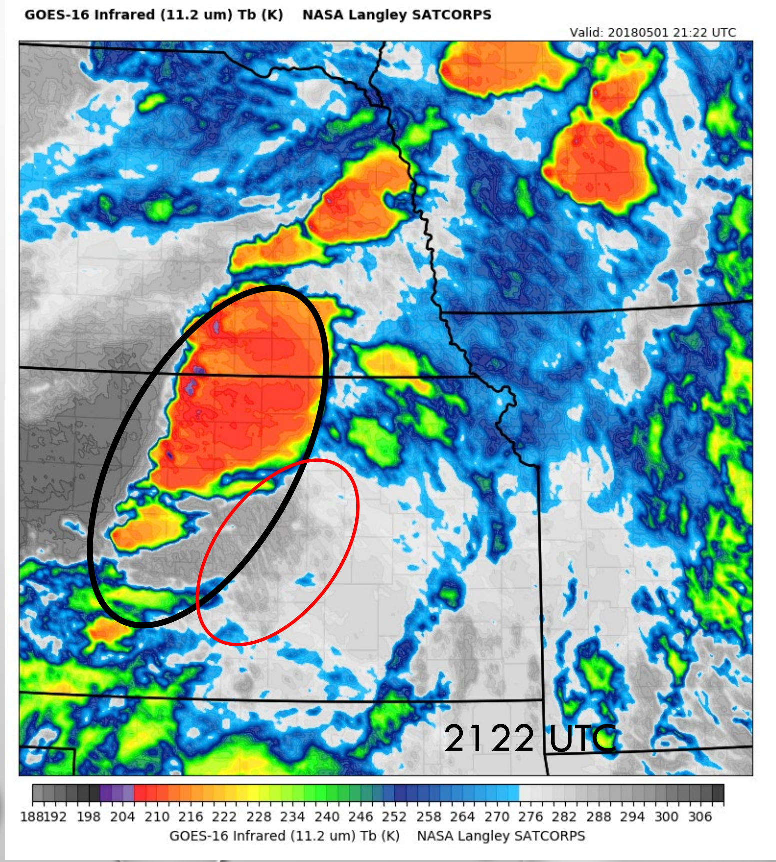
**NOCWP**




**CWP**




**GOES-16 IR**



# Improvement in Reflectivity and Rotation Forecasts

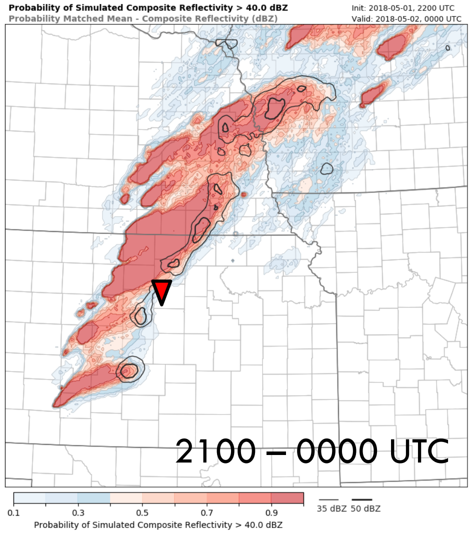
- Reflectivity and rotation objects from the model are verified against observed reflectivity and rotation objects from MRMS data. See Skinner et al. (2018) for details

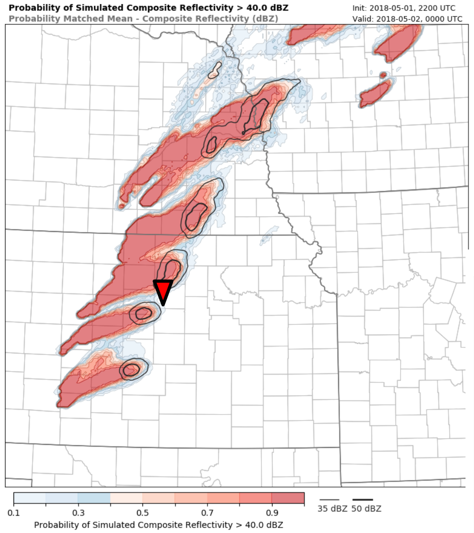
*3-h probability forecasts of reflectivity and 2-5 km updraft helicity (UH) starting at 2100 UTC 1 May 2018*

NOCWP

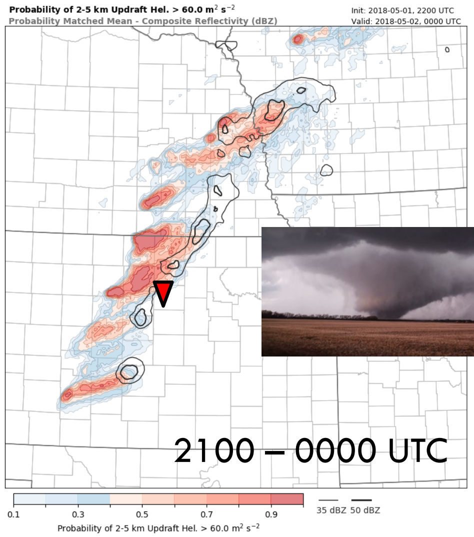
CWP

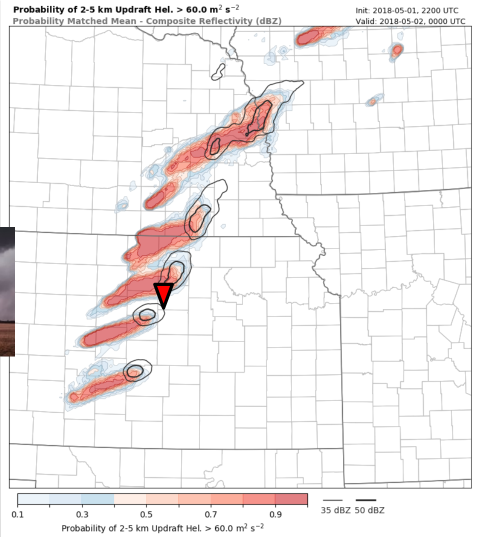
dBZ

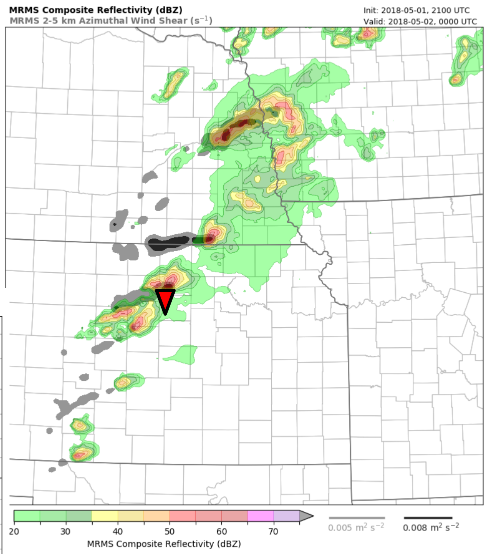



UH

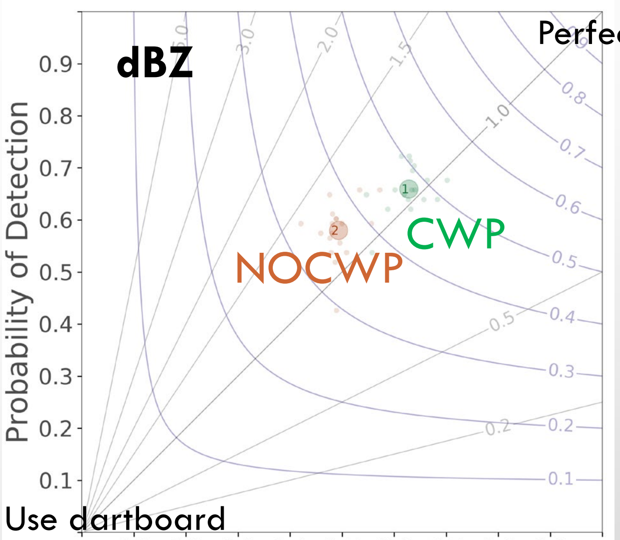


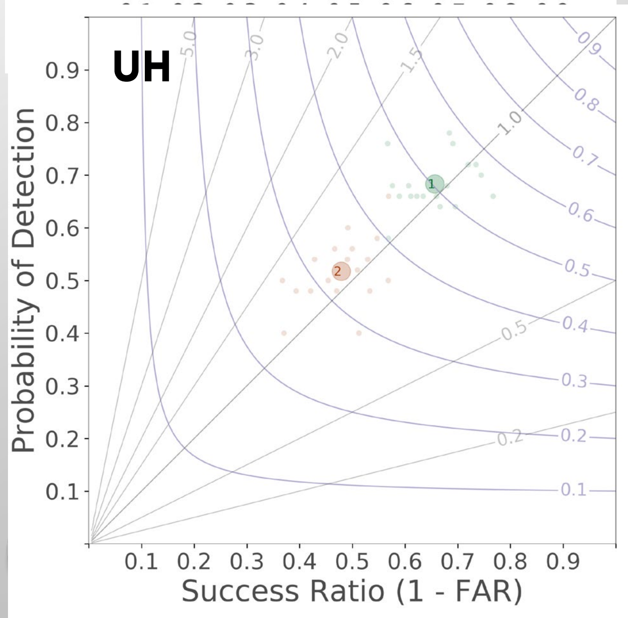




**MRMS at 0000 UTC**

Performance Diagram



# Clear-sky water-vapor radiance assimilation

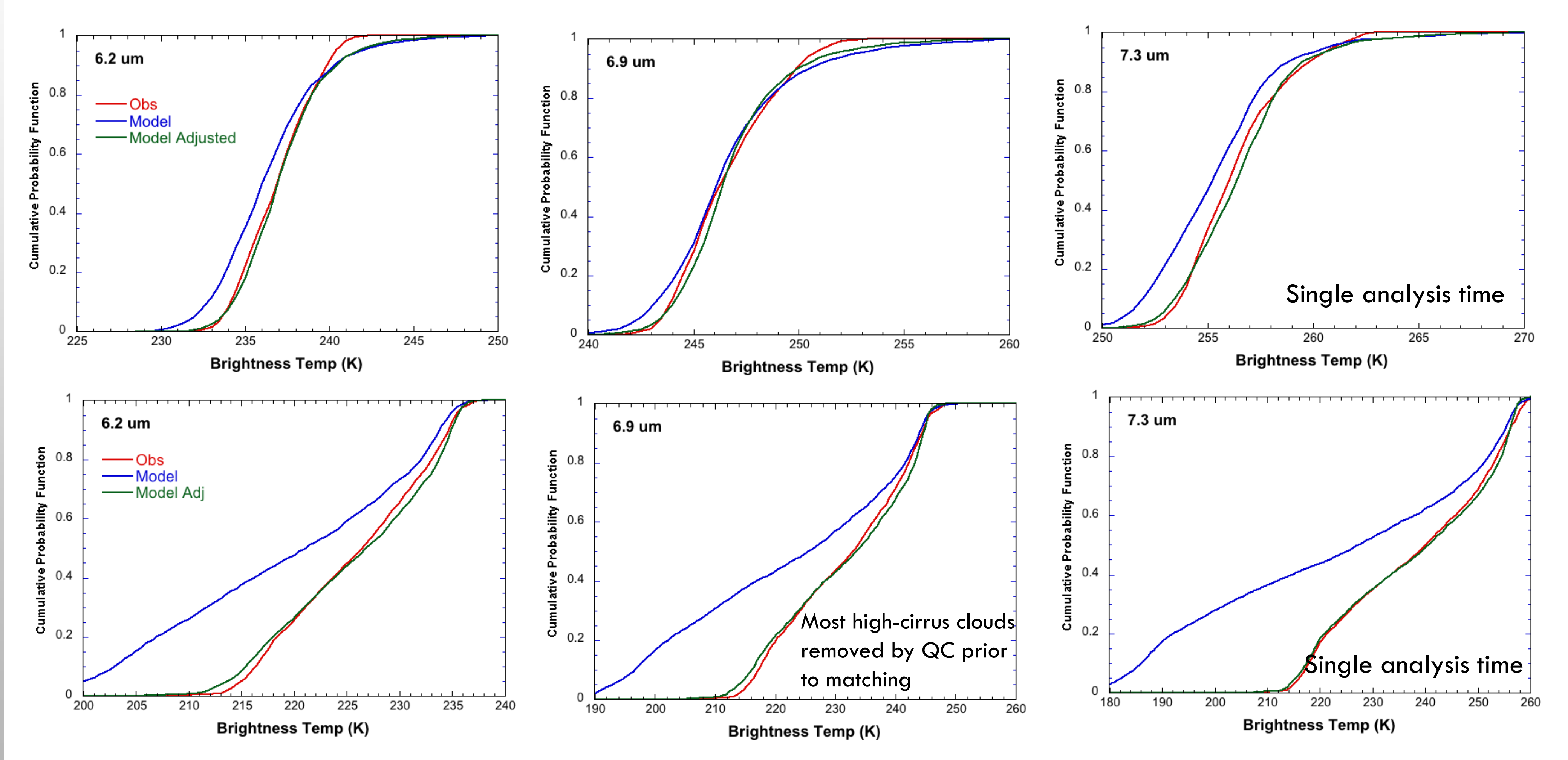
- **Assimilating radiances into the NEWS-e system required several improvements over existing methods**
- **Quality controlled, smoothed, and cloud cleared radiances are generated from L1B radiances combined with L2 cloud products**
  - Can be performed in real-time with a latency of $< 5$ minutes
  - Processed at 15 minute intervals, with a horizontal resolution of 5 km
  - Channels 8 (6.2$\mu$m) and 10 (7.3$\mu$m) assimilated. Channel 9 (6.9$\mu$m) held out due to high correlation with other two
- **New CRTM version 2.3 with updated ABI coefficients has been integrated into GSI v3.6**
  - Additional changes to include an "abi" observation type have also been made
  - Done with help from Ben Johnson and Ling Lu
  - Code updated to read in QC'ed radiance file from above.
- **New Bias-adjustment method**
  - Bias adjustment in satellite DA is important to prevent a dry or moist bias being introduced into the system
  - The current GSI-EnKF bias adjustment system is not really designed for high resolution and rapid cycling applications
  - A potentially more elegant solution is applying a histogram matching technique
    - Previously used on adjusting SSMI / TMI / AMSR-E passive microwave observations into a consistent dataset for hurricane forecasting
    - Applicable to both clear and cloudy radiances.

# Histogram matching

- The observed distribution of $T_B$ is matched to the biased synthetic distribution to generate a new, reduced-bias synthetic $T_B$ analyses, which are then used for the priors in the EnKF system
- Initial testing is positive, and functions for both clear-sky and all-sky radiance distributions. Still needs some tuning up.
- See Jones and Cecil (2006) for additional details

**Clear-sky**

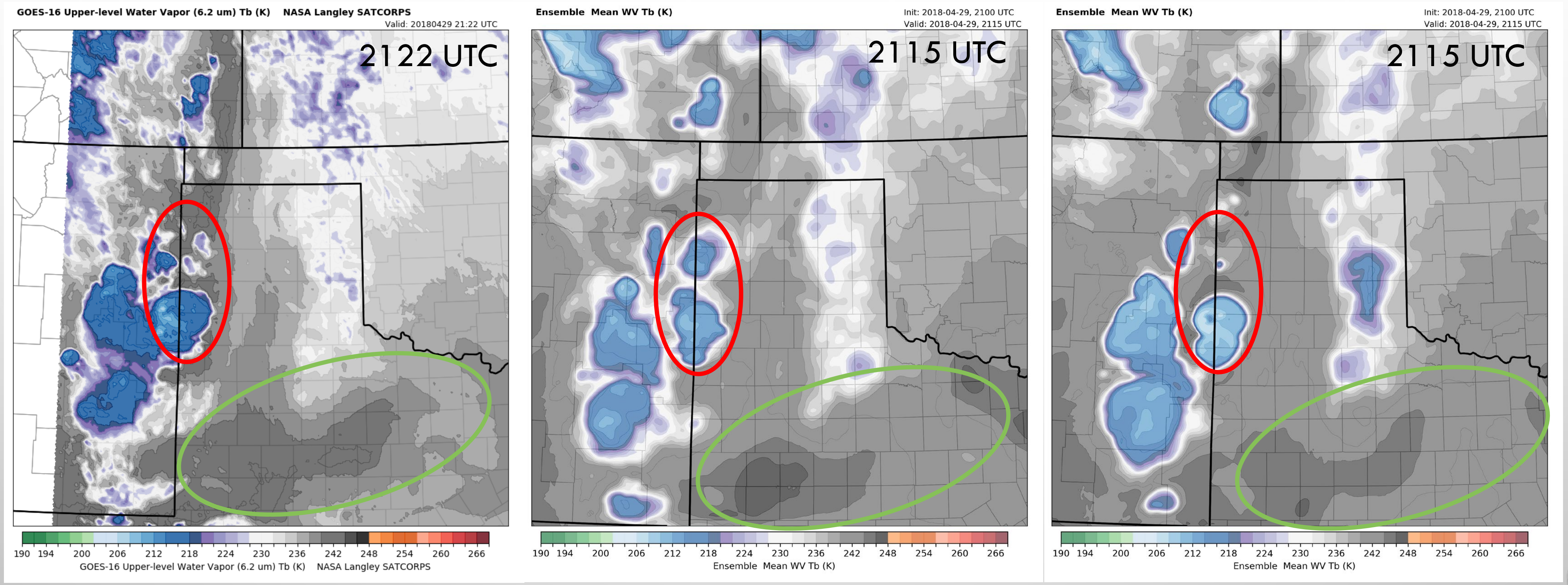
**All-sky**



# Example of GOES-16 Radiance DA

29 April 2018

GOES-16: 6.2 um | **NOWV** ensemble mean 6.5 um | **WV** ensemble mean 6.5 um

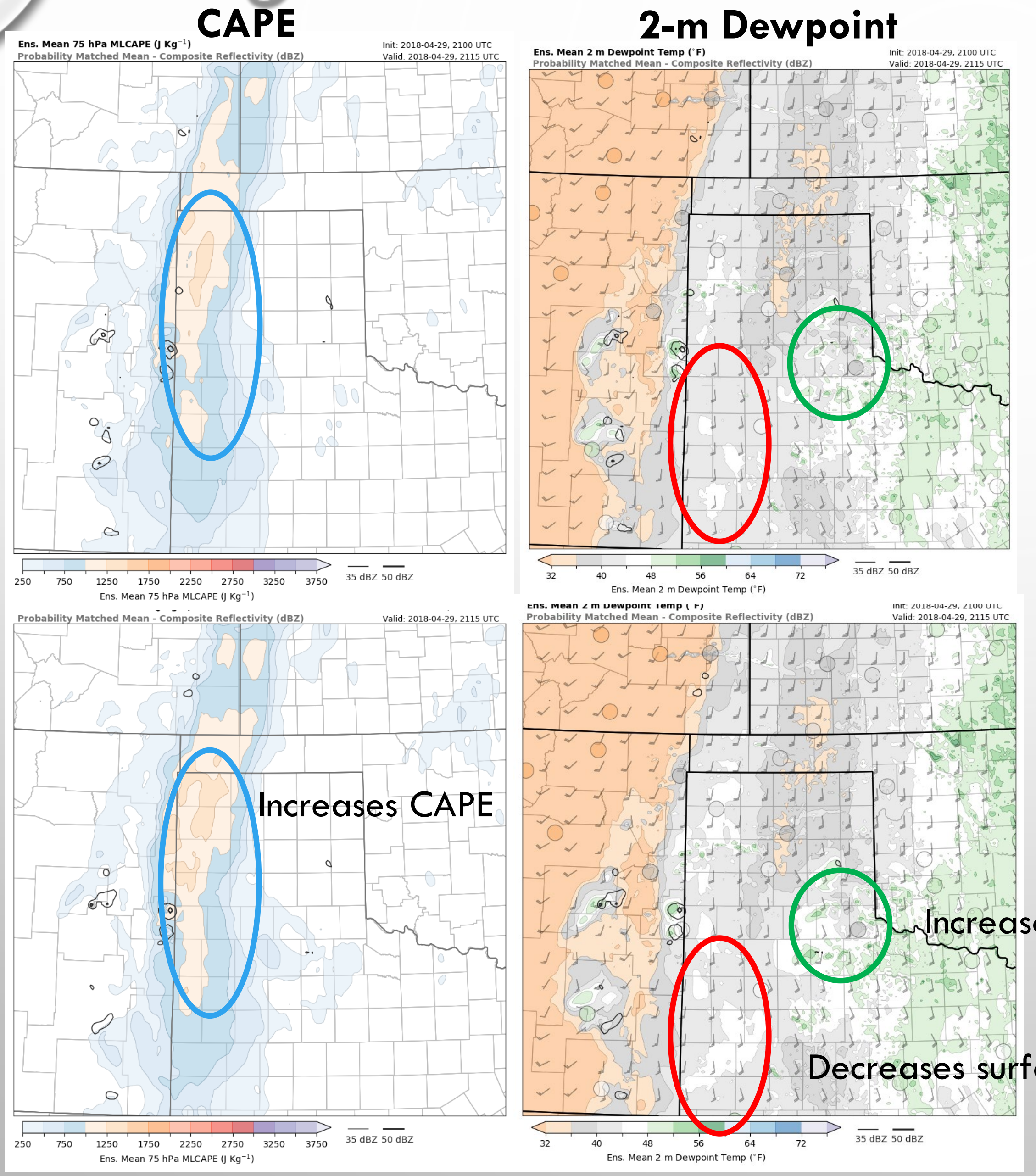



- Assimilating 6.2 and 7.3 um radiances clearly has an impact on the environment and corresponding convection
- Are the impacts significant and correct ???

# Example of GOES-16 Radiance DA 29 April 2018

NOWV

WV




- Ensemble mean CAPE and surface dewpoint at 2115 UTC (15 min forecast from 2100. UTC)
- Assimilation of clear-sky radiances modifies the environment in several ways

**Ensemble-Mean Dewpoint Biases (K)**

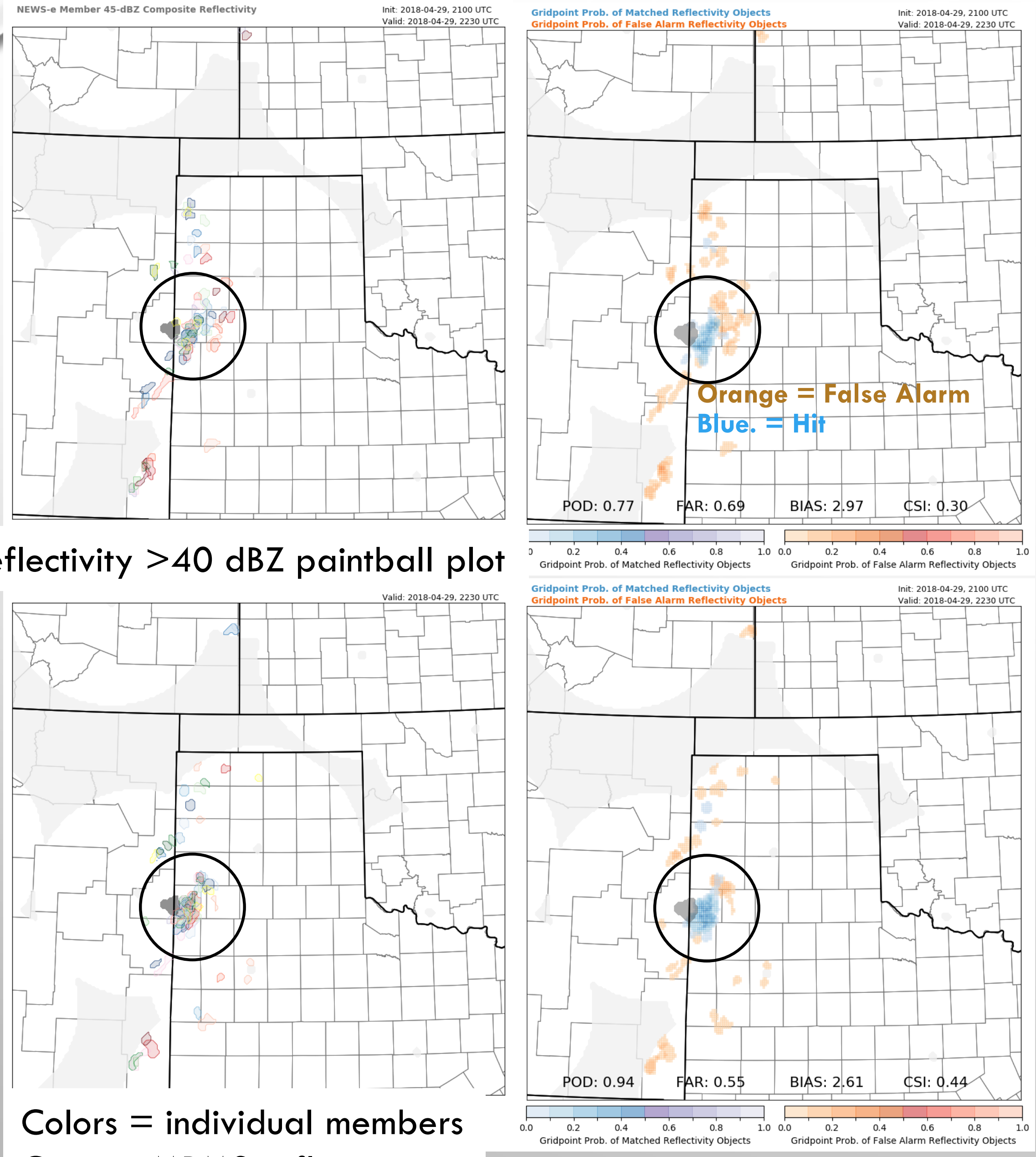
| MODEL | T=0 | T=90 |
|---|---|---|
| NOWV | -1.85 | -1.79 |
| WV | **-1.37** | **-1.24** |

- **Assimilating WV radiances appears to improve near-storm environment**

# Example of GOES-16 Radiance DA 29 April 2018

NOWV

WV




Colors = individual members

Gray = MRMS reflectivity

- 90 min reflectivity forecasts initialized at 2100 UTC
- The **NOWV** experiment moves convection too far east and has excessive member-to-member spread resulting in a high false alarm rate
- The **WV** experiment reduces false alarms with fewer members having an east bias

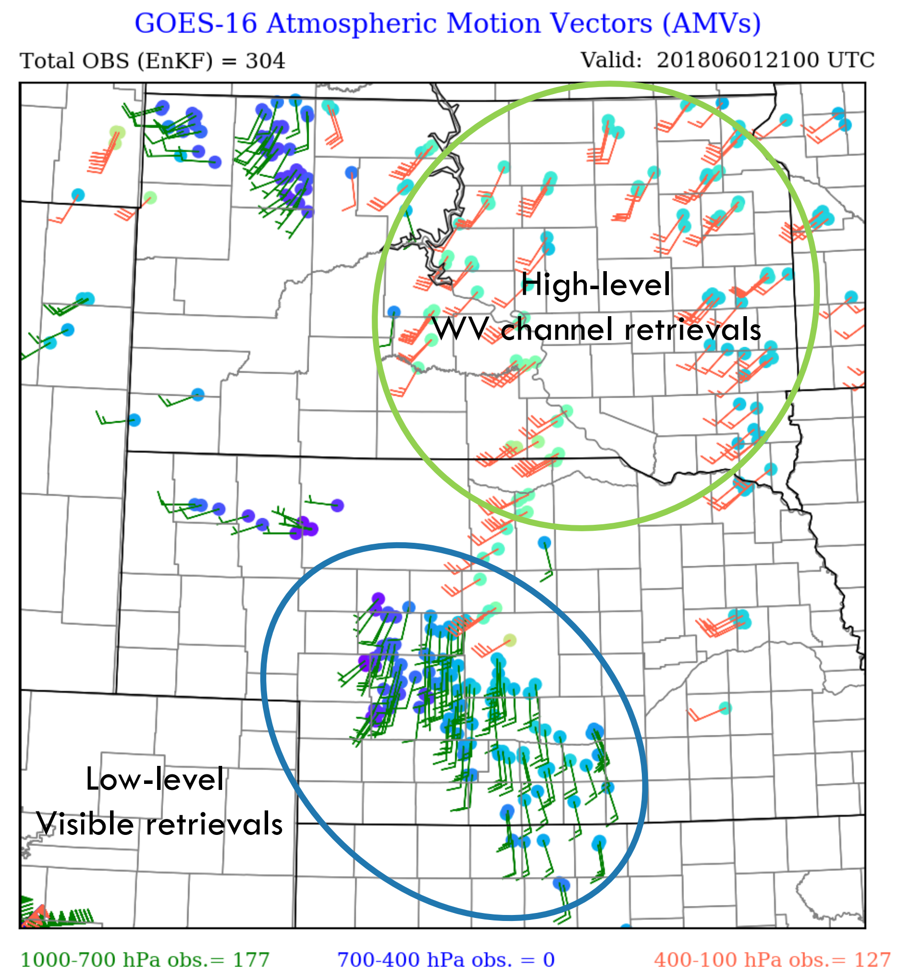
**Reflectivity Verification Skill at t=90 min**

| MODEL | FAR | POD | CSI |
|---|---|---|---|
| NOWV | 0.69 | 0.77 | 0.30 |
| WV | **0.55** | **0.94** | **0.44** |

- **Reflectivity skill scores improved!**

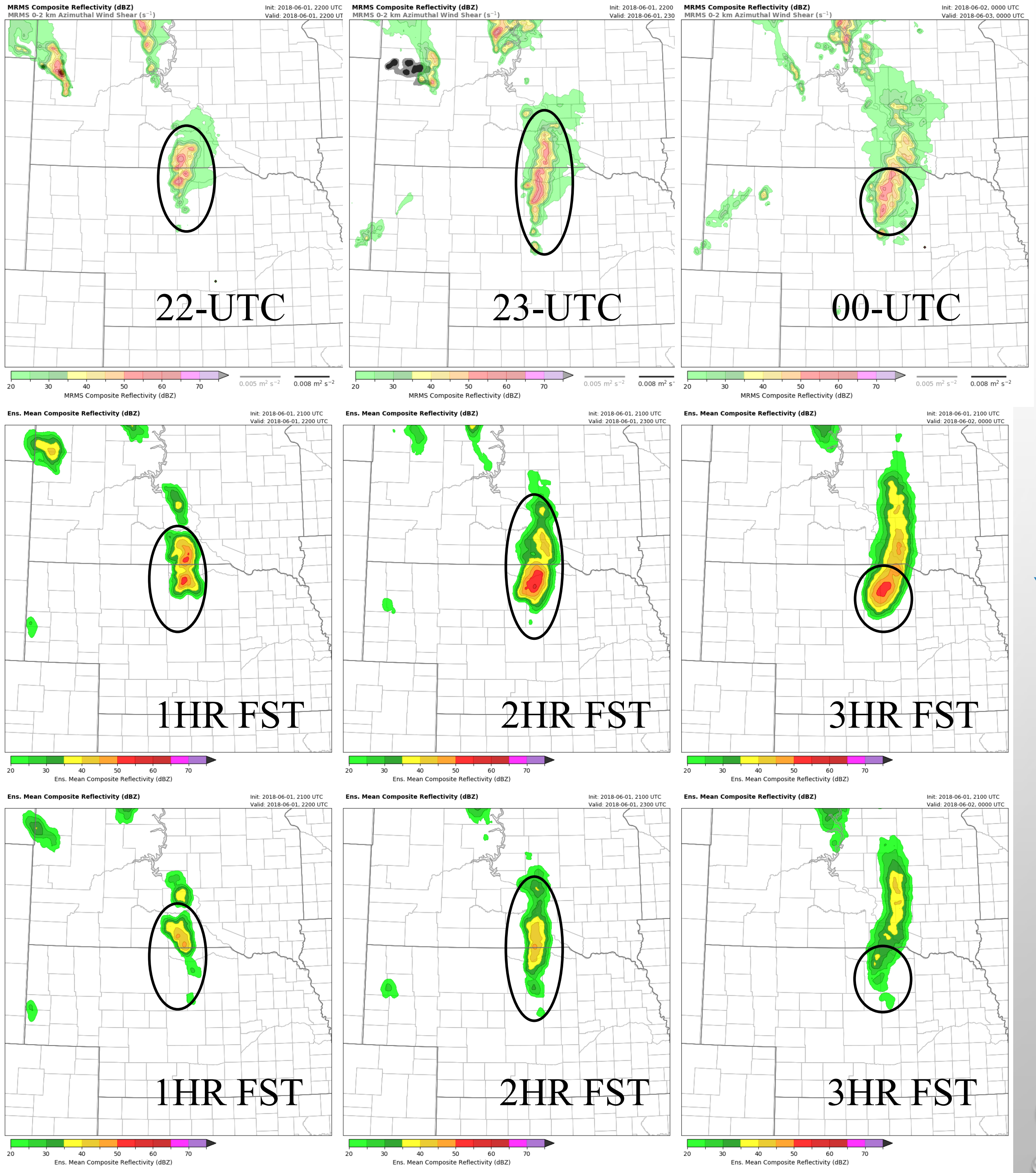
# Atmospheric motion vector assimilation

- **The AMV algorithm developed for the GOES-R ABI is used operationally at NOAA/NESDIS and follows the steps below:**
    - Obtain a set of three precisely calibrated, navigated and co-registered images in a selected IR or visible channel.
    - Locate and select a set of suitable targets in the middle image domain.
    - For each image pair, use a correlation algorithm to derive the most representative for the target scene.
        - -- When tracking cloud target scenes ABI channels 2, 7, 8 or 14 are used.
        - -- When tracking moisture gradients in clear target ABI channels 8, 9 or 10 are used.
        - -- Assign a height to the derived wind. (NCEP GFS model are used to calculate the target heights).
    - Average the vectors derived from each of the image pair.
    - Perform the quality control and assign quality indicator.
- **Assimilating AMVs can improve the environment since little wind information is assimilated otherwise**



# Event 20180601; 3-h Forecast from 2100 UTC

**OBS** (MRMS) →




**AMV** (with AMVs) →

- **Assimilating AMVs improved reflectivity forecasts**

**CNTL** (no AMVs) →

Ensemble mean reflectivity

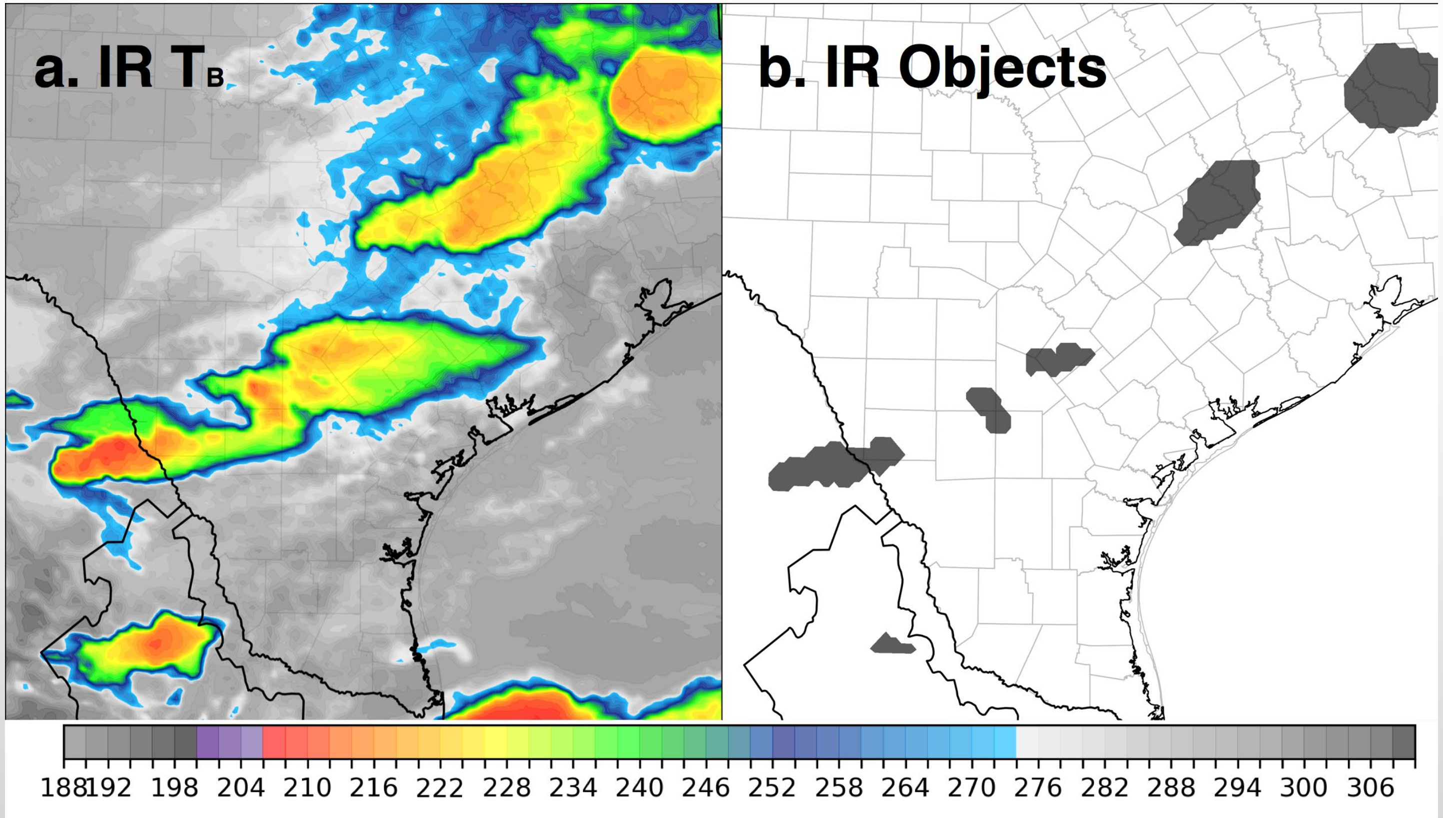
# BOO!!!

# Satellite object-based verification

Jones et al. (2018)

- **Verify cloud objects from synthetic satellite data against observations**
  - Similar to reflectivity and rotation object verification described by Skinner et al. (2018)
- Motivation for this was a high cirrus cloud bias observed during 2017 NEWS-e HWT using the NSSL 2-moment microphysics scheme.
  - The 2016 version of NEWS-e using Thompson microphysics had a more realistic depiction of cirrus clouds generated from convection
- Satellite objects were used to quantify these differences and develop a modified NSSL scheme to address the biases observed in 2017
  - One key challenge is to improve the cloud analysis without significantly impacting reflectivity and rotation scores.
  - Changes included reducing CCN, switching the ice hydrometeor fall speed formulation, and increasing hail and graupel collection efficiencies.
- Retrospective testing conducted on 6 severe weather events from 2017
  - Original NSSL (**NVD-RLT**), Thompson (**THOMP**), and modified NSSL (**NVD-MOD**) schemes were tested and validated using the satellite object based methods.

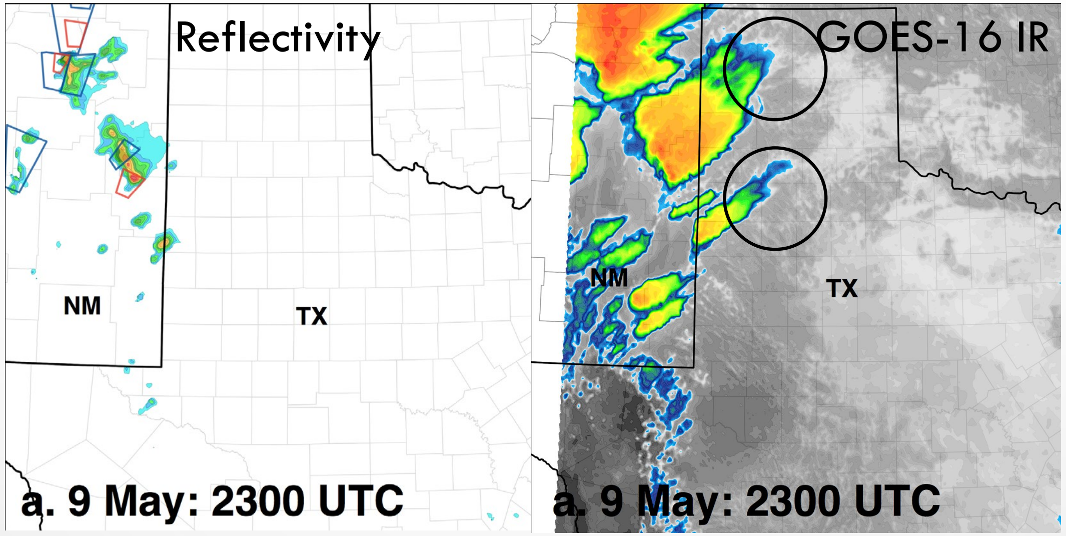
# Satellite IR Object Example



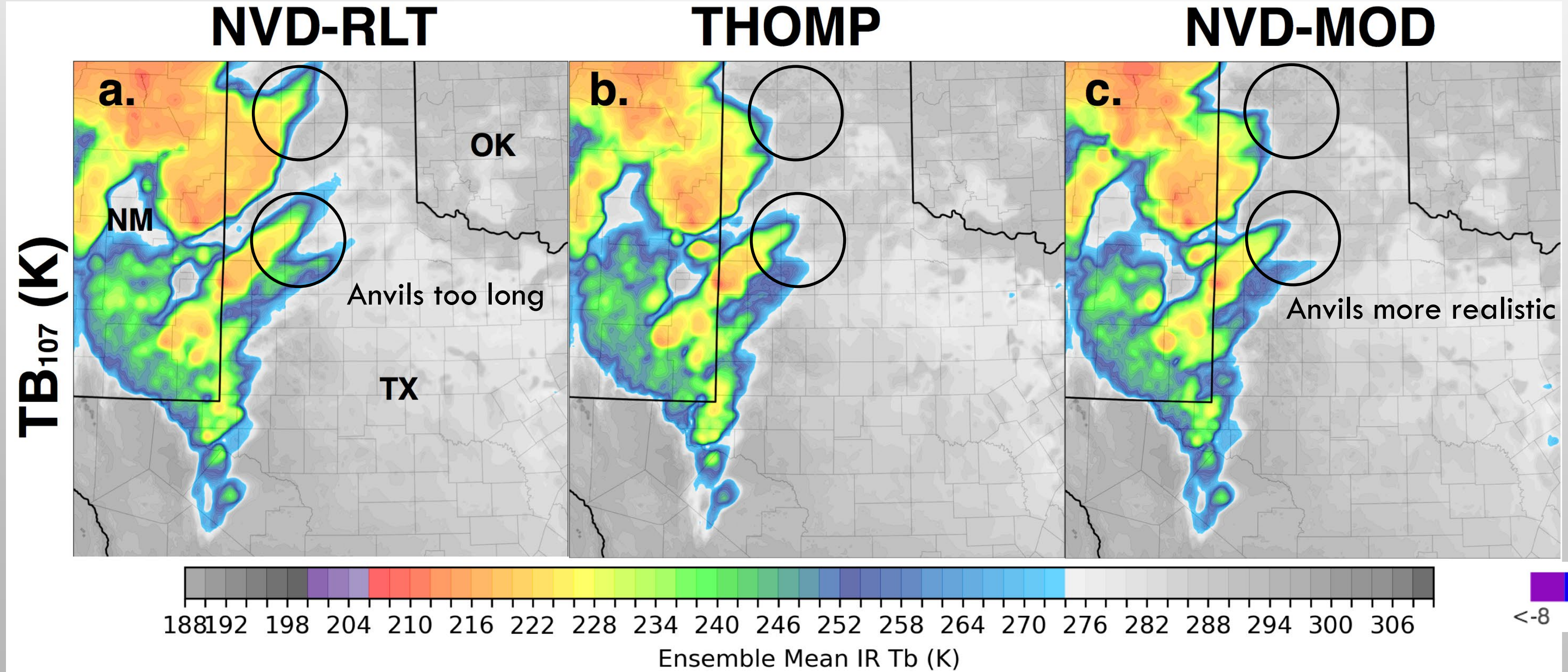

- Observed IR satellite cloud objects are defined is regions where IR $T_B$ < 225 K
- Similar methods applied to cloud top pressure and cloud water path objects
- Also possible to generate ”moisture” objects from water vapor imagery

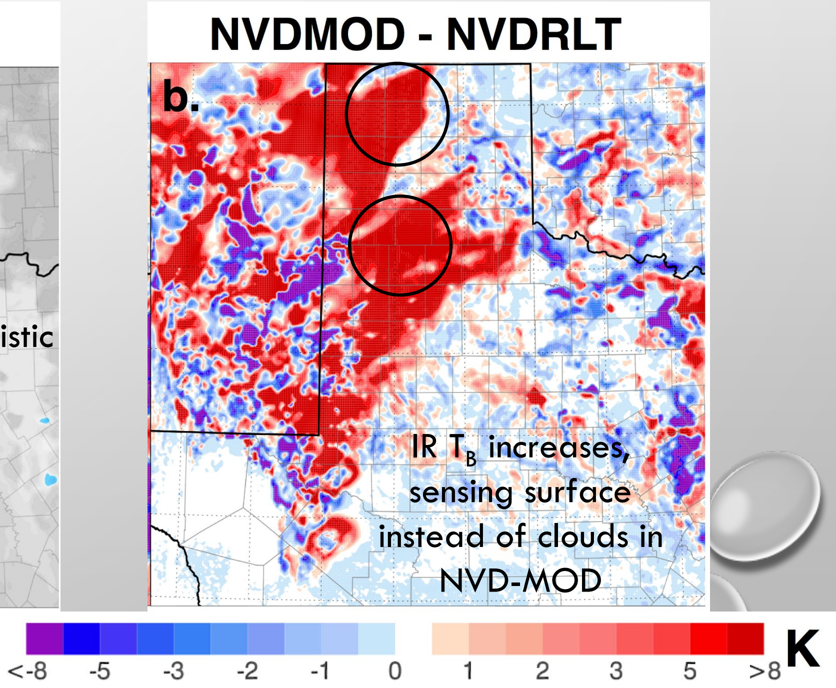
# Sensitivity of IR $T_B$ to cloud microphysics

- Tornado warned storms in New Mexico generating cirrus anvils
- Low-level clouds present over much of Texas



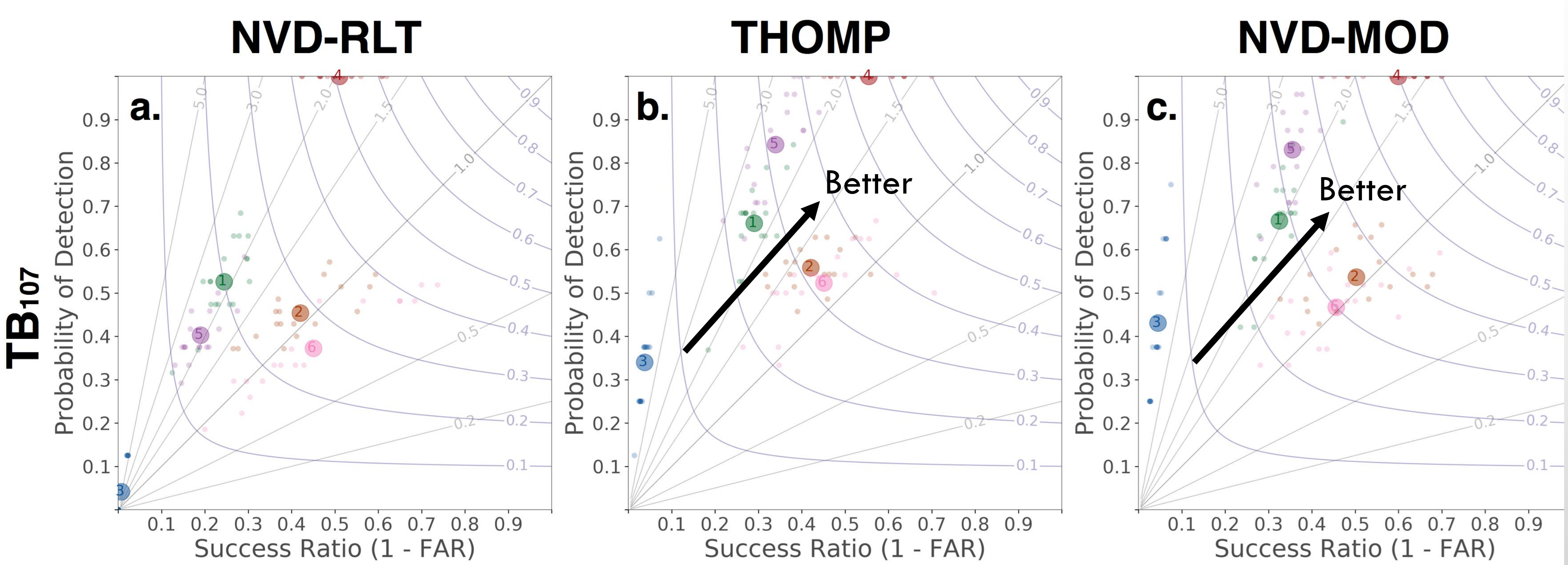

- **NVD-MOD** decreases anvil converge significantly compared to original and is similar to **THOMP** and observations



# IR Performance Diagrams

1-hour forecasts




**1. May 9** **2. May 16** **3. May 17** **4. May 18** **5. May 23** **6. May 27**

- For all 2017 cases, NVD-RLT generates the lowest skill scores for IR objects
- Thompson is generally better, with NVD-MOD having similar to improved skill compared to THOMP
- Modifications to NSSL microphysics were successful. Also, no degradation in reflectivity forecasts were observed

# Wrapping Up

- All forms of GOES-16 satellite data assimilation have shown promise in improving high impact weather forecasts using a NEWS-e based system
- CWP observations are currently the most effective, though the potential of AMVs has not been fully explored.
- Clear-sky radiance DA was successful, but the overall magnitude of the improvements are small
- **We are running out of room** to improve the current NEWS-e system by assimilating more data.
  - More DA cannot overcome model error.
- **Future Observations:**
  - All-sky radiances (better than CWP ?)
  - GLM lightning data (useful in coastal regions for hurricane forecasting)
  - Visible spectrum assimilation (utilize very high resolution information)

# Questions:

- ***Disclaimer**: No warranty is provided on the answers.*

# References:


- **Jones**, T.A and D. Cecil, 2006: Histogram matching of AMSR-E and TMI brightness temperatures, 14th Conference on Satellite Meteorology and Oceanography
- **Jones**, T. A., K. Knopfmeier, D. Wheatley, G. Creager, P. Minnis, and R. Palikonda, 2016: storm-scale data assimilation and ensemble forecasting with the NSSL experimental warn-on-forecast system. Part II: combined radar and satellite data experiments. *Wea. Forecasting*, **31**, 297-327.
- **Jones**, T. A., X. Wang, P. Skinner, A. Johnson, and Y. Wang, 2018: assimilation of GOES-13 imager clear-sky water vapor (6.5 um) radiances into a warn-on-forecast system. *Mon. Wea. Rev.*, **146**, 1077-1107.
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- Skinner, P. S. and coauthors, 2018: object-based verification of a prototype warn-on-forecast system. *Wea. Forecasting*, EOR.

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