Impact of Data Assimilation on Simulations of Continental Shallow Cumulus Near the ARM Southern Great Plains Site During HI-SCALE Campaign

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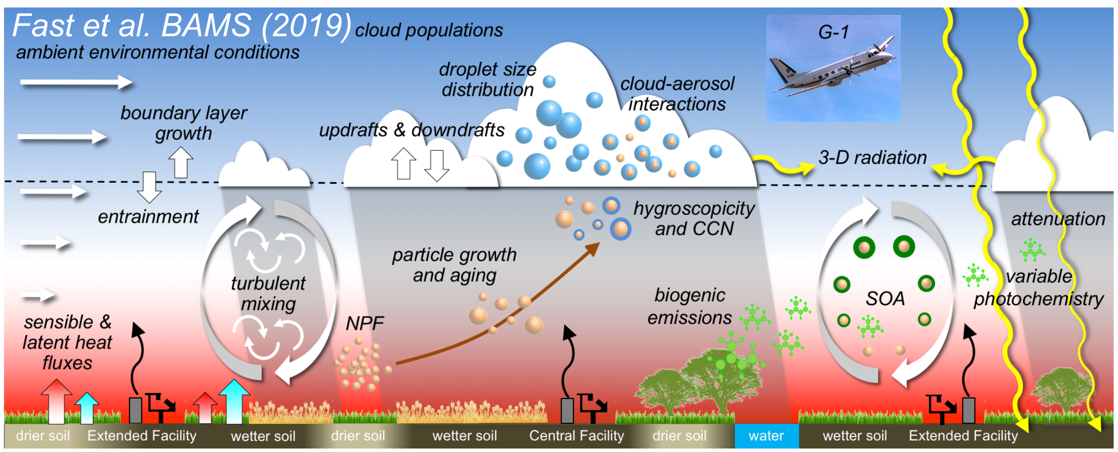
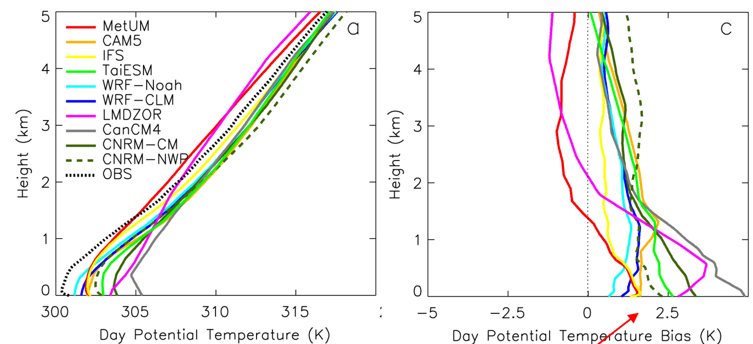
Motivation

- **Why we study shallow cumulus (ShCu)?**
  - small (diameter < 1 km), non-precipitating, wide-spread
  - atmospheric stability, Earth's radiative budget, transition to convection
  - poorly represented in climate model which makes future projection more uncertain
  - involved processes: ambient environment, land-atmosphere, boundary layer, aerosol, etc.



Morcrette et al. JGR Atmos. (2018)



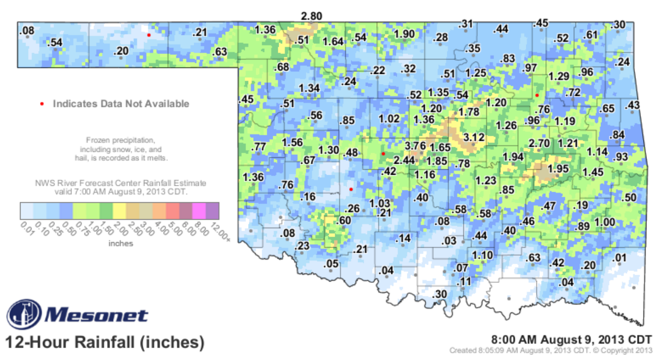
Near-surface warm bias over U.S. SGP

- **Boundary layer (BL):**
  - its evolution strongly controls formation and growth of ShCu
  - most uncertain layer in weather and climate models
  - need more constraints

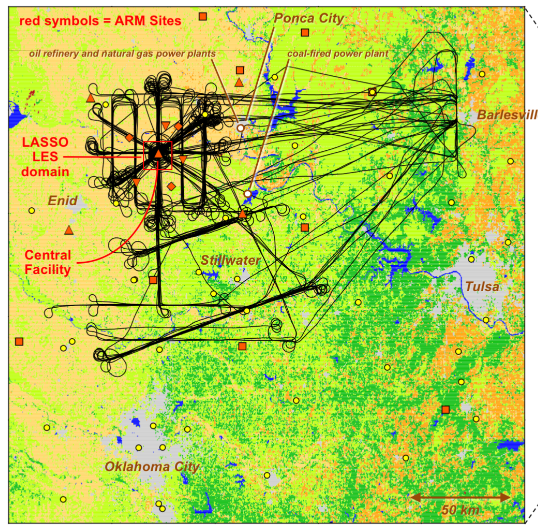
Approach

- **Holistic Interactions of Shallow Clouds, Aerosols and Land Ecosystems (HI-SCALE)** provide critical in-situ measurements of the boundary layer, cloud microphysics and dynamics, and aerosol properties

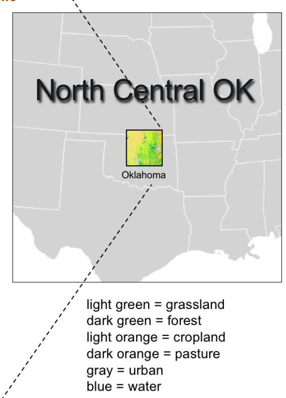
- **Oklahoma Mesonet**

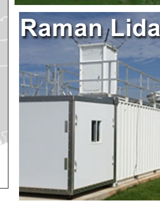


https://www.kgou.org/post/flooding-takes-oklahoma-city-mans-life



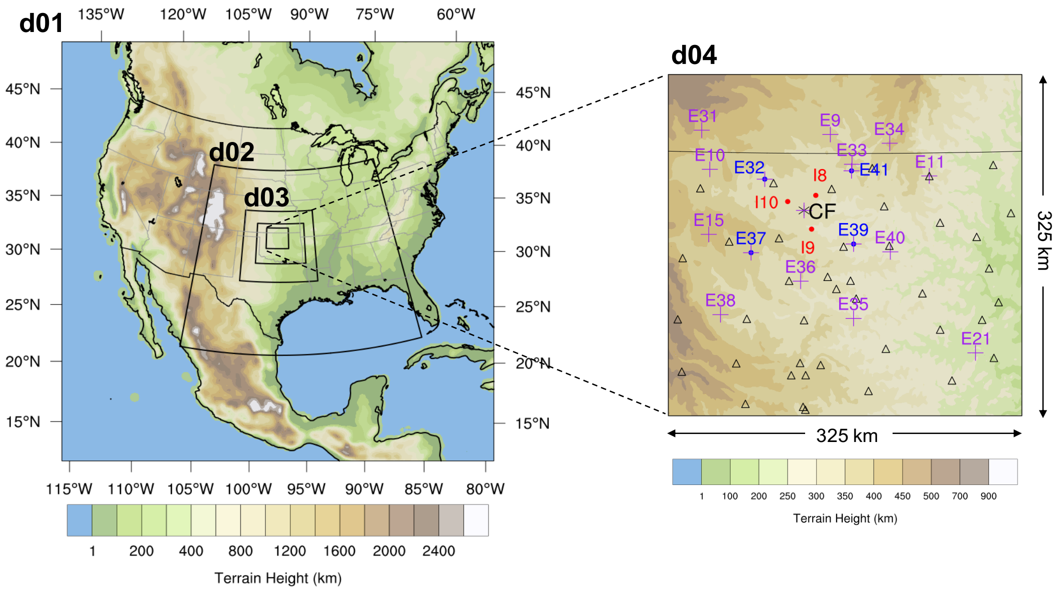
ARM





- **Multi-scale data assimilation** integrates available observations to constrain:
  - large-scale weather pattern and mesoscale ambient environmental conditions
  - boundary layer structure and properties

Forecast model and assimilation scheme



- **Weather Research and Forecasting (WRF) ARW V3.9.1.1**
  - four one-way nested domains.
  - 36, 12, 4, 1.3 km resolution
  - 74 sigma layers with finer grid in BL
  - d04 covers all ARM SGP sites

Sonde, Raman Lidar, wind profilers, Doppler lidars, SGP mesonet, Oklahoma mesonet

- **Community Gridpoint Statistical Interpolation V3.6**
  - **4DEnVar** (outperforms 3DVar and 3DEnVar)
  - Hybrid (0.85 flow-dependent + 0.15 static)
  - 54 multi-physics ensemble members for all domains
  - NCEP NAM model forecasts → static

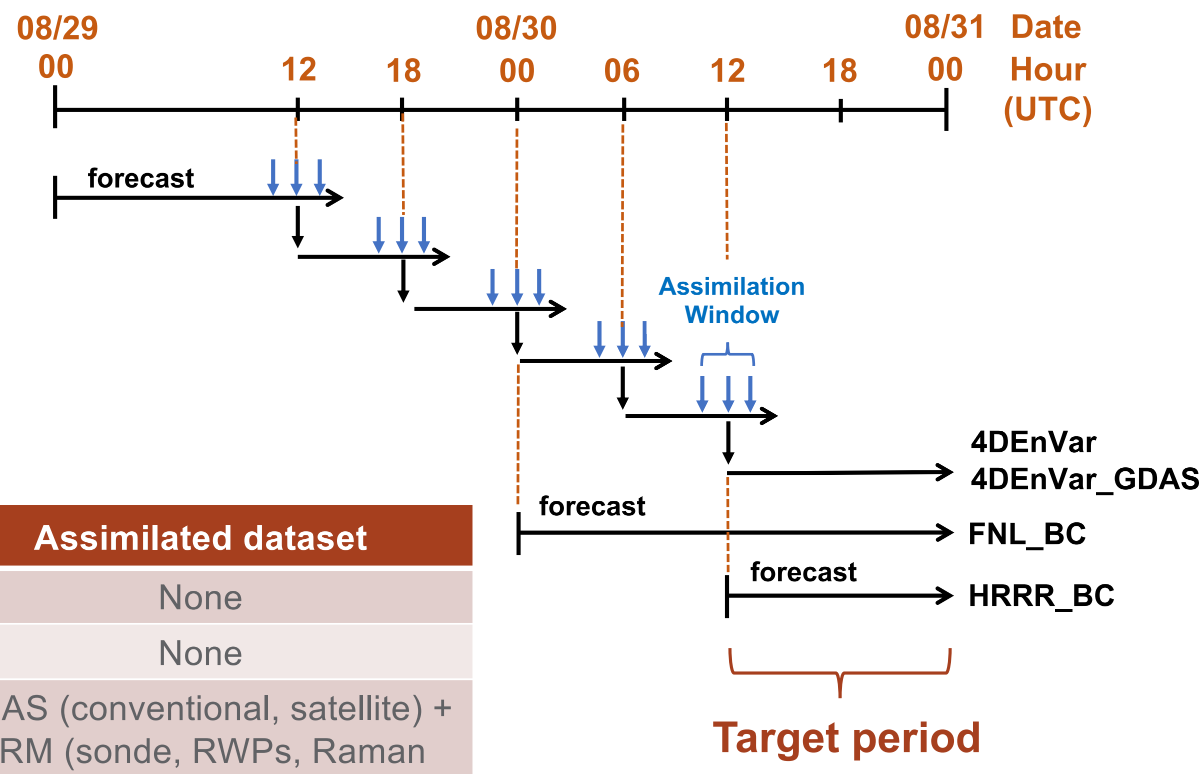
Multi-physics ensemble

PBL	Cumulus (d01,d02)	MP	Land
MYJ	KF_CuP	Morrison	Noah
YSU	Grell 3D Ensemble	Thompson	Noah-MP
MYNN	Tiedtke	WSM6	

Experimental design

- **Target period:** 12 UTC Aug. 30 to 00UTC Aug. 31, 2016
- **Assimilation strategy:**
  - 5 times 6hourly assimilations
  - 3 hours 4DEnVar window
- **Initialization time** varies due to adaptive needs of spin-up
- **Experiments**

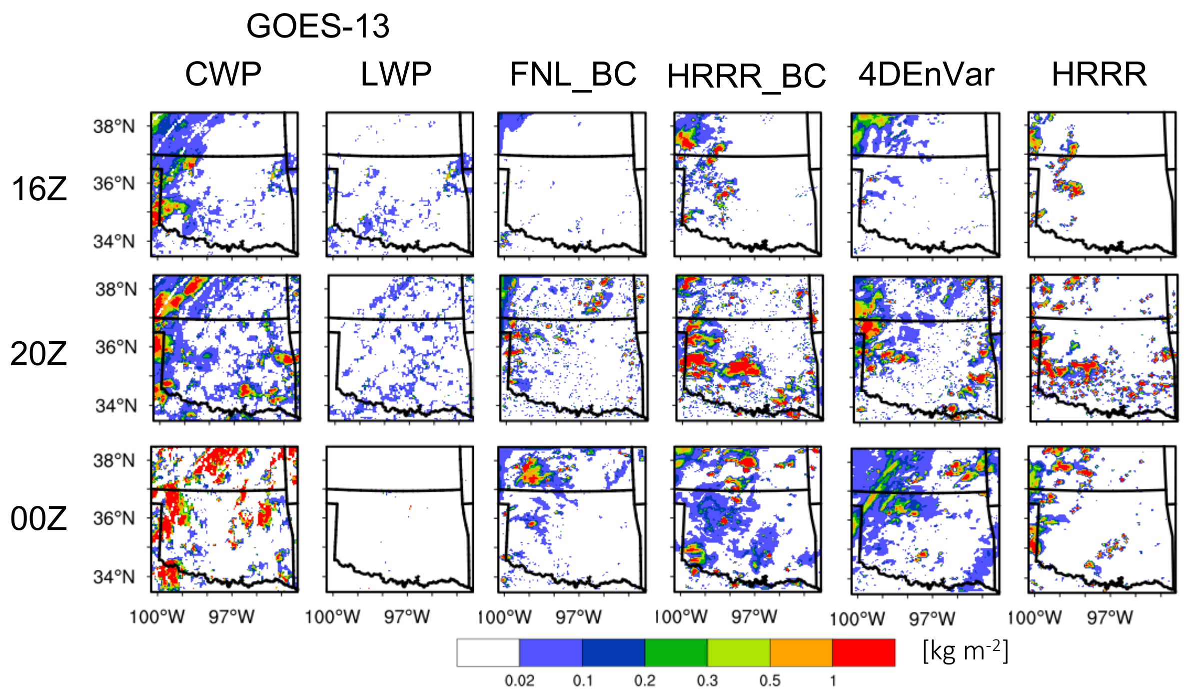
Experiment	I.C. & B.C.	Assimilated dataset
FNL_BC	NCEP FNL (1°)	None
HRRR_BC	HRRR (3 km)	None
4DEnVar	NCEP FNL (1°)	GDAS (conventional, satellite) + ARM (sonde, RWPs, Raman Lidar, mesonet) + OK Mesonet
4DEnVar_GDAS	NCEP FNL (1°)	GDAS (conventional, satellite)



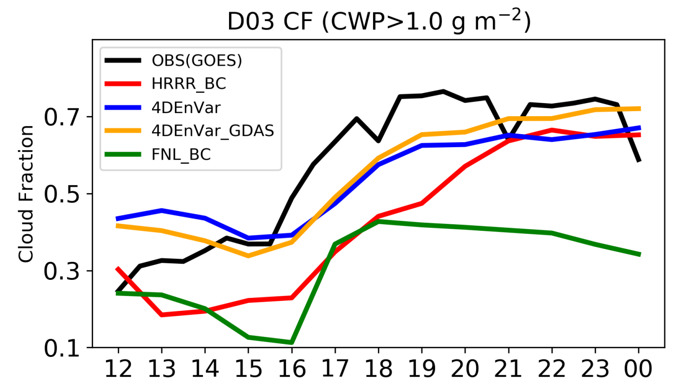
Simulated clouds in domain 3 (4 km res.) against GOES-13 retrieval

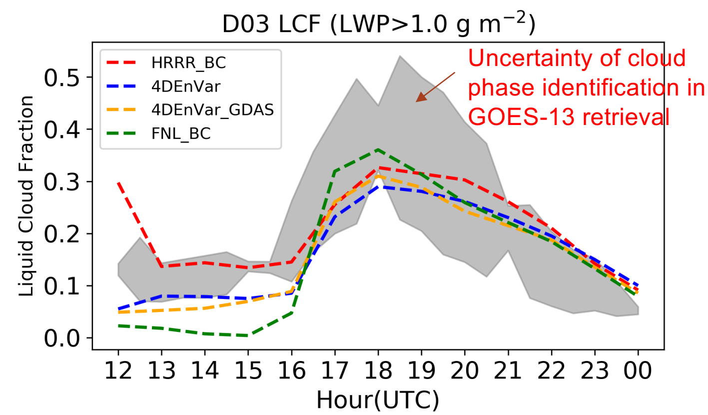
Comparison of cloud water path (CWP)

- GOES-13 5-km retrievals (Minnis et al., 2008, 2011)
- Operational HRRR forecast is introduced as reference (ver. 2)



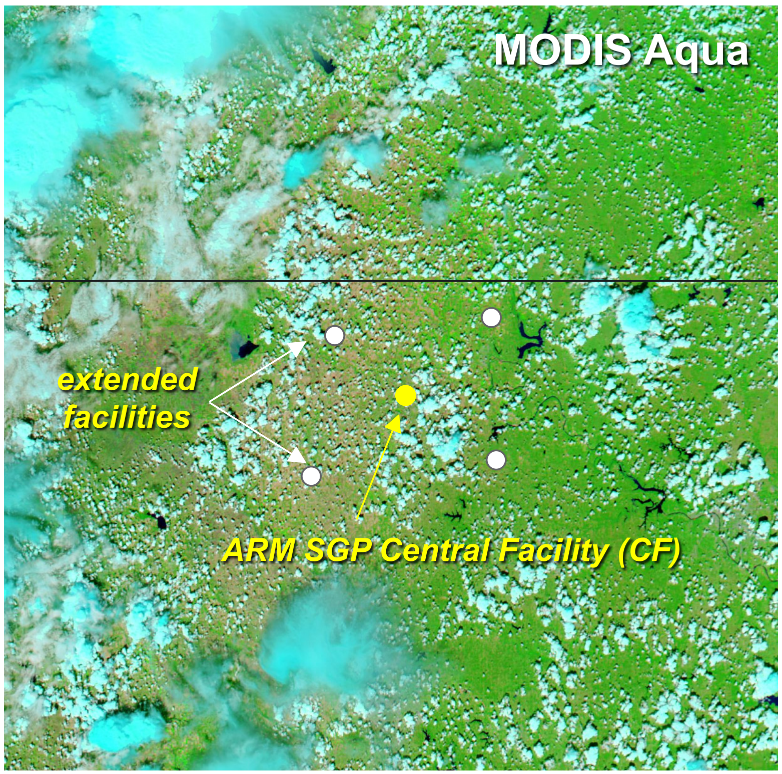
Evaluation of CF and LCF



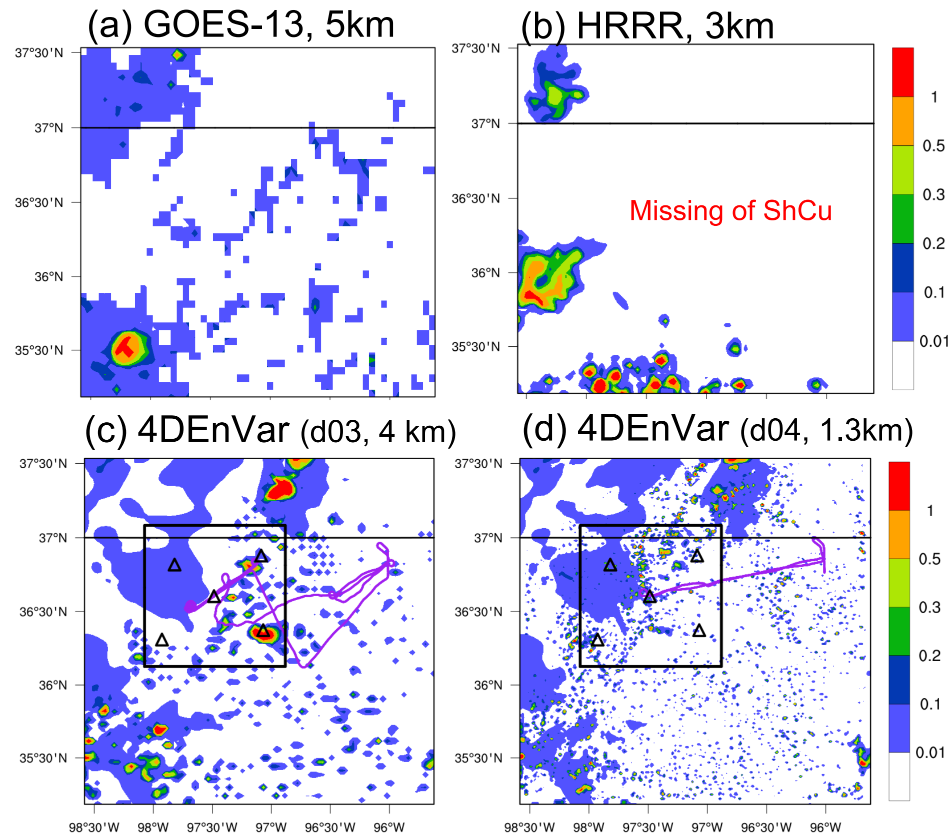


Observed and simulated clouds at noon around the ARM SGP site

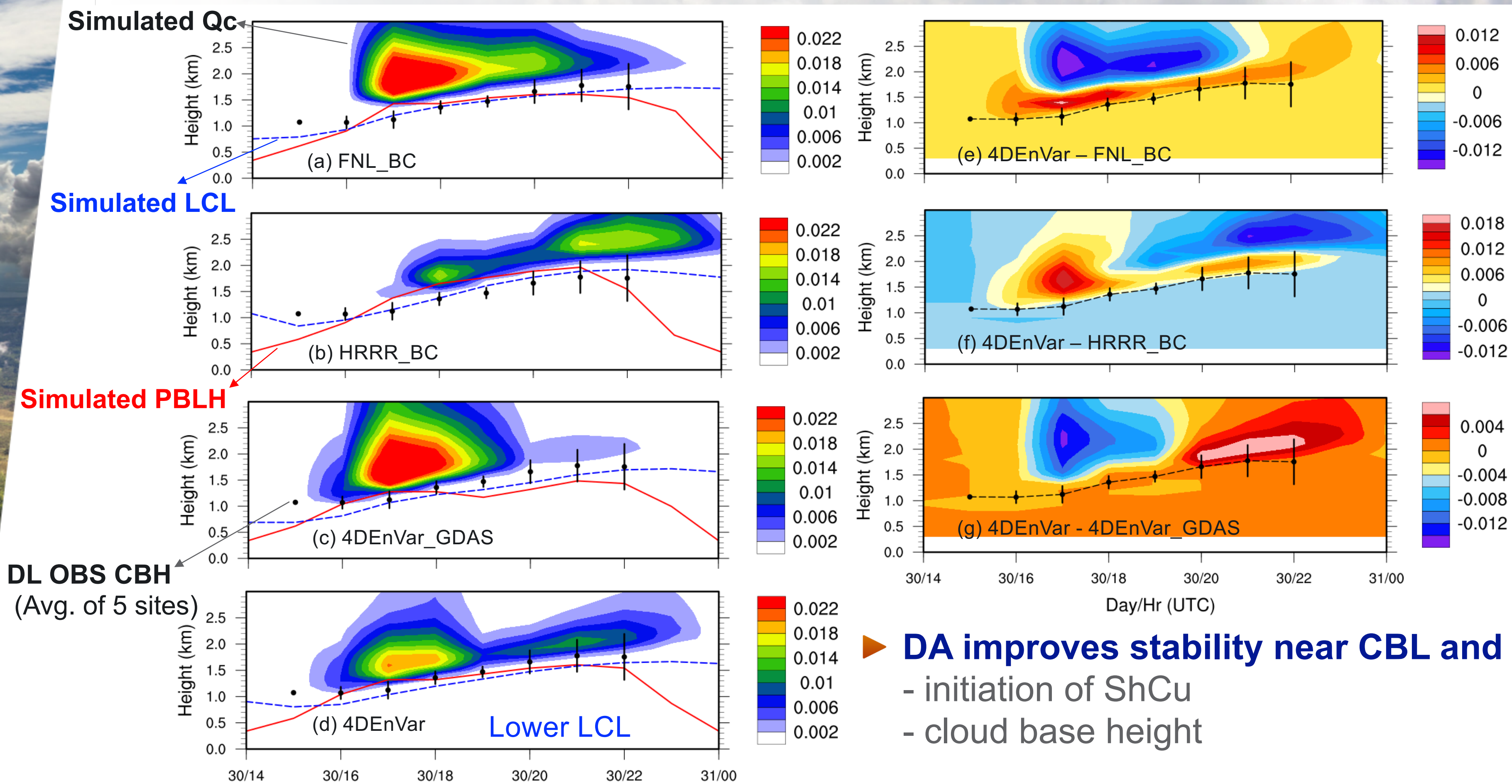
▶ Visible Satellite Image ~ 1950 UTC



▶ Cloud Water Path at 1800 UTC

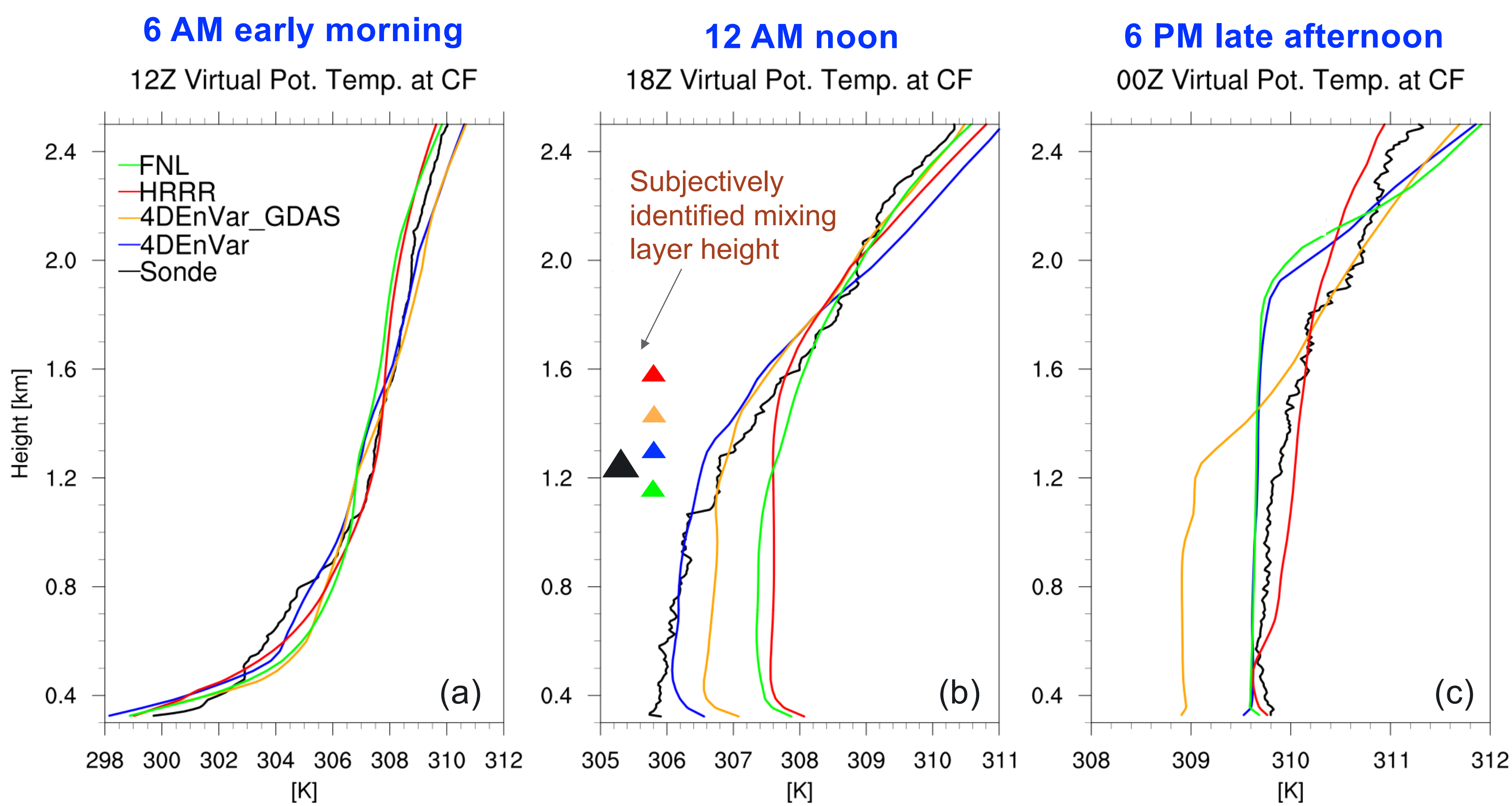


Lifecycle of shallow cumulus clouds: CBH estimated by Doppler Lidars

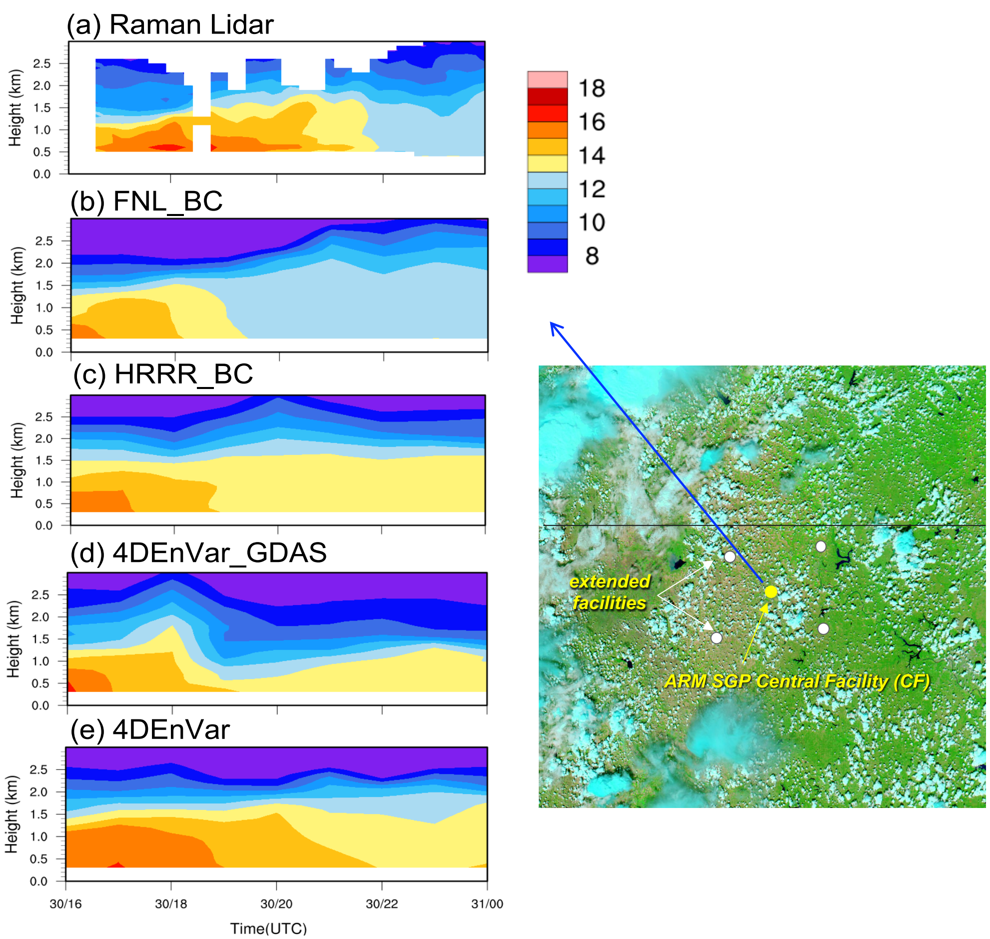


- **DA improves stability near CBL and alters**
  - initiation of ShCu
  - cloud base height

Convective boundary layer (CBL) evolution evaluated by CF radiosonde



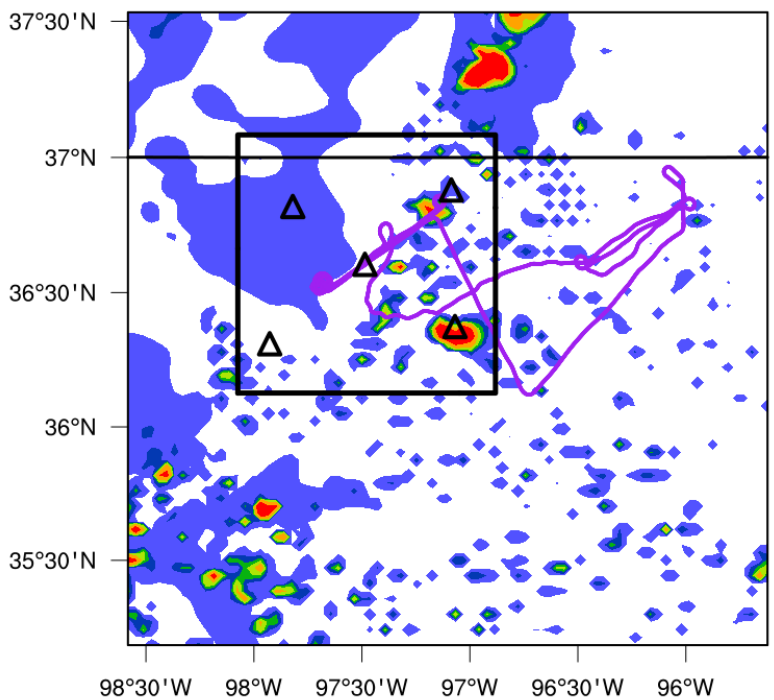
Moisture mixing in CBL: comparison with Raman Lidar observation at CF

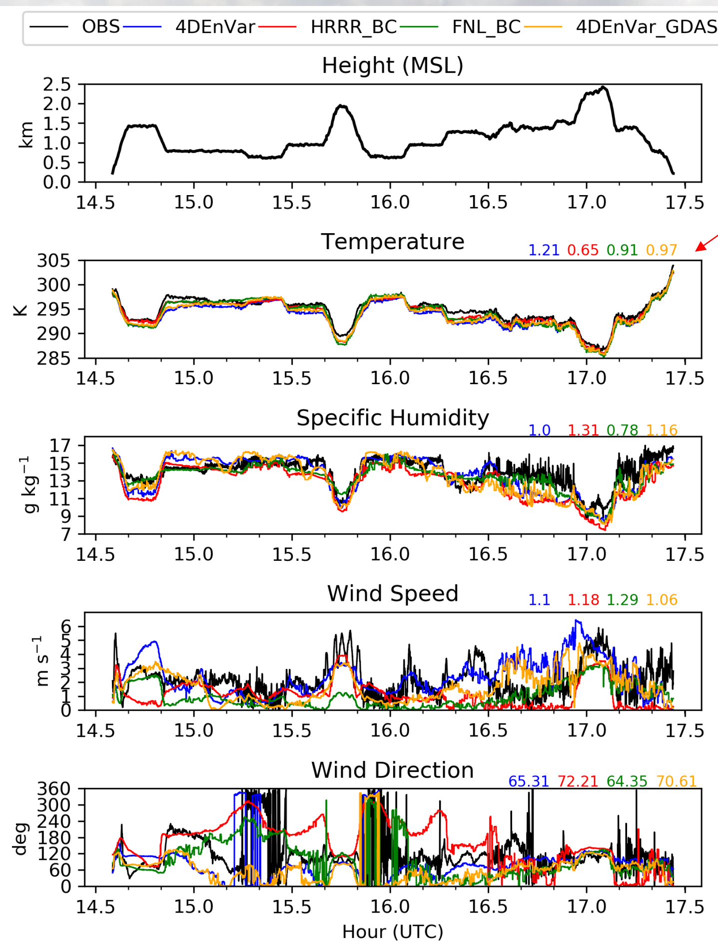


- **Raman Lidar** observed vertical moisture mixing due to turbulence within CBL until 22Z
- **FNL_BC, HRRR_BC**, **4DEnVar_GDAS** become too dry after around 19Z
- **4DEnVar** is able to maintain reasonable amount of moisture mixing within CBL through the daytime period
- **More moisture within CBL** increases instability

Meteorological Condition in CBL evaluation by G-1 aircraft measurements

▶ **Morning mission (1435 – 1726 UTC)**





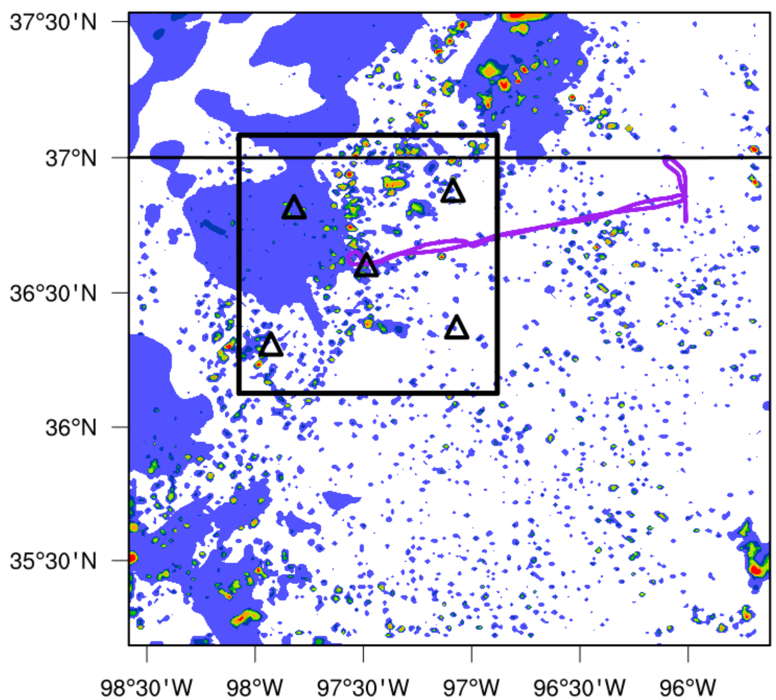
Mean absolute error

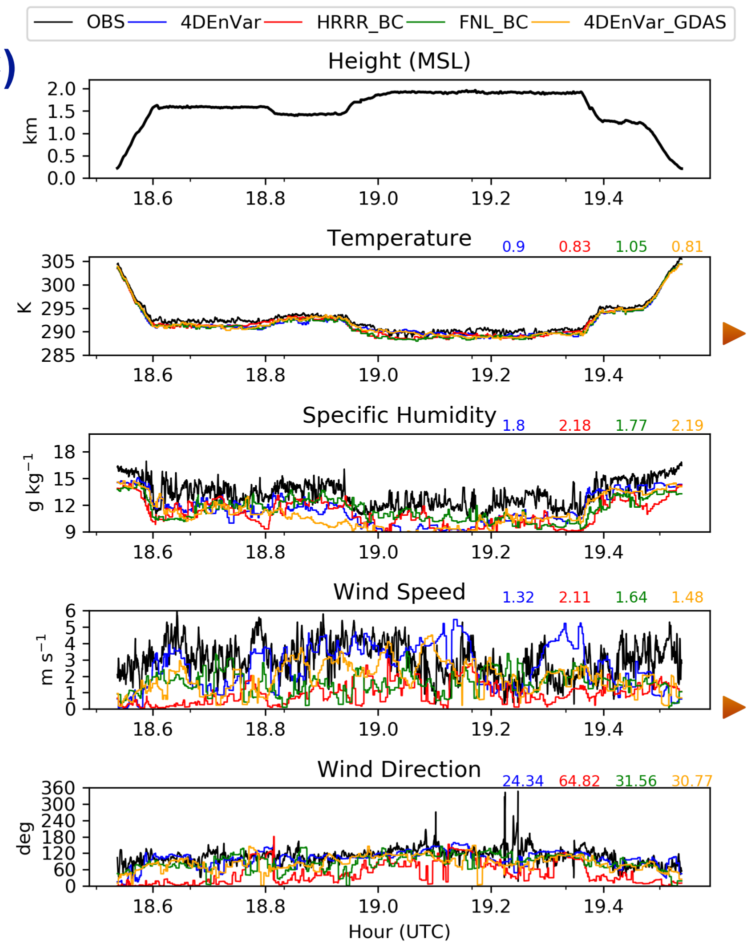
Comparable with OBS

Larger uncertainty in WDIR when in lower WSPD regions

Convective Boundary Layer Meteorological Conditions evaluated by G-1 aircraft measurements

▶ Afternoon mission (1832 – 1932 UTC)





- Larger errors in the afternoon especially in specific humidity

Possible causes:
1) drifted states
2) more clouds

- Better in WDIR indicates less model uncertainty at higher altitudes

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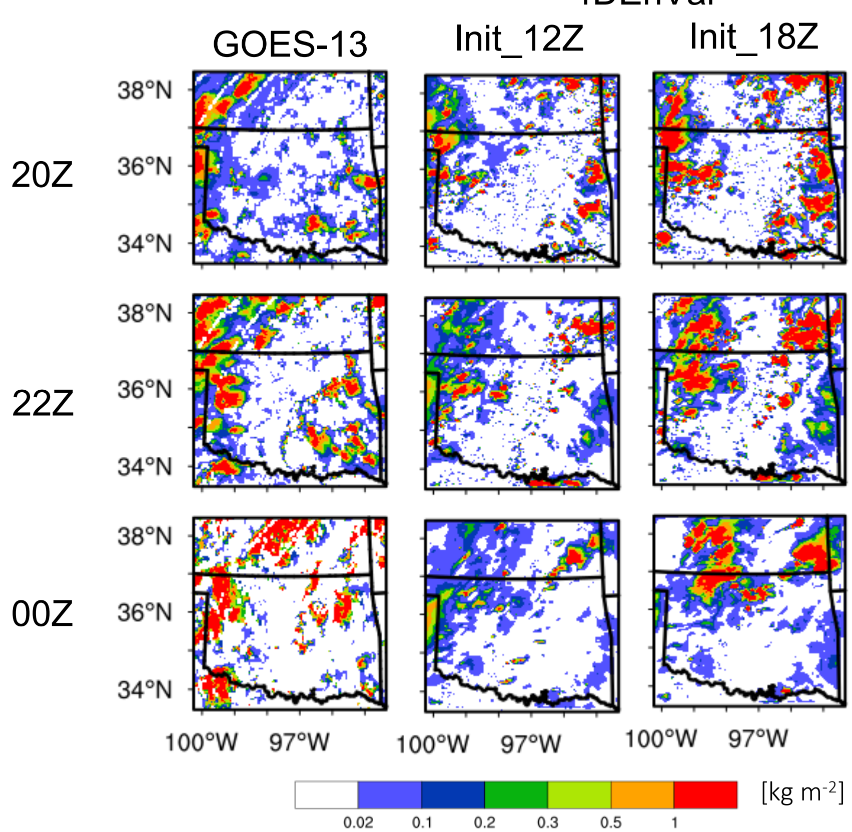
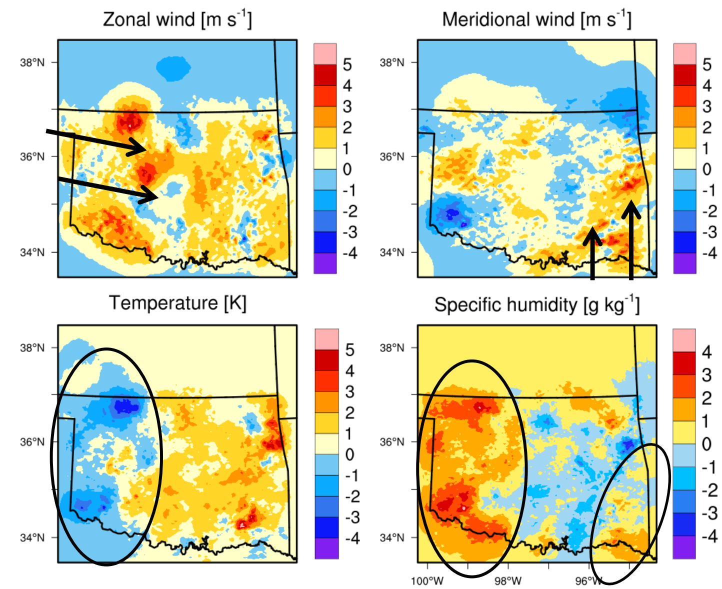
Sustaining transitioned convective Clouds: Impact of additional assimilation at 18Z

▶ Cloud Water Path



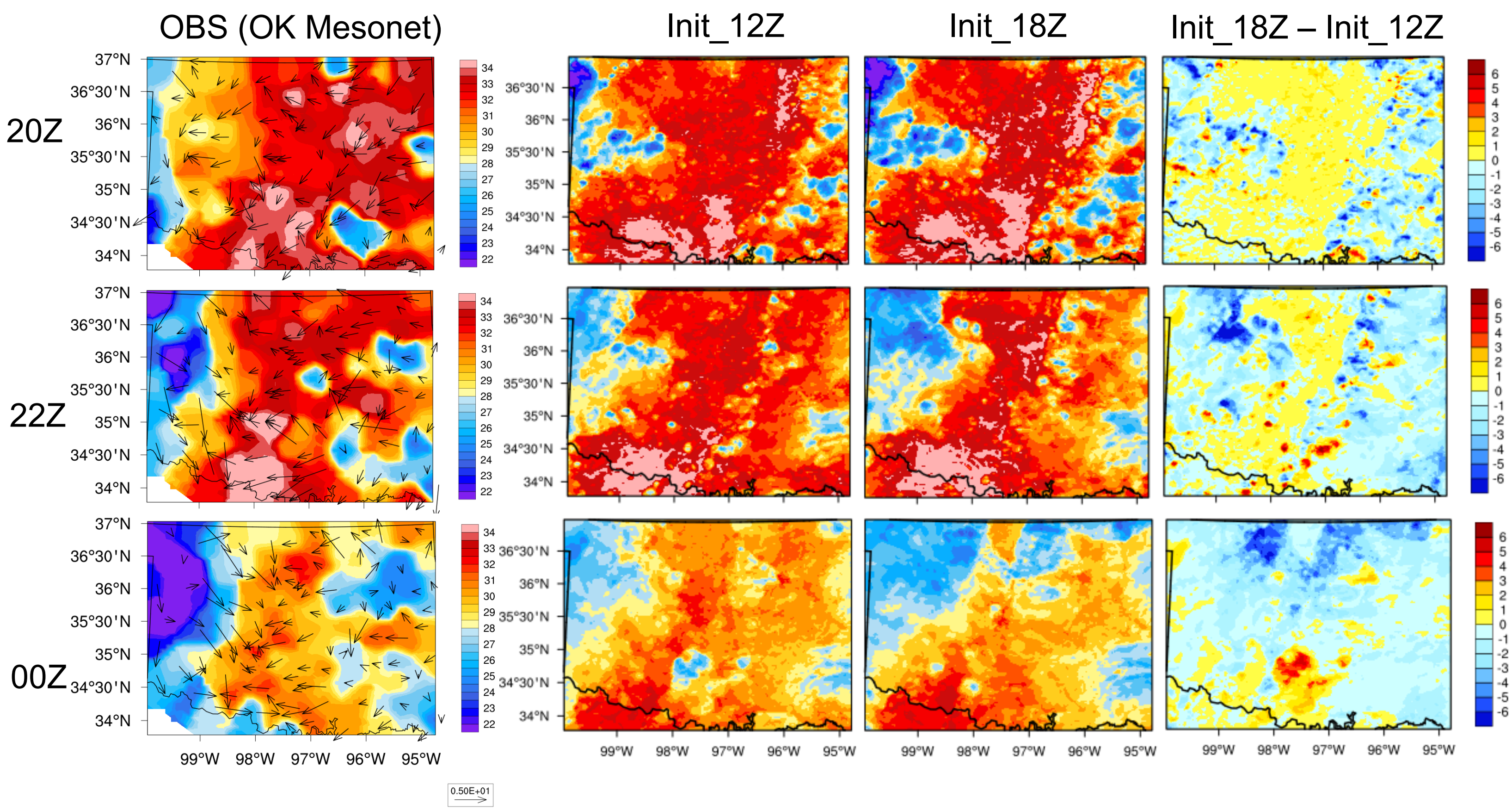
▶ Surface Increments at 18Z



- GOES-13 retrieval shows tendency of increasing CWP
- 18Z assimilation helps maintain convective strength

Strengthened Cold Pools: against OK Mesonet temperature

- **Evolution of Surface T**



Conclusion and next step

- **Data assimilation** works reasonably well to constrain cloud-resolving model especially within boundary layer, leading to more accurate ShCu and convective cloud simulation
- **HI-SCALE field campaign** datasets complements data assimilation and model-observational analysis
- **Remaining uncertainty on cloud presence** can be further constrained by assimilation of hydrometeors (cloud water path, radar reflectivity)
- **Providing I.C. and B.C. to reduce uncertainties in LES** :
  - large-scale weather pattern and mesoscale ambient environmental condition
  - boundary layer structure and properties
- **Parameterized processes of land-atmosphere coupling, PBL evolution, and aerosol effects** are challenging but essential components on the path toward better prediction of ShCu