Use of 1-min resolution GOES-16 Satellite Imagery and Ground-based Observations for Cloud Process Determination

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Motivation, Study Hypothesis & Science Questions

- Many prior studies have examined growing convective clouds in visible and infrared imagery:
  - From GOES and MSG – 12-16 channels in visible and infrared at 5 min temporal resolution
  - Identified 6/8 field rankings for cloud depth, glaciation indicators and updraft strength assessment
- Senf and Deneke (2017) analyzed over 100 cases from 2012-2014 over central Europe using SEVIRI aboard MSG to gain insights into cloud top properties related to precipitation.
- Prior studies (Lareau 2018; 2020) have examined the statistical behaviors of cumulus clouds from upward-looking ground-based instruments, to help understand in-cloud processes.

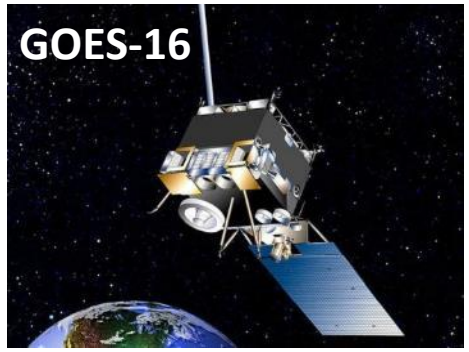
Hypothesis: By combining 1 min resolution GOES-16/-17 data of cloud-top features and trends with high-resolution ground-based observations of the same clouds, one can further understand in-cloud processes.

Question: Can parameters within convective parameterization schemes be replaced through examination of real-time satellite fields?

Data Collection and Methodology

- GOES-16 data were collected for various convective initiation days in the Southeast and Central United States (1 m Flex Mesoscale Sector) - **IR Channels 7-16**
- WSR-88D data was collected from various radars in the regions to analyze the storms and determine the convective initiation time
  - **Defined as first echo of ≥ 35 dBZ (Mecikalski et al. 2010a) or multiple scans of ≥ 30 dBZ**
  - Gridded via Python Py-ART (Python ARM Radar Toolkit; Helmus & Collis 2016)
    500m x 500m x 500m spatial resolution (x,y,z)
- Satellite data read into McIDAS (Lazzara et al. 1999)
  - **Band 13: 10.35 µm "Clean" Longwave IR Channel**: not affected by atmospheric gases and can be used as a proxy for cloud top temperature (Rossow and Schiffer 1999)
  - Tracked clouds for 60 minutes (-30 to +30) at 1 minute temporal resolution
- KAZR (Ka-Band ARM Zenith Radar) – probes the extent and composition of clouds at mm wavelengths
- Doppler Lidar (DL) – uses laser pulse to measure atmospheric constituents such as ice crystals and water vapor
  - Value Added Product (VAP) that can calculate the vertical velocity and binned every 15 minutes (averaging)
  - Laser signal gets attenuated once it reaches clouds

Experimental Design



GOES-16 Information

- Channel differences to determine cloud top rising rates, cloud top glaciation, cloud top height and cloud expansion rates.
- Determine moist adiabatic lapse rates over a cloud ensemble region.

KAZR
In-cloud frozen hydrometeors

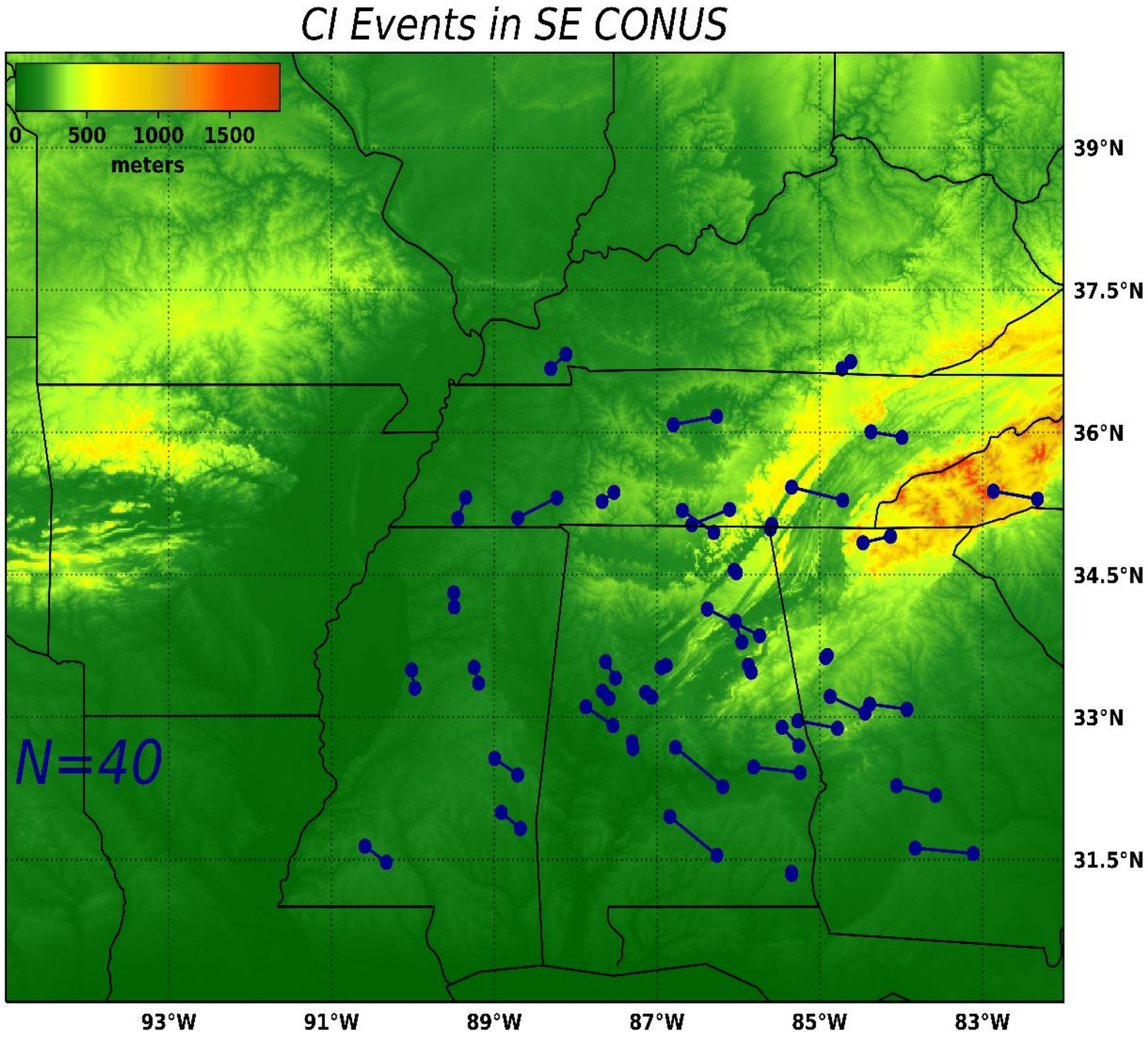
cumulus cloud

main updraft

In Cloud Motions - Ideas for this:
1. Dual Doppler Analysis
2. Cloud Radar Doppler Spectrum

Ceilometer
Cloud bases height

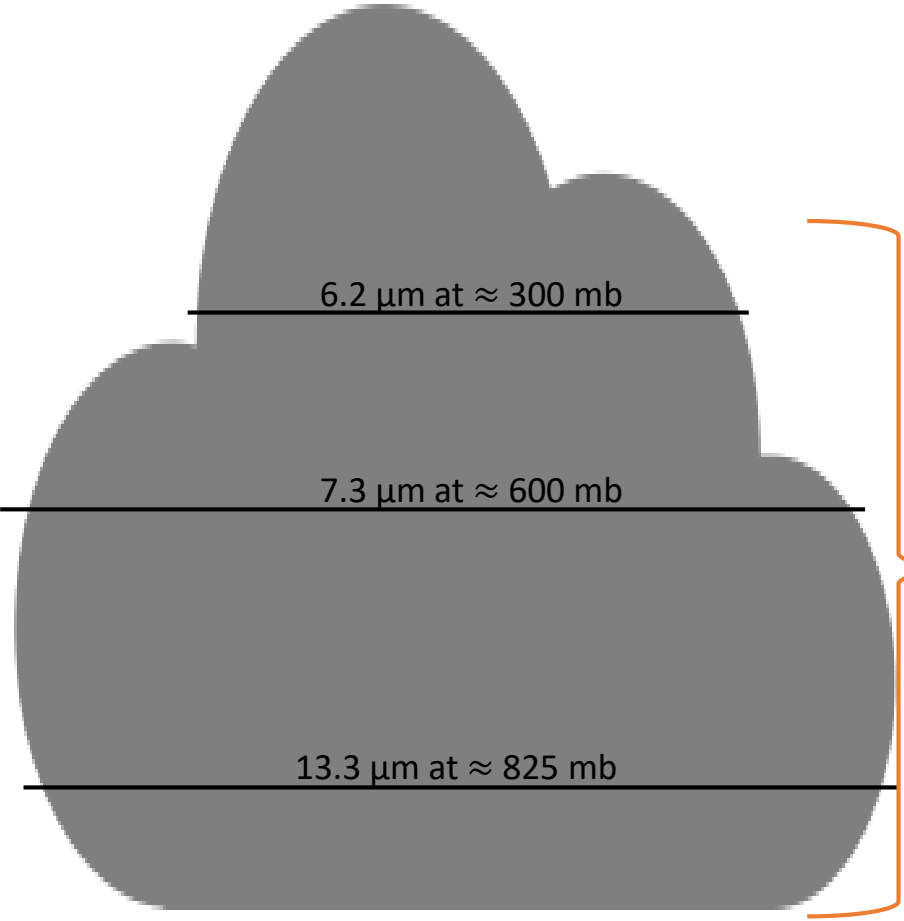
Doppler Lidar
Cloud base vertical velocity



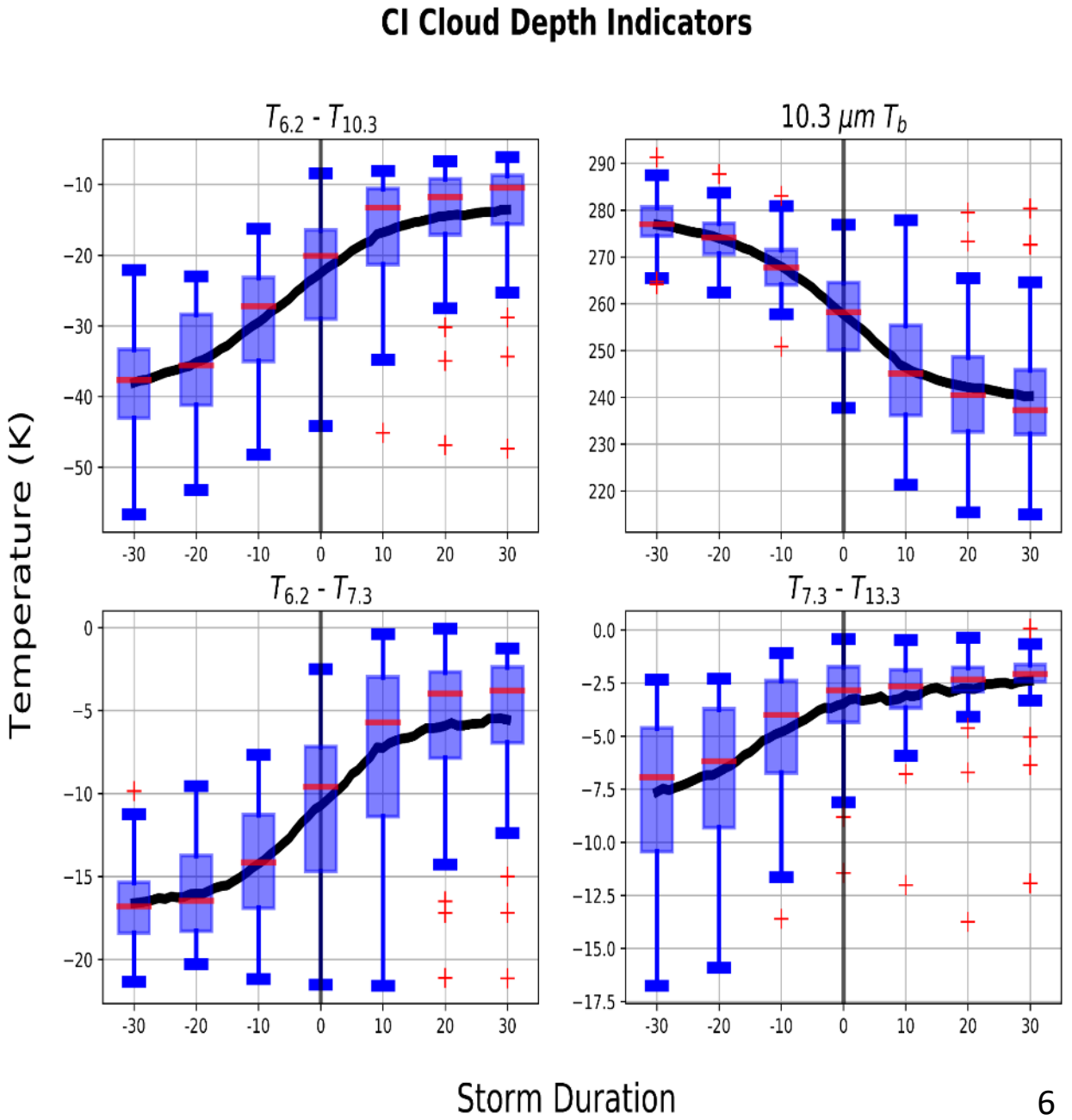
CI Dates	# of Events
July 14, 2018	7
June 3, 2018	5
June 24, 2018	5
July 22, 2018	6
July 21, 2018	7
May 20, 2018	10

Convective Initiation (CI) Events

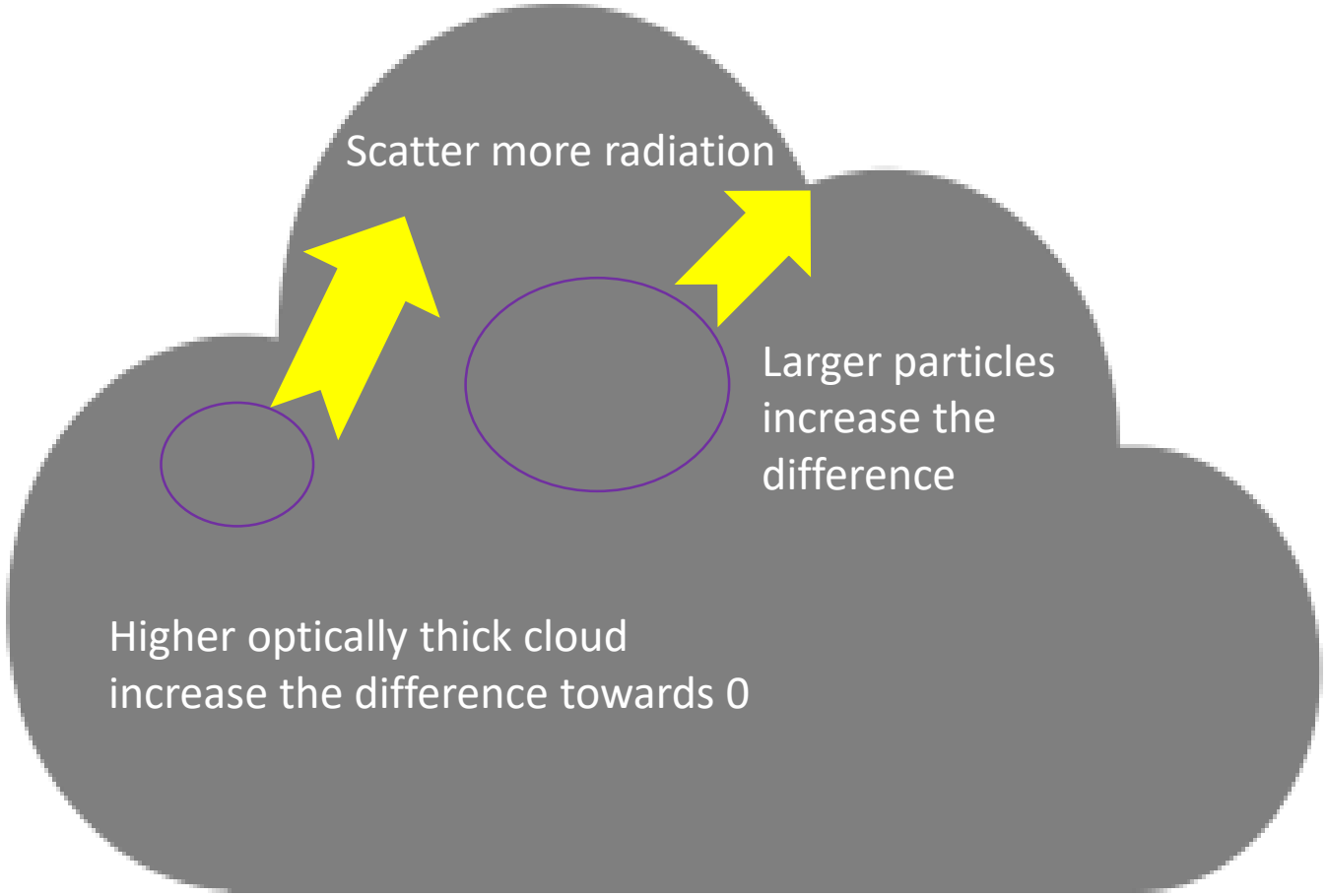
- Collect CI events in Southeast U.S. and Southern Great Plains
- Data collected every 1 minute for the 60 minute duration of the events

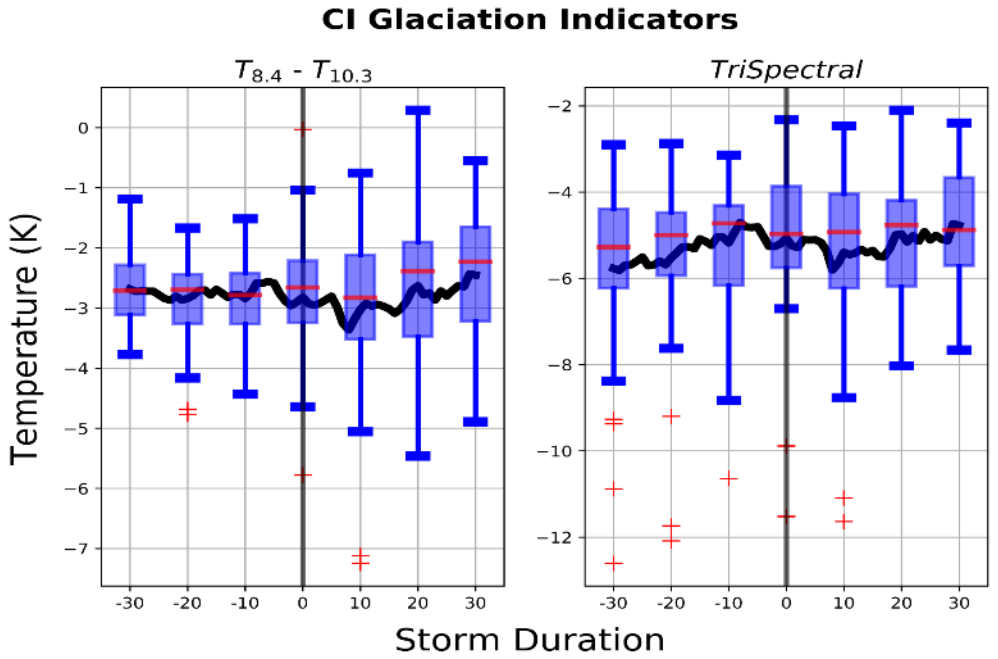


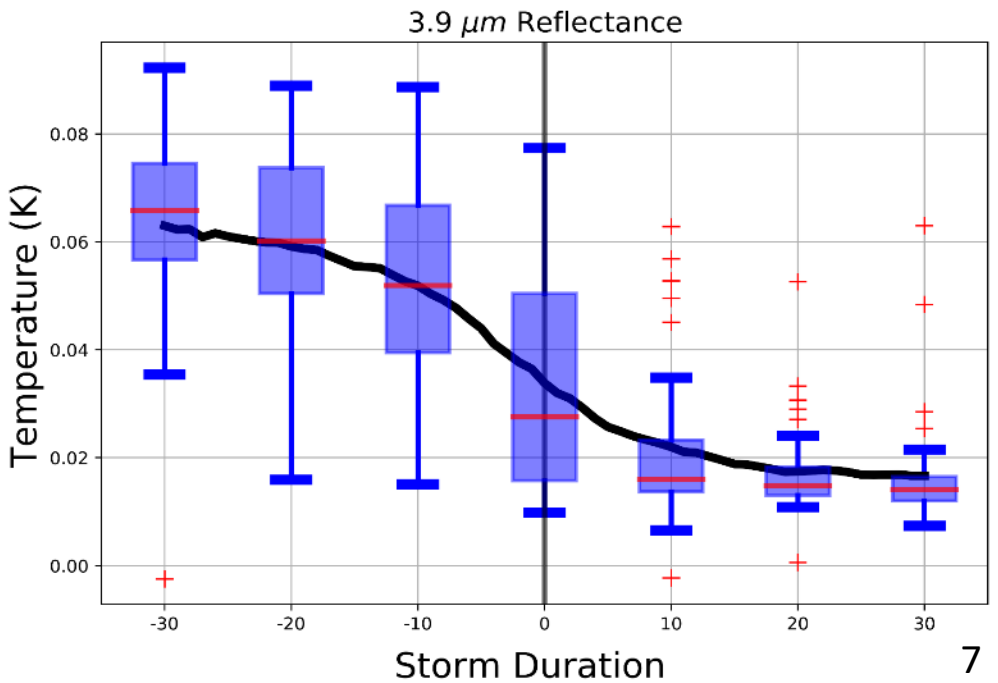
Channel Difference Temperature → 0, the cloud is growing



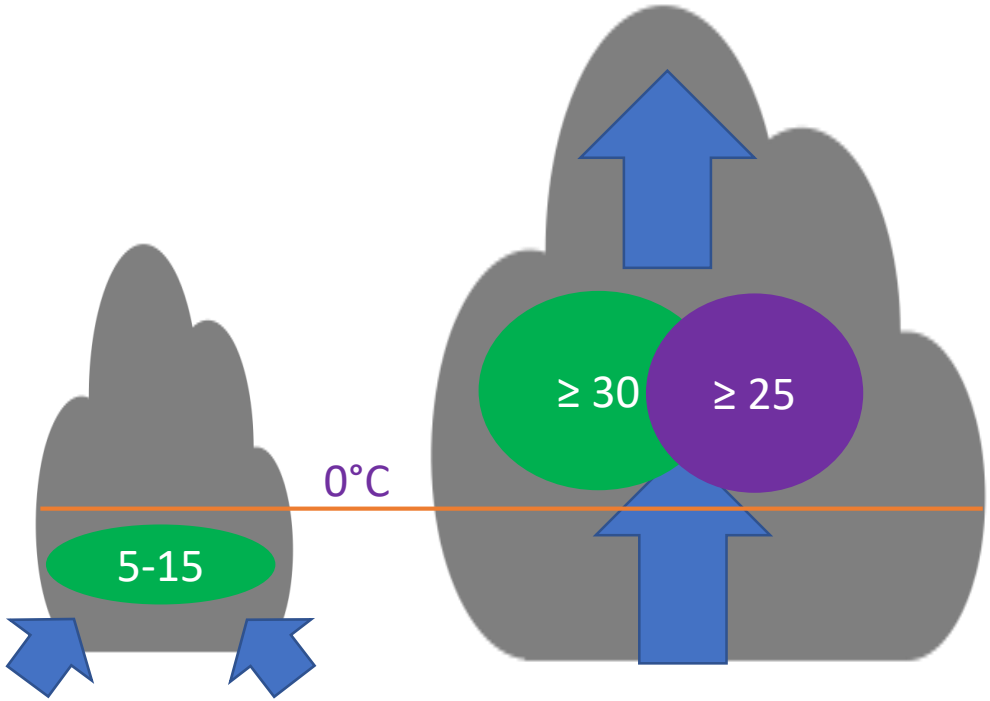
- **Cloud Depth: the larger the difference, the shallower the cloud is and as the difference increases towards zero, the cloud gets larger**
- 10.3 µm Tb:
  - Proxy for cloud top temperatures: decreases over time as the storm matures to values between 240-245 K



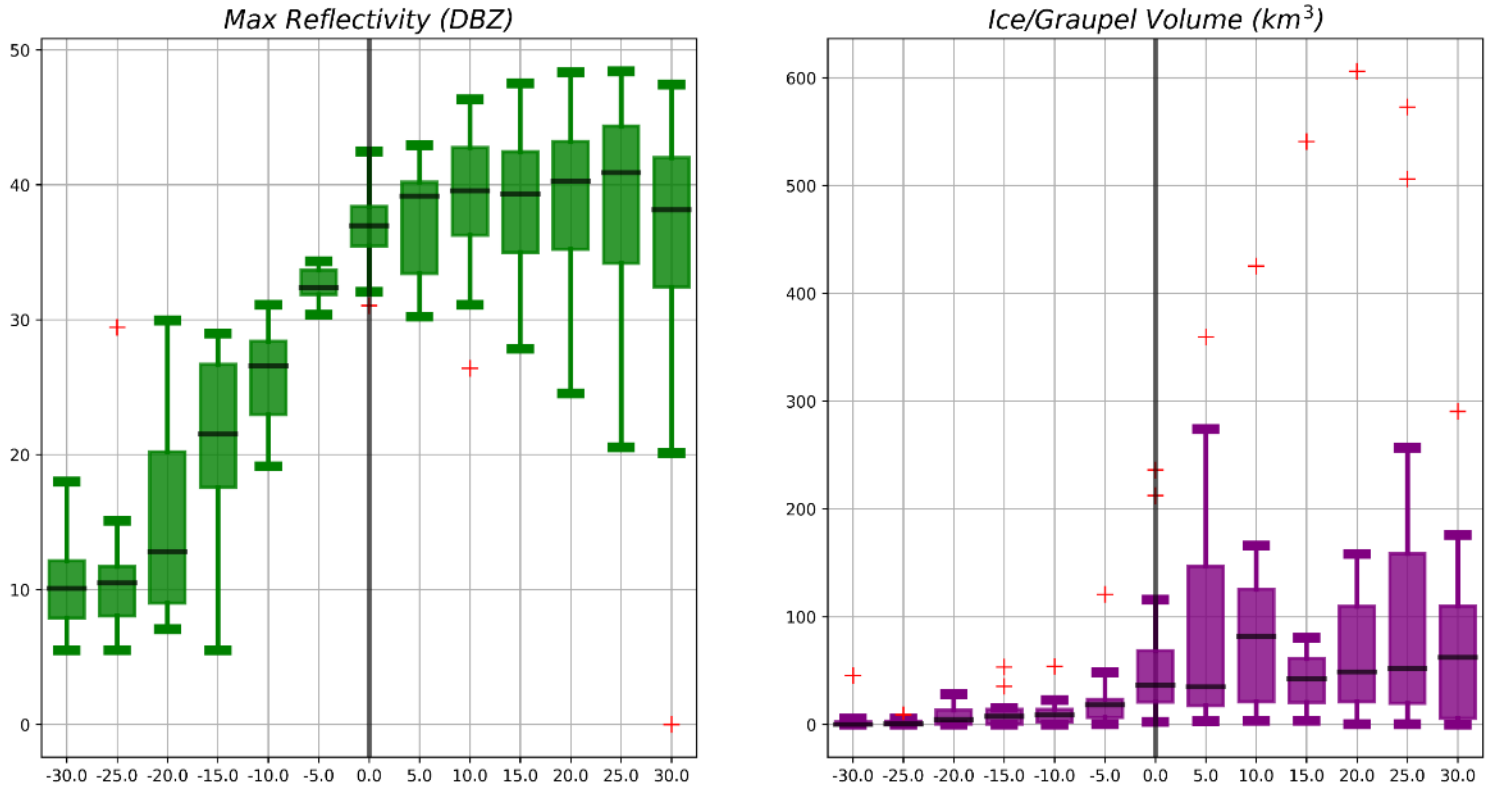




- 8.4-10.3 µm: **Cloud Particle Size, Water Vapor Absorption** is CRUCIAL
  - Low optical thickness with large particles, or high optical thickness with smaller particles
- TriSpectral [(8.4-10.3 µm) – **(10.3 – 12.30 µm)**]
  - Higher Particle Sizes decreases overall values
- 3.9 µm Refl. is affected by both solar and longwave infrared radiation
  - Values decrease as the cloud transitions from liquid water droplets to ice hydrometeors as absorption of ice increases

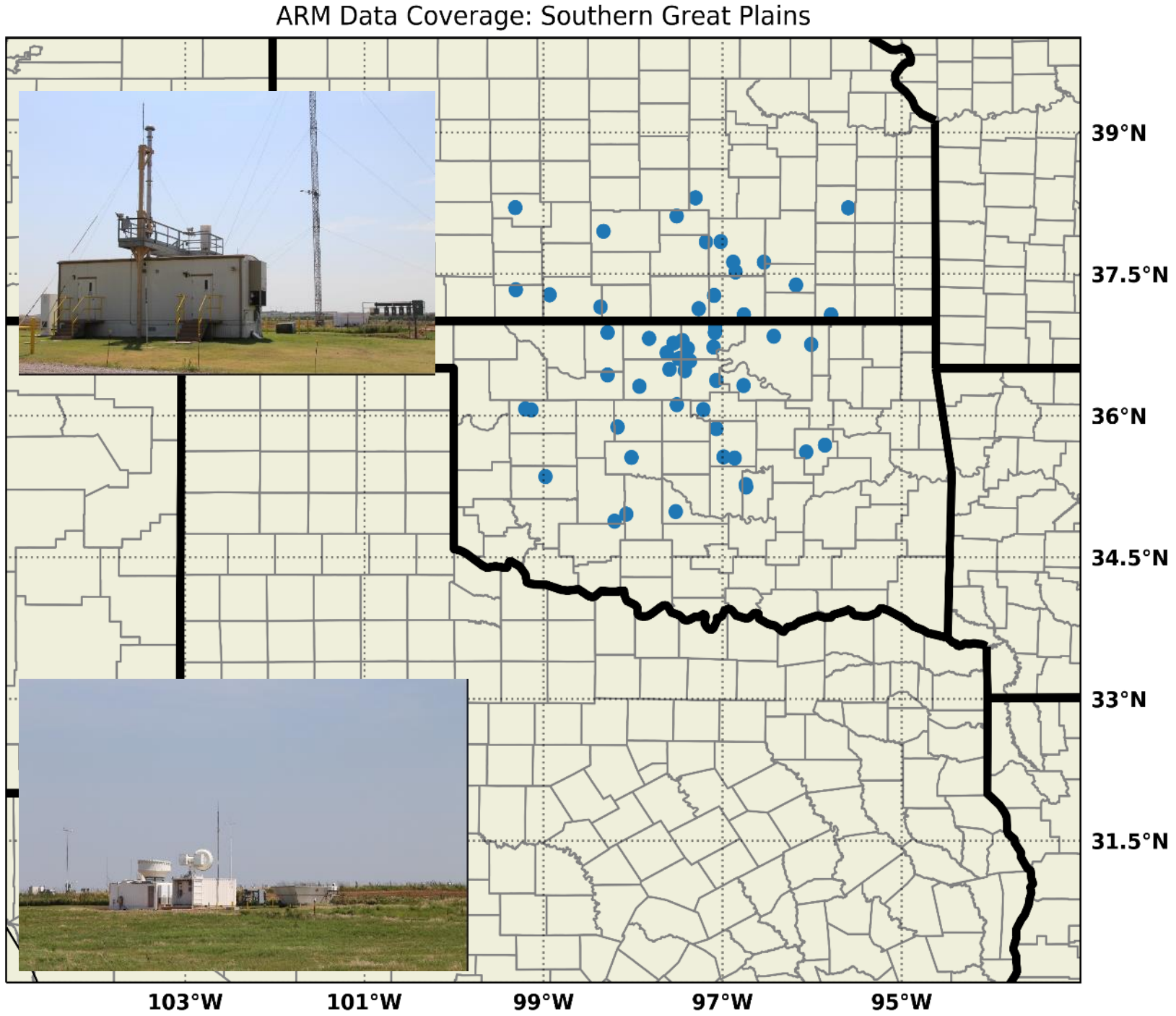


Microphysics



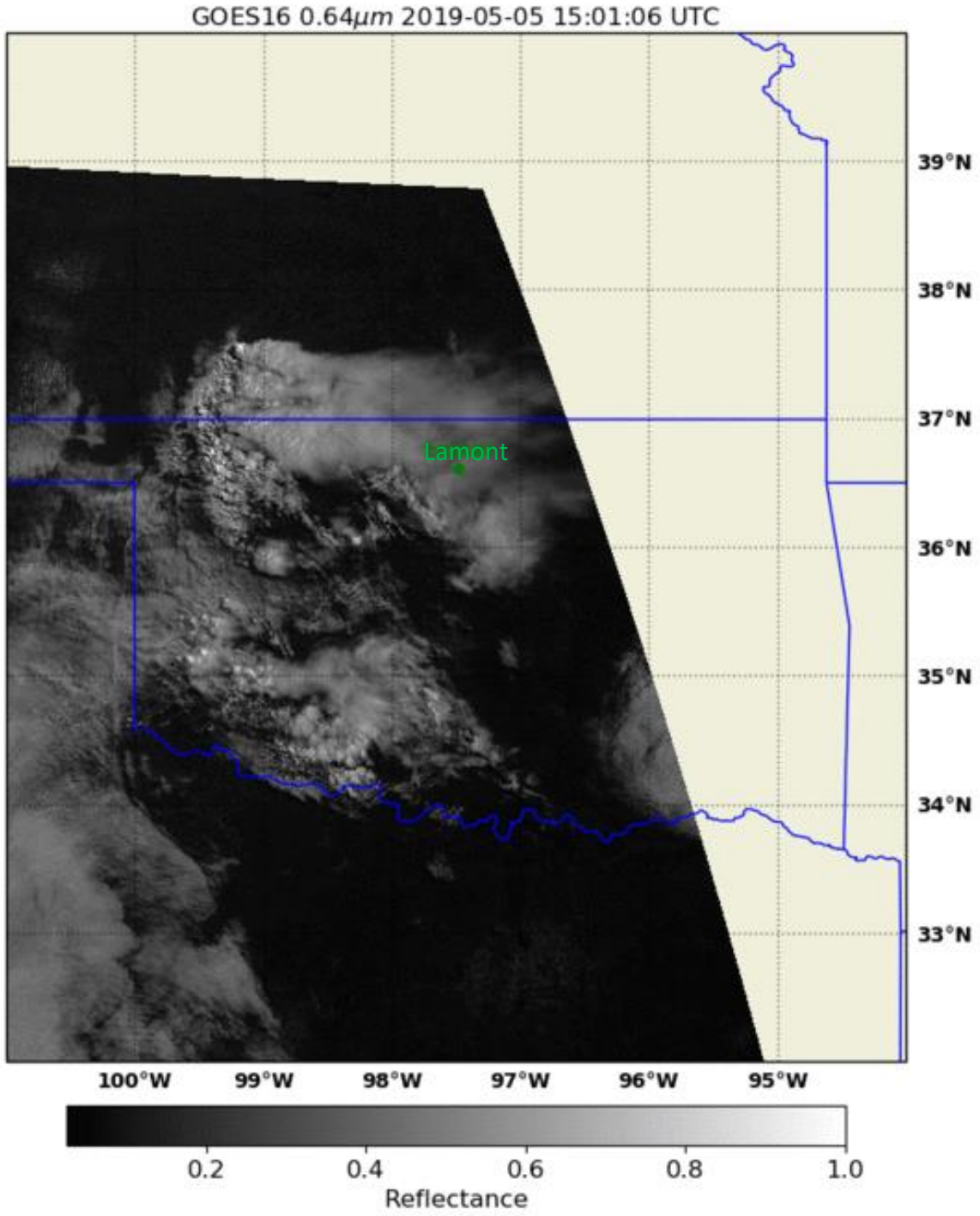
Reflectivity and Ice/Graupel Volume increase over time

- Updraft matures and hydrometeors being lofted above the freezing level



- **The Atmospheric Radiation Measurement** (ARM; https://www.arm.gov/) facility is a multi-laboratory funded by the Department of Energy
  - Southern Great Plains (North-Central Oklahoma to southern Kansas), North Slope of Alaska and the Eastern North Atlantic
- Instruments that measure both surface and upper atmospheric properties such as clouds, and aerosols

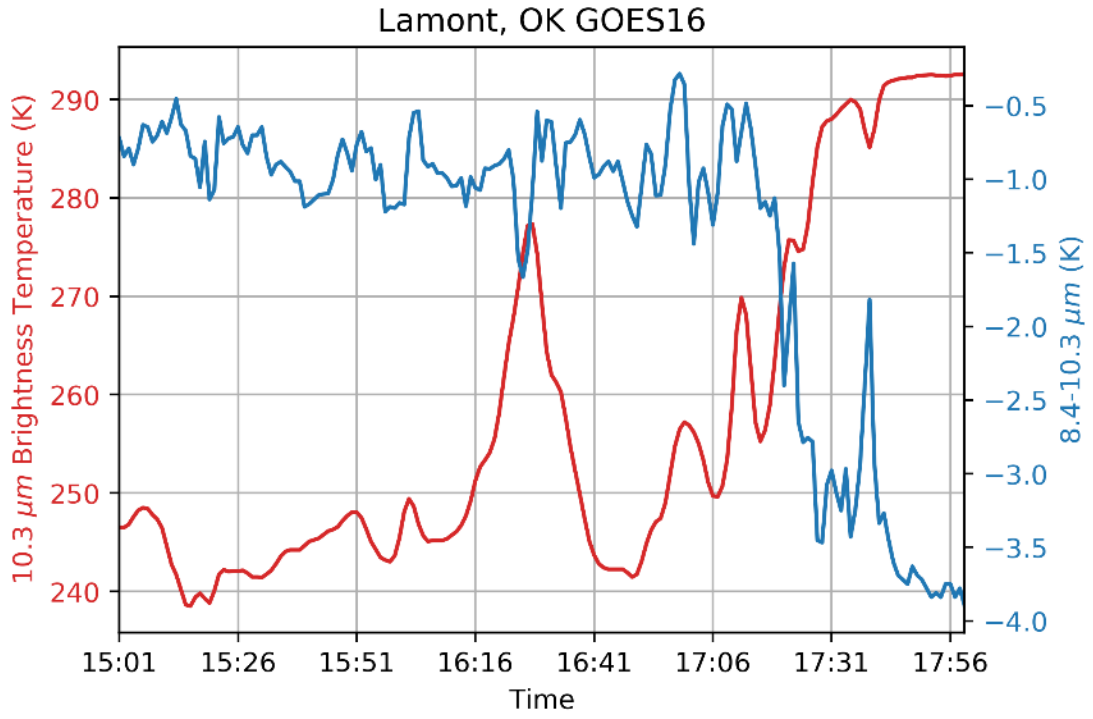
- **Southern Great Plains:**
  - > 50 facilities
  - Radiometers, Radars, Lidars, etc.
  - A large and most extensive climate research facility.



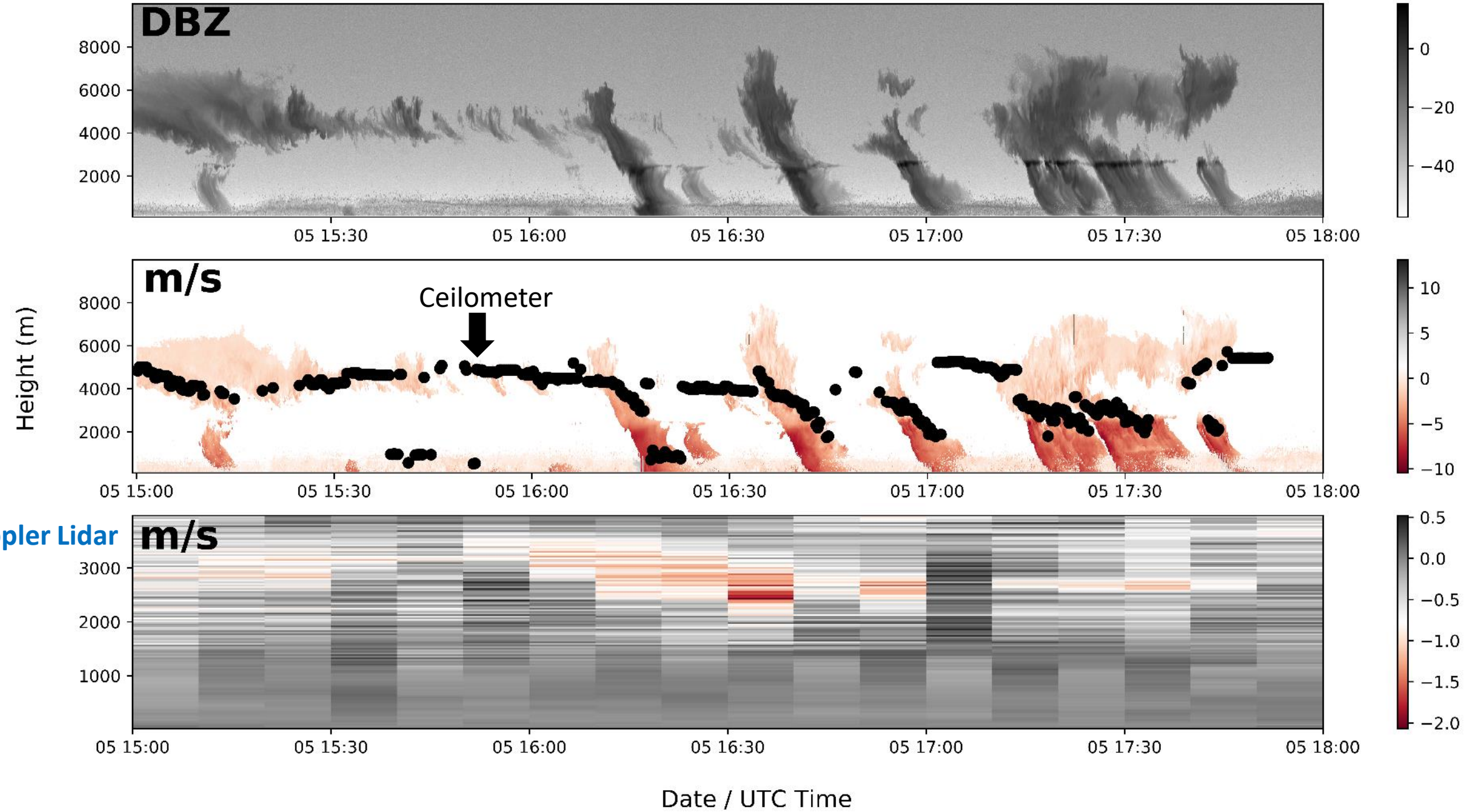
Identify Cases

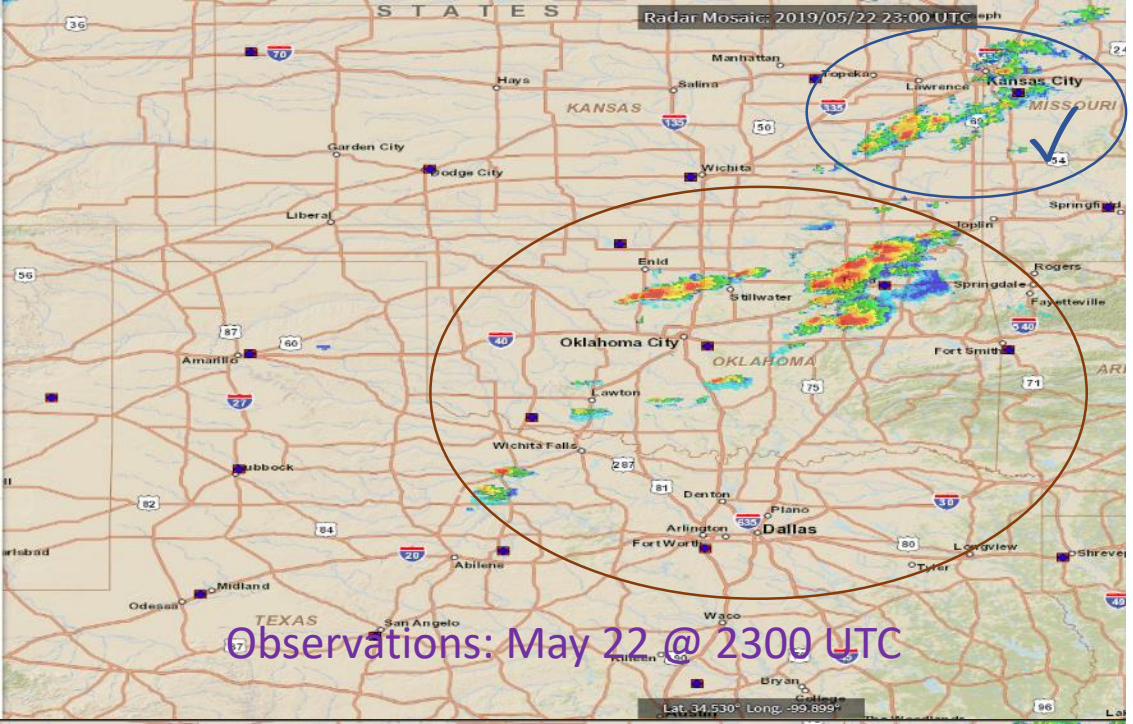
Work to find Southern Great Plains (SGP) convective initiation events in a near the ARM site.

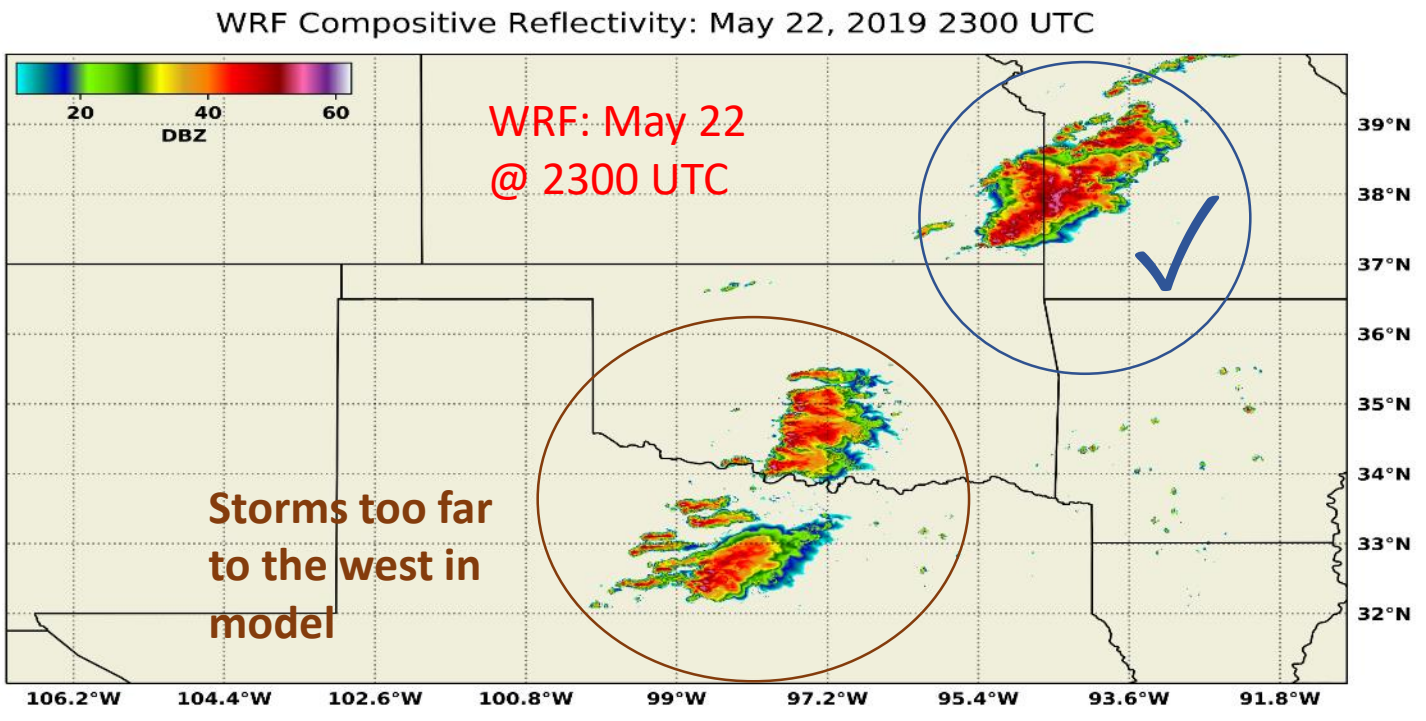
Retrieve IR-field cloud-top fields for moving clouds, over an ensemble of clouds.

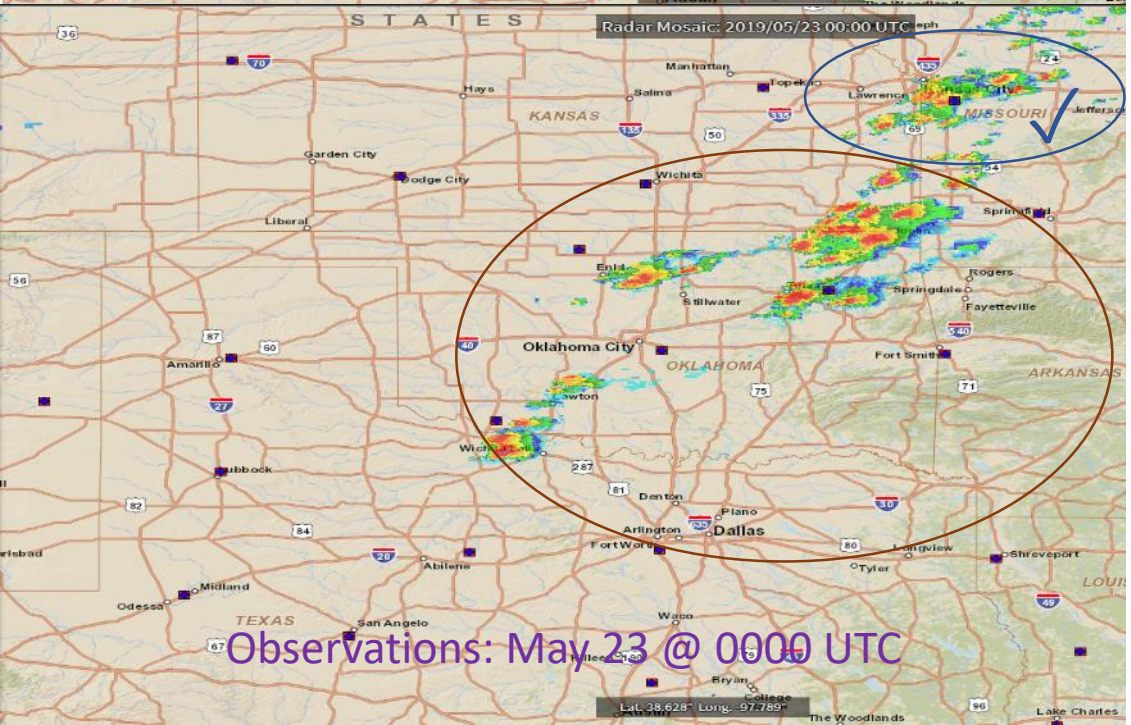


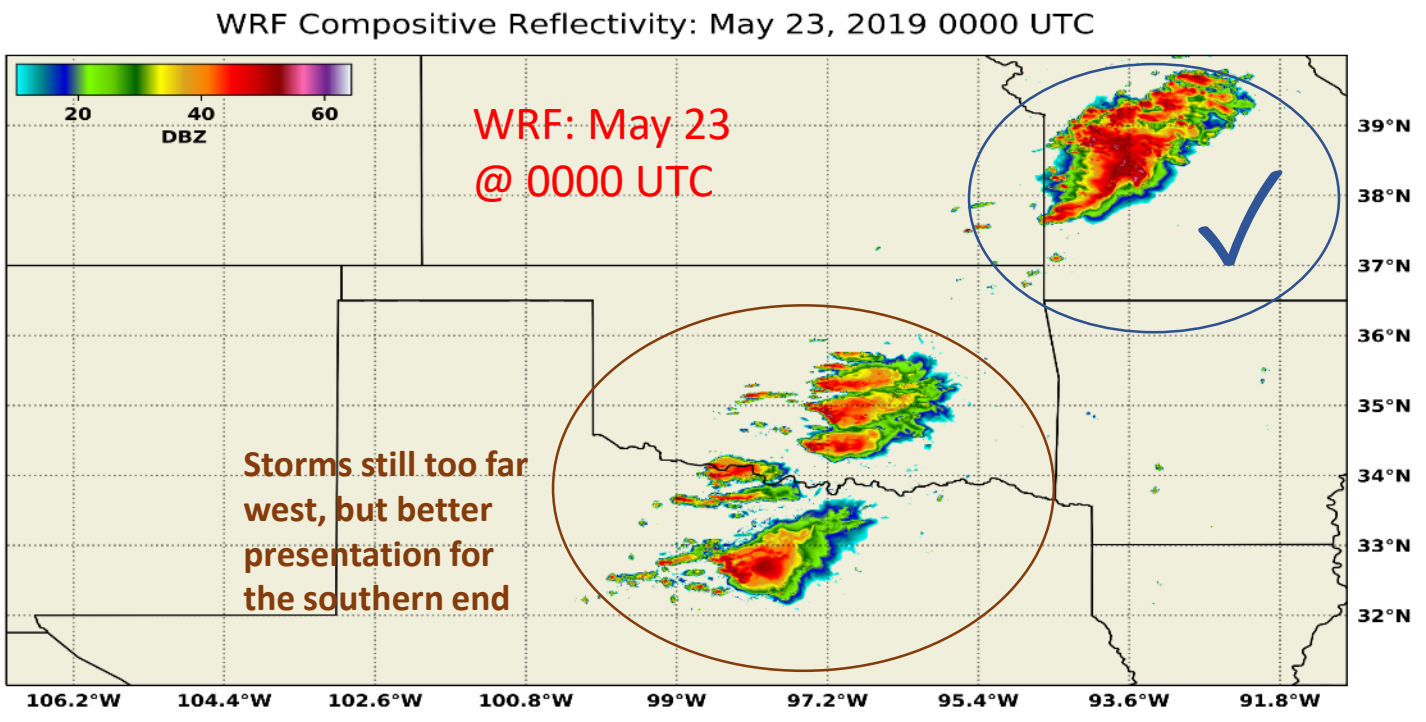
KAZR Doppler Imagery



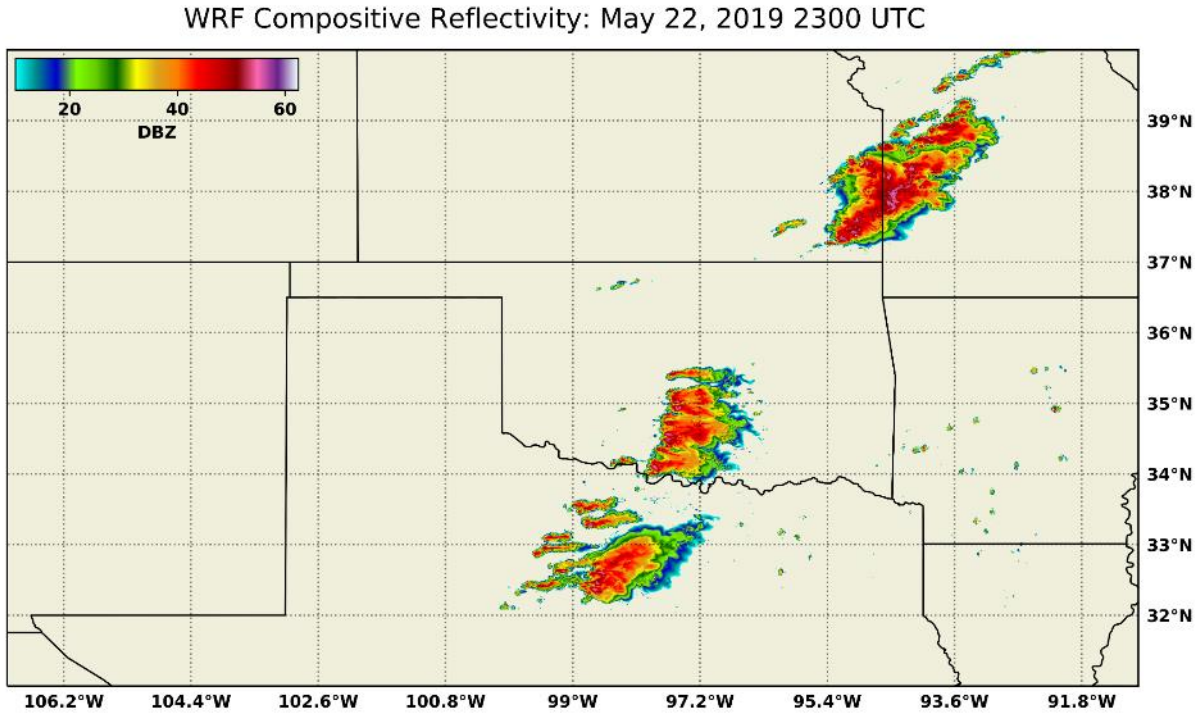

Radar Mosaic: 2019/05/22 23:00 UTC
Observations: May 22 @ 2300 UTC


WRF Compositive Reflectivity: May 22, 2019 2300 UTC
DBZ
20
40
60
WRF: May 22
@ 2300 UTC
Storms too far
to the west in
model
106.2°W
104.4°W
102.6°W
100.8°W
99°W
97.2°W
95.4°W
93.6°W
91.8°W
39°N
38°N
37°N
36°N
35°N
34°N
33°N
32°N


Radar Mosaic: 2019/05/23 00:00 UTC
Observations: May 23 @ 0000 UTC

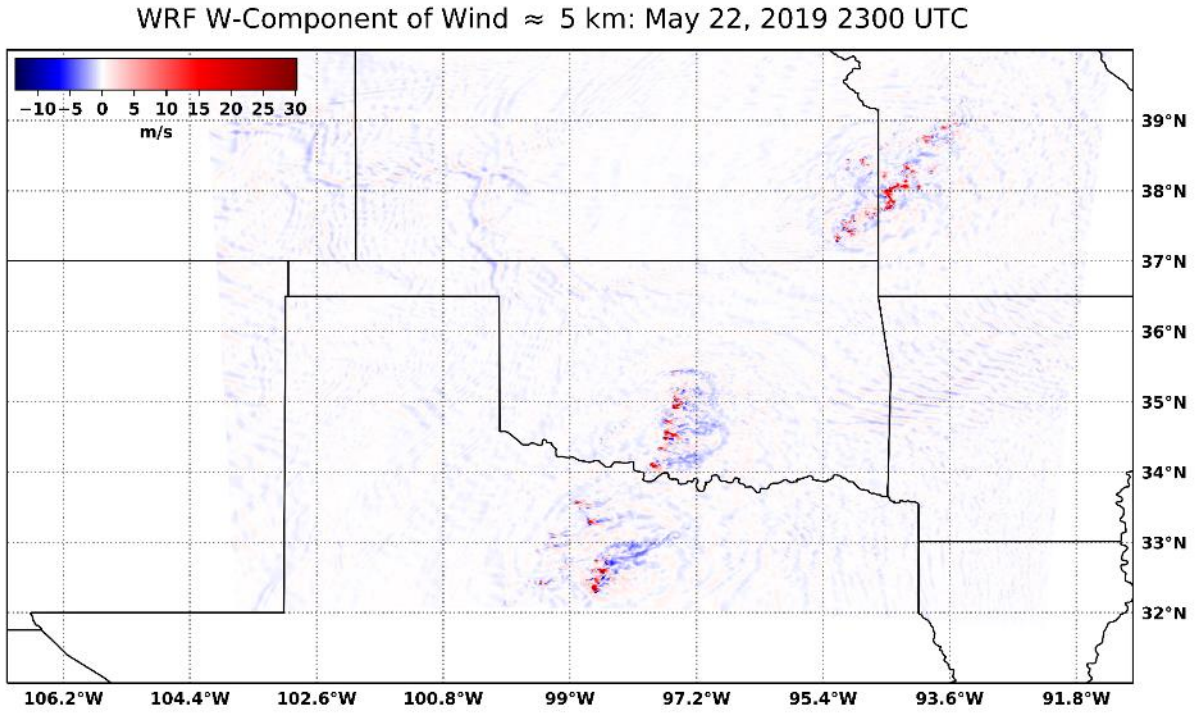

WRF Compositive Reflectivity: May 23, 2019 0000 UTC
DBZ
20
40
60
WRF: May 23
@ 0000 UTC
Storms still too far
west, but better
presentation for
the southern end
106.2°W
104.4°W
102.6°W
100.8°W
99°W
97.2°W
95.4°W
93.6°W
91.8°W
39°N
38°N
37°N
36°N
35°N
34°N
33°N
32°N

Weather Research and Forecasting Model Simulations



- WRF Simulation: **1 km resolution**
- Once Ground and satellite observations derive relationships, **model parameterization tuning will begin with case dates**
- Tunable parameters in convective parameterization schemes will allow for robust analysis to create ensemble of solutions to nudge model towards the observations

- w-component wind shows small magnitudes around most of the domain
- Closer to convection – vigorous updrafts and downdrafts with values exceeding 10 m s^{-1}



Parameters to Modify within Convective Scheme

- **Two Different Ways of Parameterizing Convection (Stensrud 2009):**
  - Convective Adjustment:
    - Assumes that the atmospheric instability that is built up is used for convection
    - After convection, model re-adjusts and removes instability
  - Mass-Flux:
    - Key ingredients for the development of convection (instability, moisture and a lifting mechanism)
    - Calculates updrafts and downdrafts – important for convection to form and is preferred over the adjustment schemes (Yoshimura 2015)

- **Tunable Parameters:**
  - Kain-Fritsch (Mass-Flux):
    - **Updraft Mass Flux** – mass of air that goes through cloud base / initial mass in the ≈ 50 mb updraft source layer
      - Sensitive to the **lapse rates in the cloud layer** and **θ_e of the downdraft air**
  - Convective Adjustment:
    - Very sensitive to **cloud-layer relative humidity (RH)**
  - Vertical Distribution of Heat, Moisture:
    - **Entraining / Detraining Parameters**

Ongoing Research

- Analyze CI events over SGP using ARM and GOES-16 (1 min) datasets
  - **ARM dataset (ground observations), radar (in-cloud microphysics), and satellite (top perspective)**
  - Further analysis with complete satellite/microphysical properties from addition days
  - Pull in **Level 2 cloud products** for **cloud particle size, cloud top phase, and cloud optical depth**
  - **Develop relationships between GOES-16 and ground-based datasets**
  - Use **dual-Doppler radar analysis** to assess in-cloud kinematics
  - Develop science paper

- Complement field observations with WRF simulations
  - Analysis of **cloud properties** in the simulation
  - Analyze clouds from different perspectives
  - **Form connections between satellite observations and convective parameterization schemes**

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