Using Satellite All-Sky Infrared Brightness Temperatures for Model Verification

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With contributions from many people!

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Utility of Satellite Brightness Temperatures

- Sensors provide detailed information about atmosphere and land/ocean surfaces
    - Obtained from visible, shortwave, infrared, and microwave bands
- Our studies have focused on all-sky infrared brightness temperatures because they provide valuable information about clouds and water vapor, both of which are susceptible to large errors in NWP model forecasts
- Geostationary satellites provide routine coverage over large areas, whereas polar-orbiting satellites provide global coverage, but with less frequent updates

Project Description – Model Verification

- Results from a 24-hr case study from July 2015 were used to assess merits of different verification methods

- Assess HRRR forecast accuracy using GOES infrared brightness temperatures

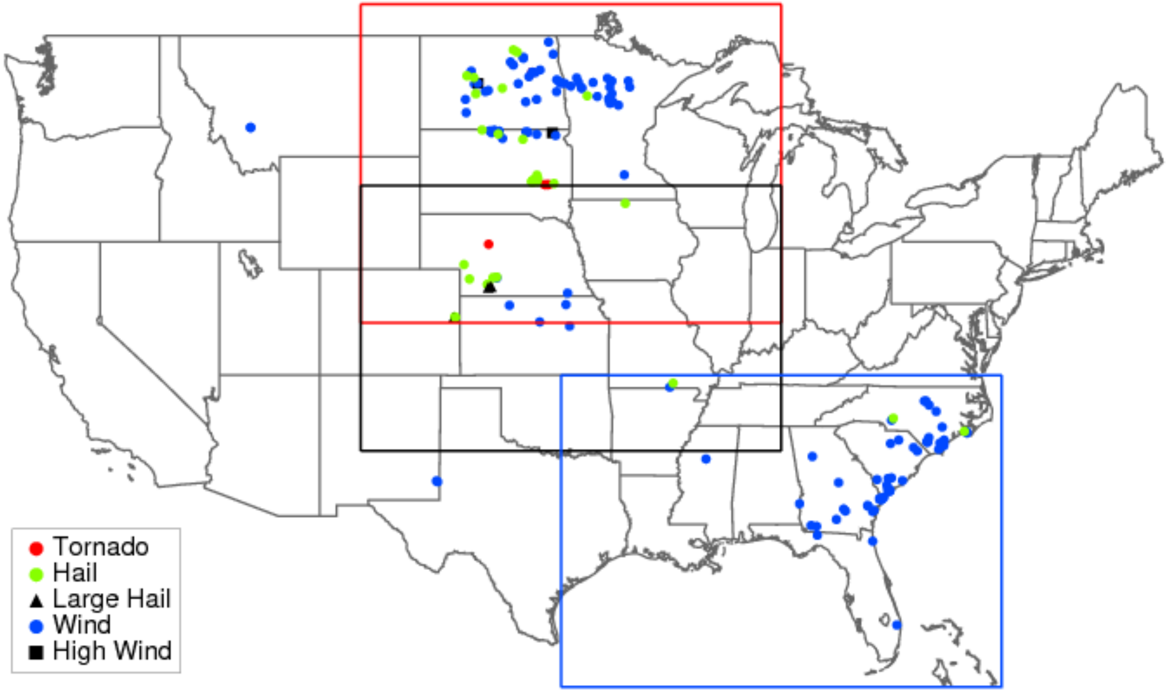
    - Primary focus is to assess accuracy of cloud and moisture fields using observations from the 10.7 μm window band that are sensitive to clouds and surface temperatures

    - Accuracy assessed using grid-point statistics (RMSE), neighborhood methods (Fractions Skill Score), and object-based tools (e.g., MODE)

- Use of traditional, neighborhood, and object-based verification methods should provide a more complete analysis of the forecast accuracy

Case Study Description

SPC Storm Reports from 12 UTC on July 23 to 12 UTC on July 24 2015

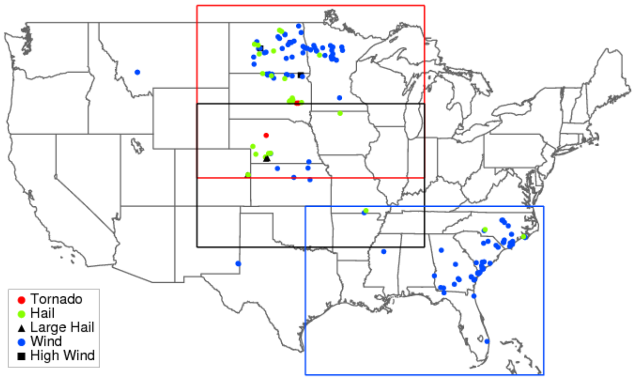


• 23-24 July 2015 chosen because different types of convection were observed across the U.S., including:

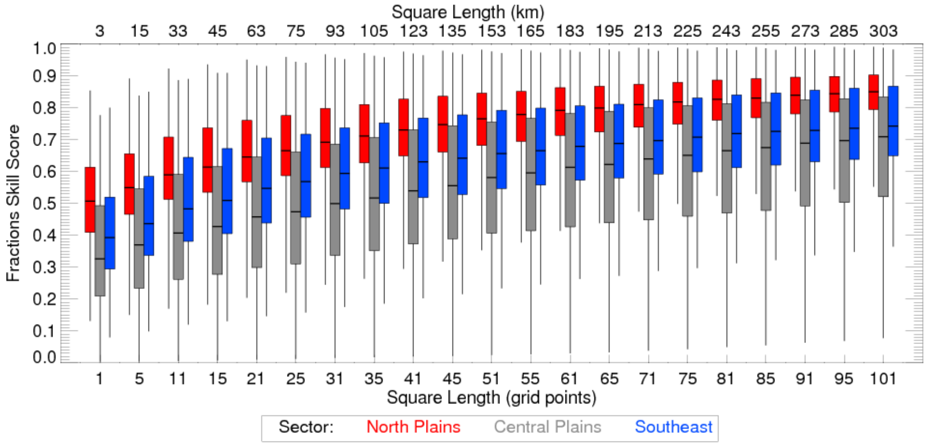
• Surface Low and Frontal passage, Isolated Convection, and Stationary Front and Sea Breeze

Case Study – Fractions Skill Score (FSS)

SPC Storm Reports from 12 UTC on July 23 to 12 UTC on July 24 2015



Fractions Skill Score from 12 UTC on July 23 to 12 UTC on July 24 2015



- Threshold: 10% GOES and HRRR BT threshold applied, respectively
- Box plot includes forecast lead times between 00h and 12h
- Box width where FSS exceeds 0.5 is scale where HRRR contains useful information
- Lowest skill associated with the single cell convection, indicating most difficult to accurately forecast

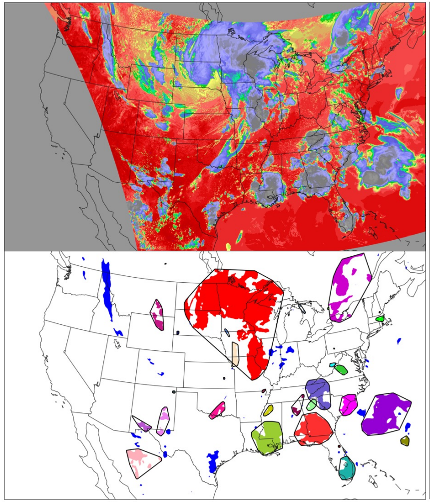
MODE Configuration – Seasonal Analysis

Object Pair Attribute	Weight (%)	Description
Centroid Distance	25.0	Distance between objects' "center of mass"
Boundary Distance	18.75	Minimum distance between the objects
Convex Hull Distance	6.25	Minimum distance between the polygons surrounding the objects
Angle Difference	6.25	Orientation angle difference
Area Ratio	25.0	Ratio of the forecast and observation objects' areas (lowest value)
Intersection Area Ratio	18.75	Ratio of observation (forecast) object to the objects' intersection area (highest value)

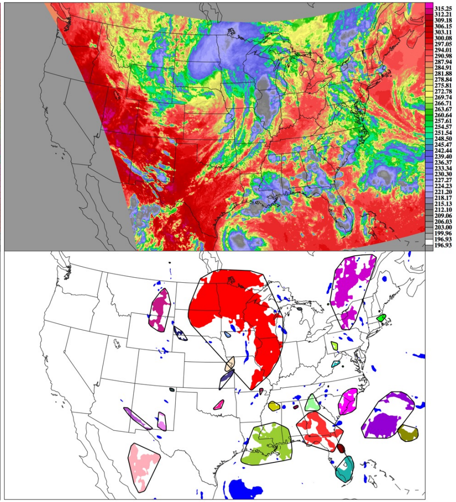
- Equal weight given to object distance and size (area ratio) attributes
- Boundary Distance has a lower weight than the Centroid Distance so that more weight was placed on the displacement between the object's center of mass
- Intersection Area Ratio lower than Area Ratio because it can be artificially high when a small object is fully enclosed by a larger object

Case Study Time Periods

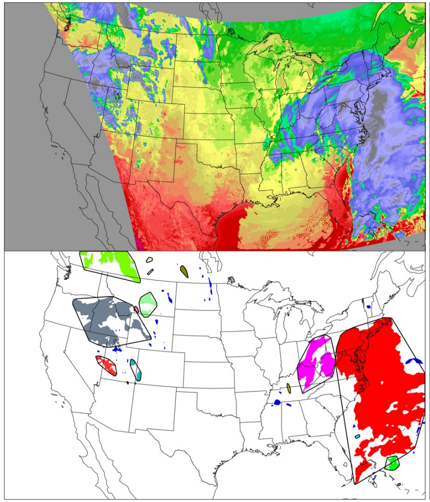
4-h HRRR from 1800 UTC on 20150818



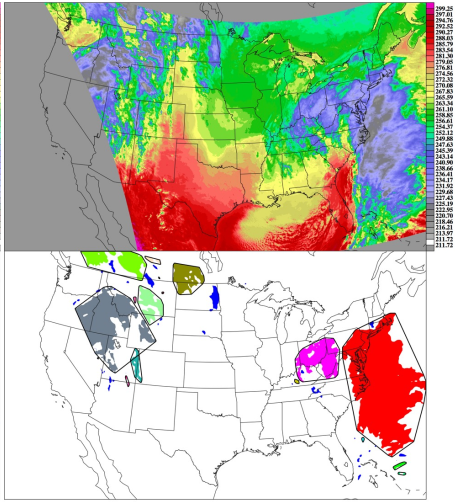
GOES from 2200 UTC on 20150818



2-h HRRR from 2100 UTC on 20160122



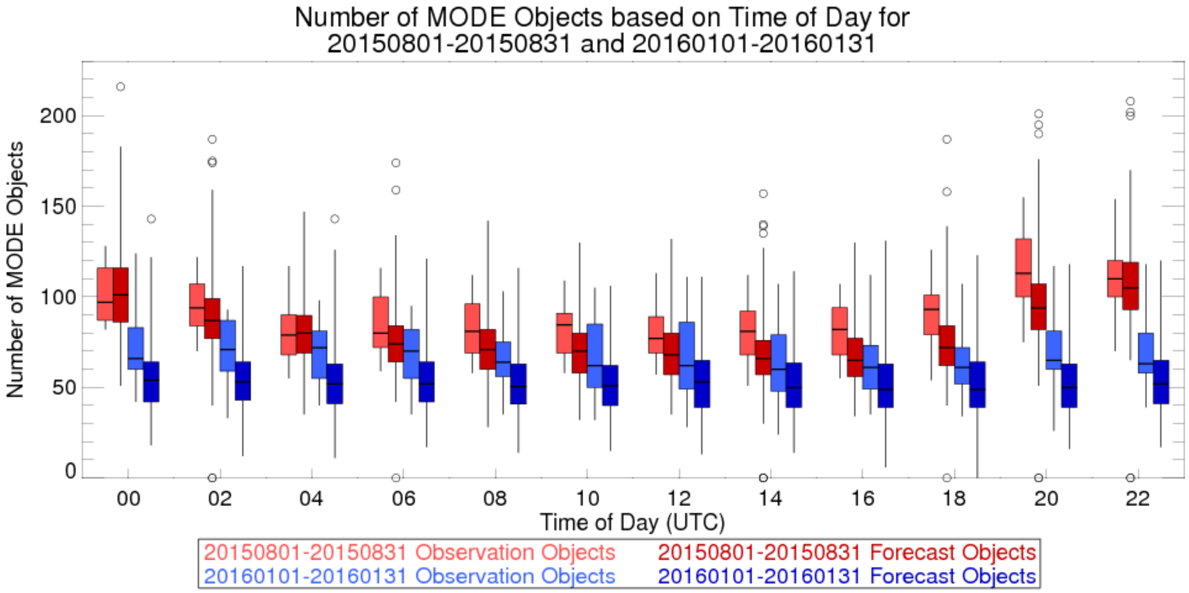
GOES from 2300 UTC on 20160122



- **Summer Example**: Forecast hours 0-24 from HRRR initializations from August 1-31, 2015

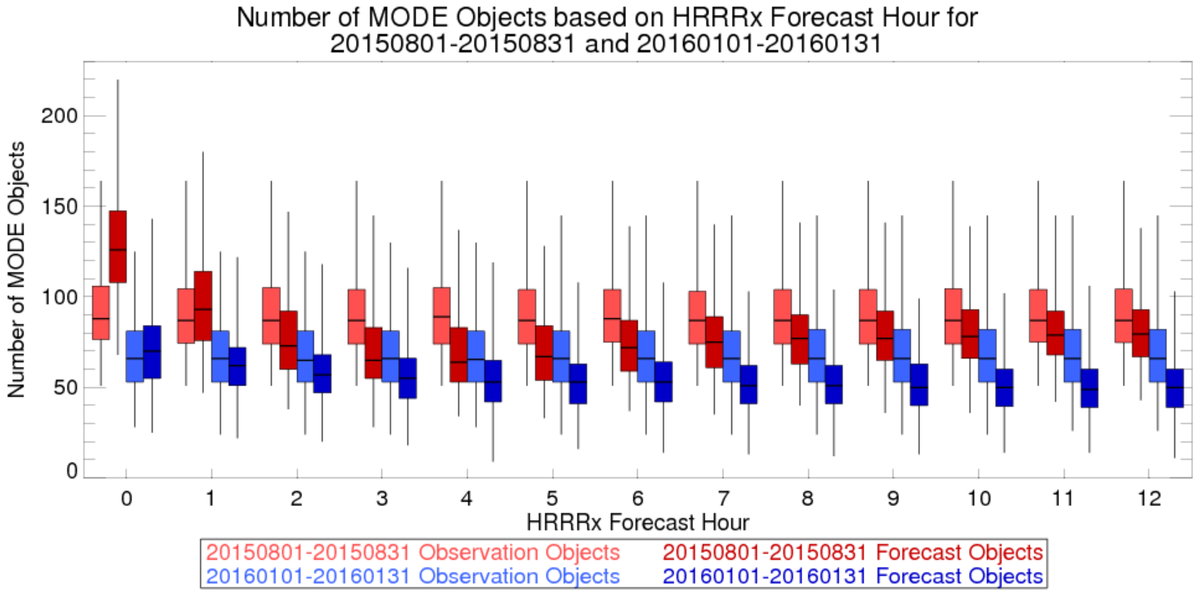
- **Winter Example**: Forecast hours 0-24 from HRRR initializations from January 1-31, 2016

Number of MODE Objects – Function of Time of Day



- MODE identifies more cloud objects during August
  - Average cloud object is smaller (larger) during August (January)
- Diurnal cycle is much larger during August
  - Minimum (maximum) near 12 UTC (20 UTC)

Number of MODE Objects – Function of Forecast Hour



- Too many forecast cloud objects during August for forecast hours 0-1
    - Indicates cloud objects are too small in HRRR initializations
- More observed cloud objects than HRRR forecast objects overall
- Steady drift toward fewer forecast cloud objects during January

Assessing the Impact of Land Surface Models on Convection over the Southeastern United States Using High-Resolution Model Simulations and GOES-16 Satellite Observations

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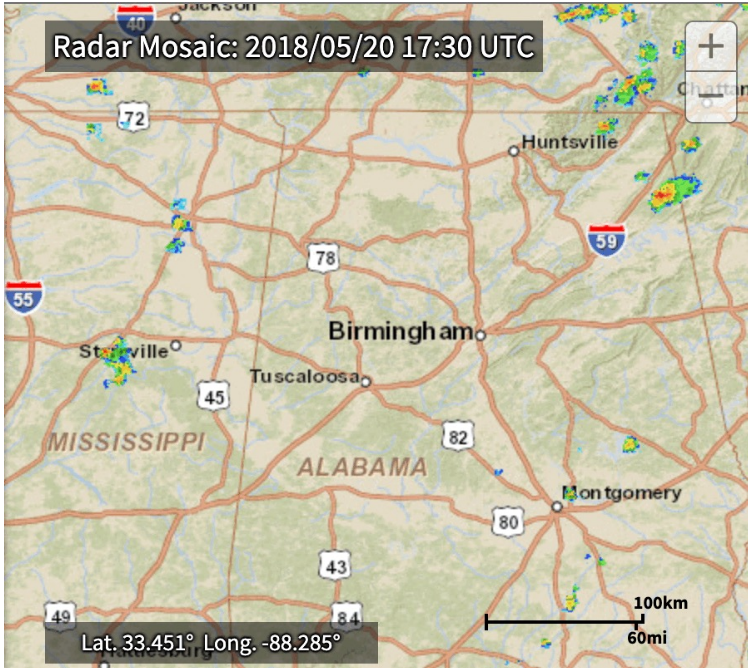
Convective Initiation Over Southeastern United States

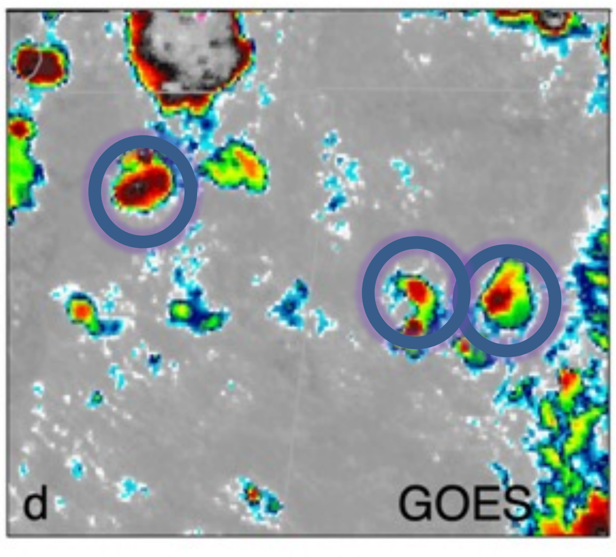
- Long-standing challenge to forecast the location and timing of convective initiation that could lead to severe thunderstorms
  - Southeast U.S., typically form and develop long-lived storms without synoptic forcing
  - Isolated storms make up a significant portion of the spring and summer precipitation totals
  - Numerical models struggle to predict the location and timing of this convection



From NOAA NCEI

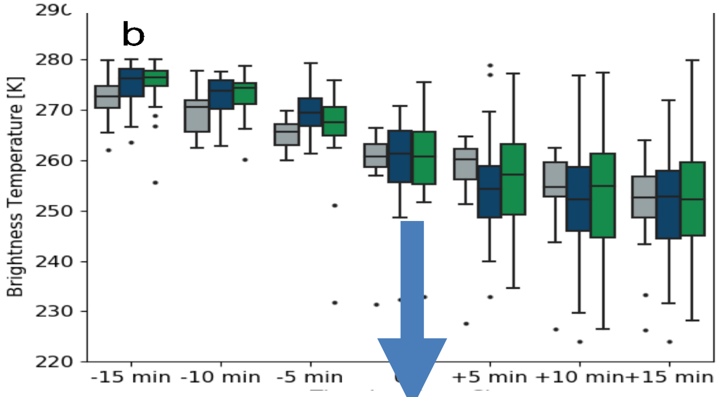
Geostationary Satellites Important to Study CI

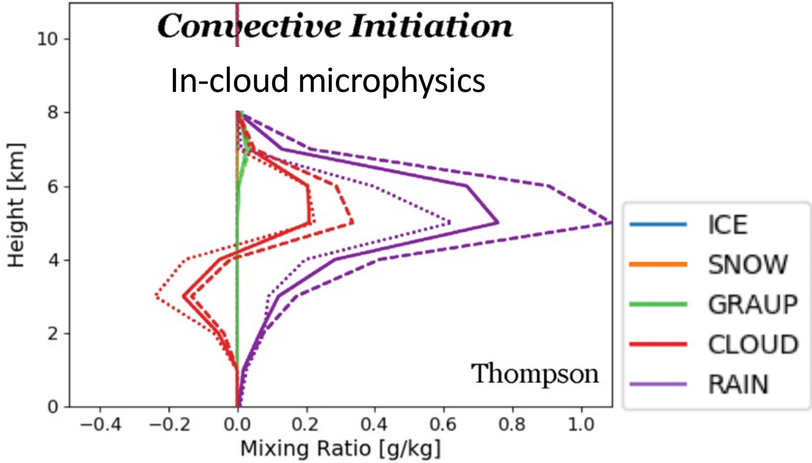
Identify time a cloud object reaches CI (35 dbZ)



Track characteristics over time

Object-based comparison of the cloud evolution between models and observations





Henderson D.S., J. Otkin, J. Mecikalski, 2021: Evaluating convective initiation in high-resolution numerical weather prediction models using GOES-16 infrared brightness temperatures. *Mon. Wea. Rev*, **149**, 1153-1172.

Geostationary Satellites Important to Study CI

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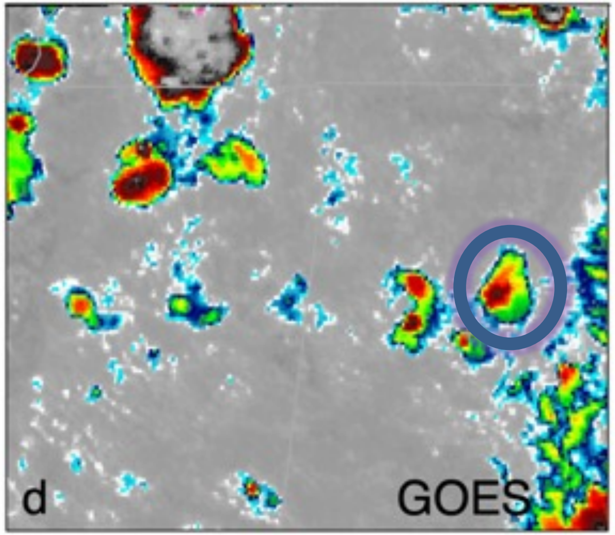
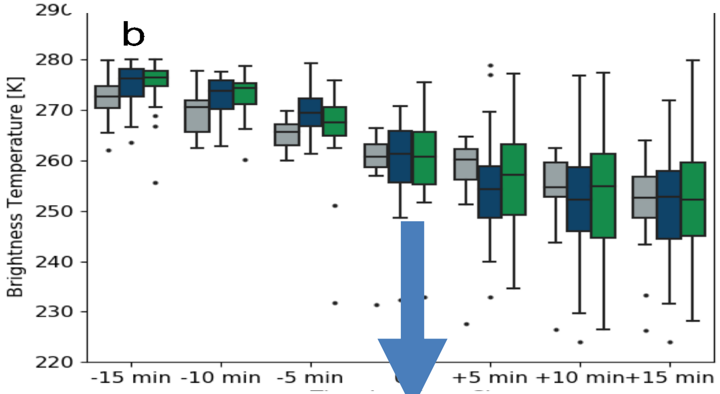
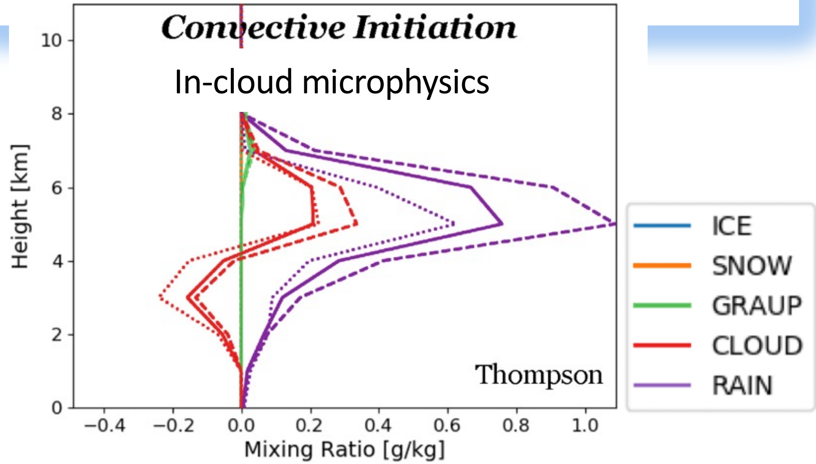


Track characteristics over time

Object-based comparison of the cloud evolution between models and observations





- We can compare cloud objects identified in satellite imagery to similar objects in models to compare cloud characteristics, such as growth rates and brightness temperature distributions

Geostationary Satellites Important to Study CI

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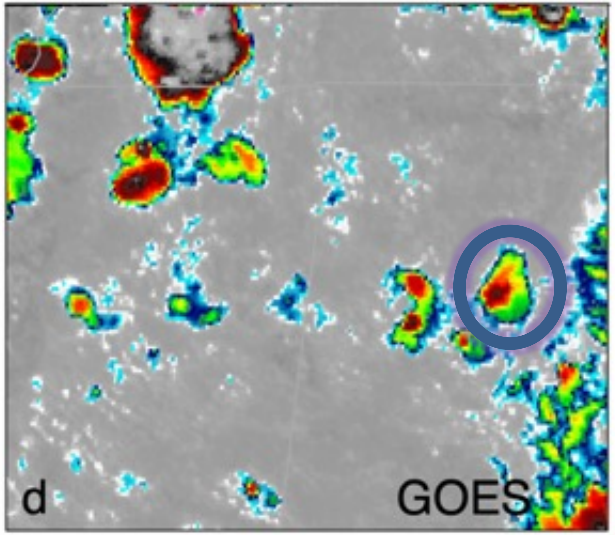
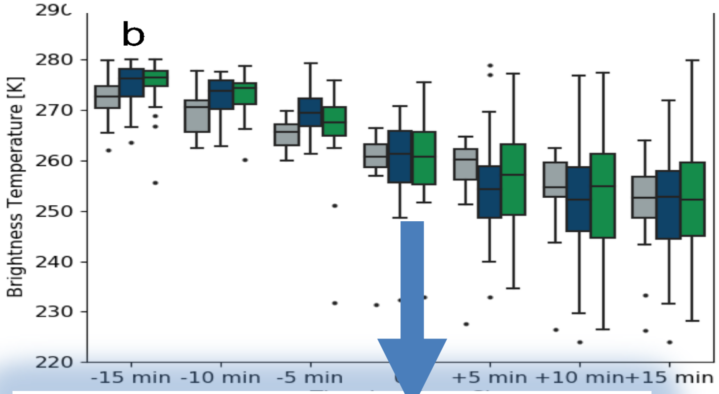
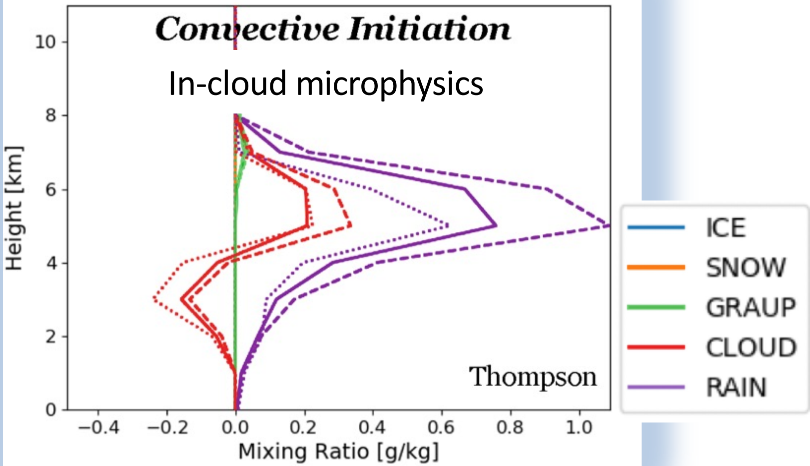


Track characteristics over time

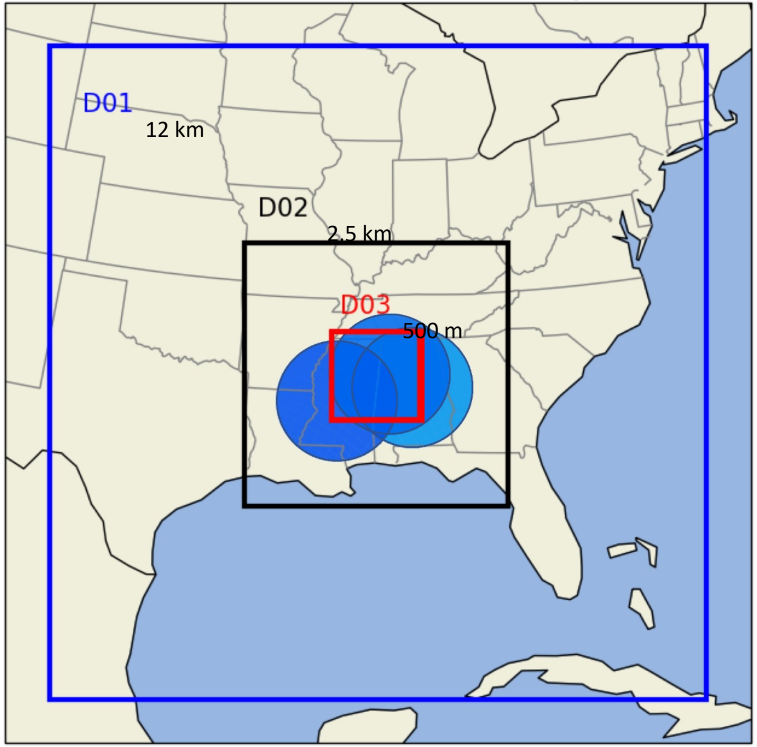
Object-based comparison of the cloud evolution between models and observations





- Using cloud objects with similar characteristics to the observations, we can then use the model simulations to evaluate processes that lead to differences in convective initiation when using different model parameterization schemes

WRF Model Configuration



WRF ARW V3.9.1.1 simulations:
12 UTC to 23 UTC allowing 6 hours of model spin-up

- Model data output every 5 minutes to match GOES-16
- Inner domain: dX = 500 meter, 53 vertical levels up to 40 hPa
- Initial conditions: NCEP Final (NCEP FNL) at 0.25-degree

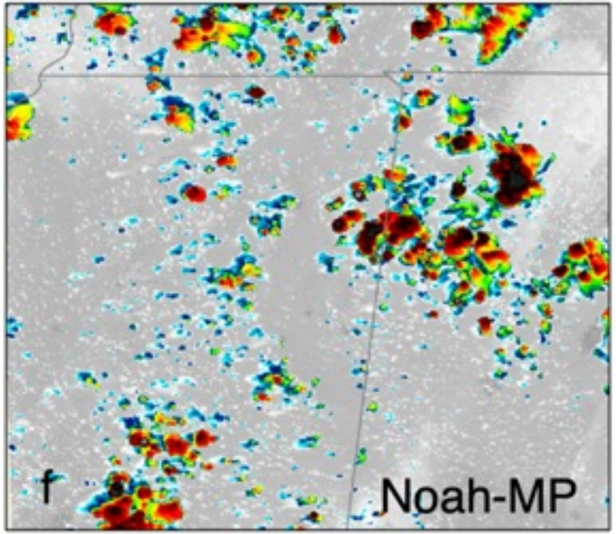
Microphysics:	**Thompson**
PBL Scheme:	**MYNN**
Surface Scheme:	**NOAH LSM and NOAH-MP LSM**

Simulated GOES-16 ABI infrared brightness temperatures computed using the Community Radiative Transfer Model

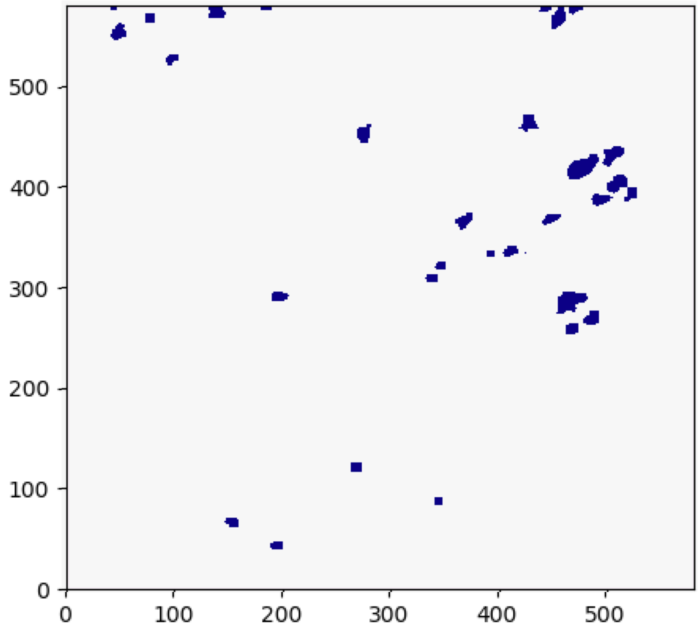
Object-based Identification; Henderson et al. (2021)

Cloud objects are identified using 10.3 μm brightness temperatures by adapting methods from TOOCAN; Fiolleau and Roca, 2013

10.3 μm Brightness Temperatures [K]
5-20-2018



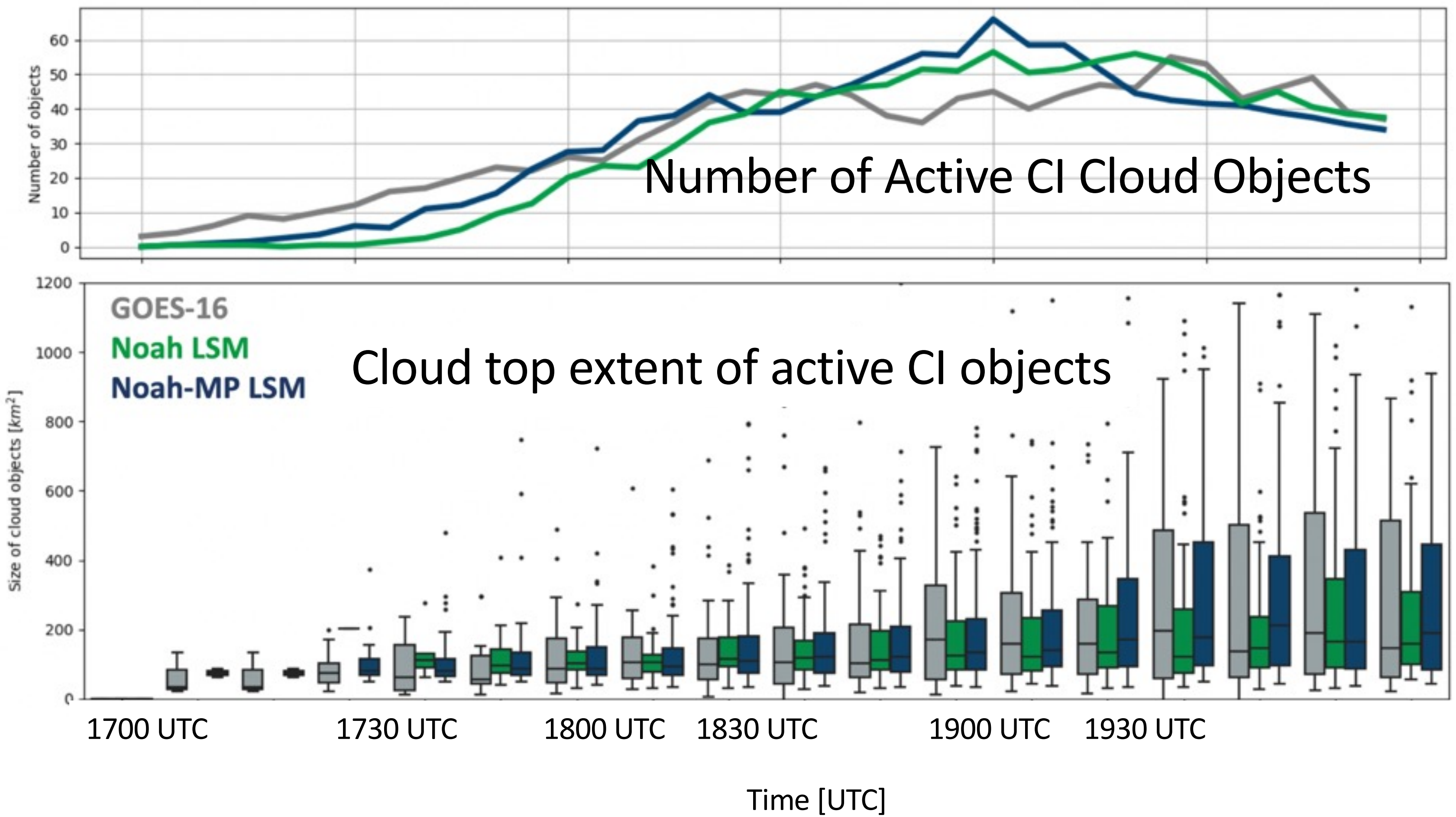
Resulting cloud objects cold cloud cores



Use coldest brightness temperatures to find core of object first and then build outward using successively warmer brightness temperature thresholds

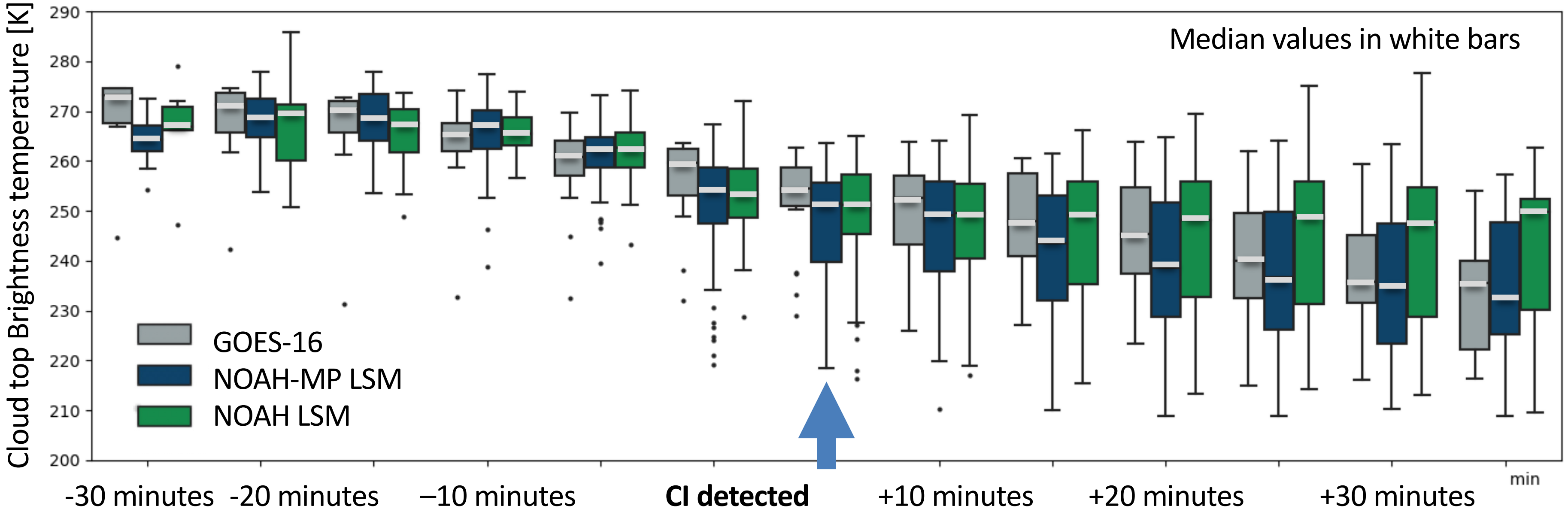
Performed iteratively until a cloud boundary of 285 K is reached for a given object or two boundaries intersect

Comparing Cloud Top Characteristics CI Cloud Objects



Evolution of 10.35 μm Cloud-top Brightness Temperatures – Cloud Growth

30 minutes before and after CI is detected

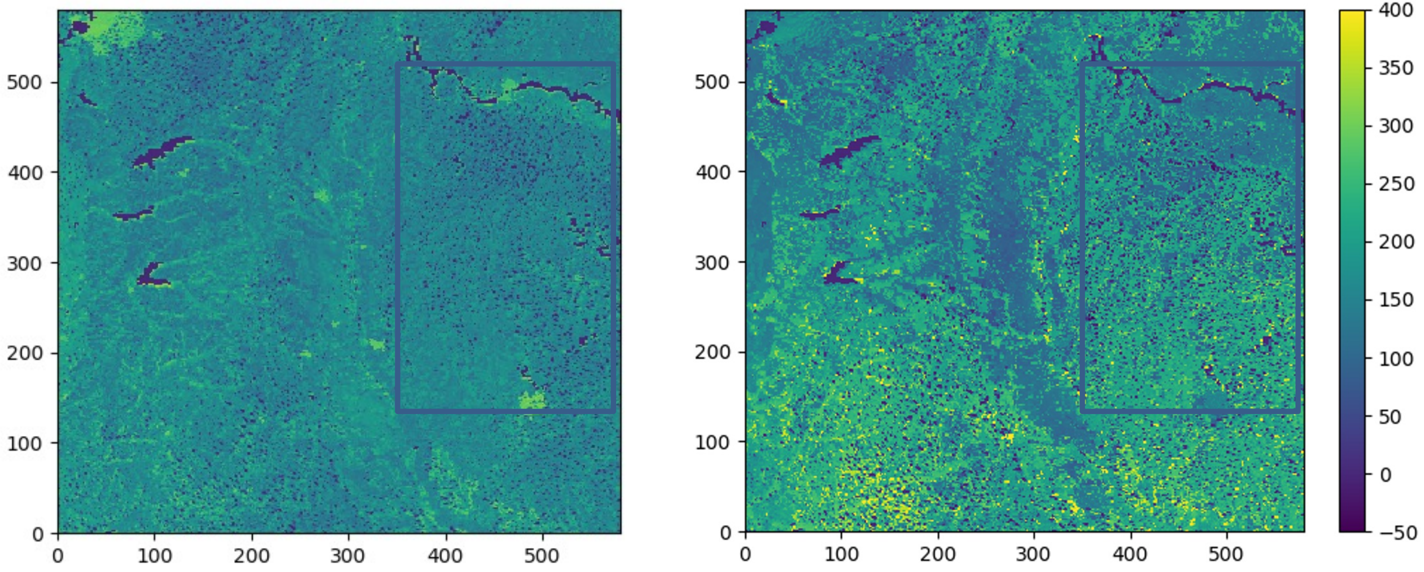


Noah-MP clouds continue to cool after CI; most notable from 15 min onward

Clouds that reach CI in Noah-MP more likely to develop into deep convection

Noah-MP leads to more accurate cloud growth rates

Sensible Heat Fluxes [W m^{-2}]

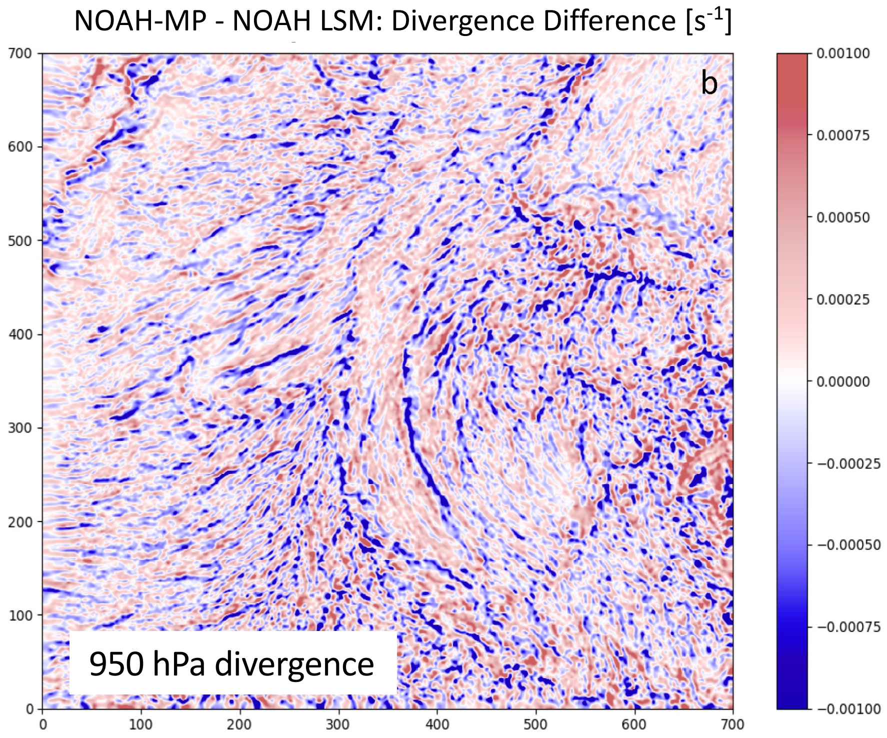


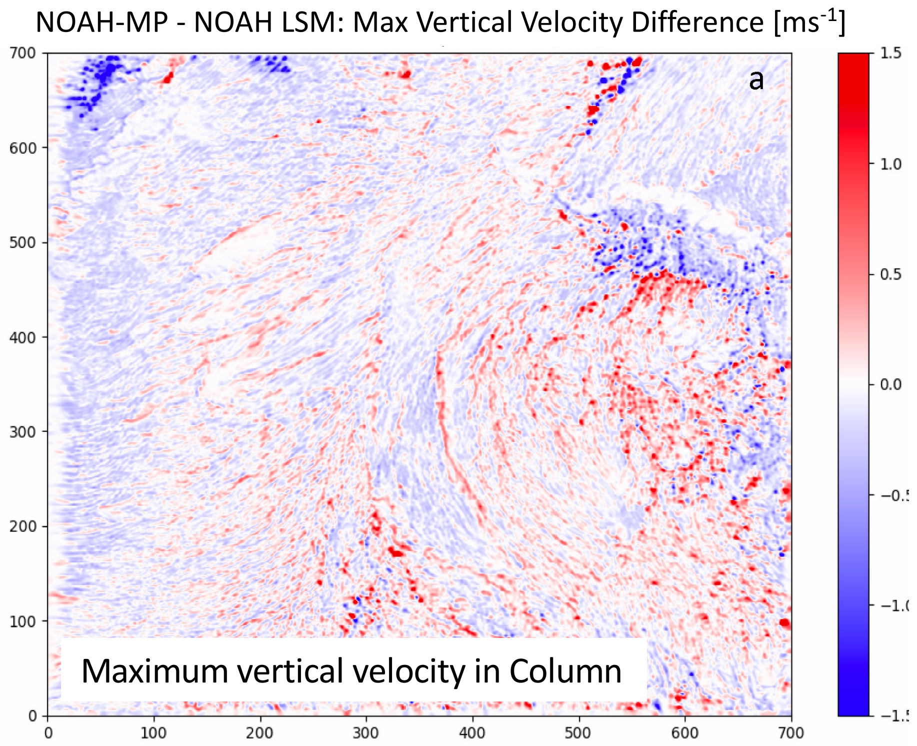
Sensible Heating Noah

Sensible Heating Noah-MP

- Sensible heat fluxes are larger in general for the Noah-MP simulation in forested regions, but they are smaller in cropland and grassland areas, such as the north-south band of lower heat fluxes through the middle of the domain
- There is greater spatial heterogeneity in the sensible heat fluxes in the Noah-MP simulation

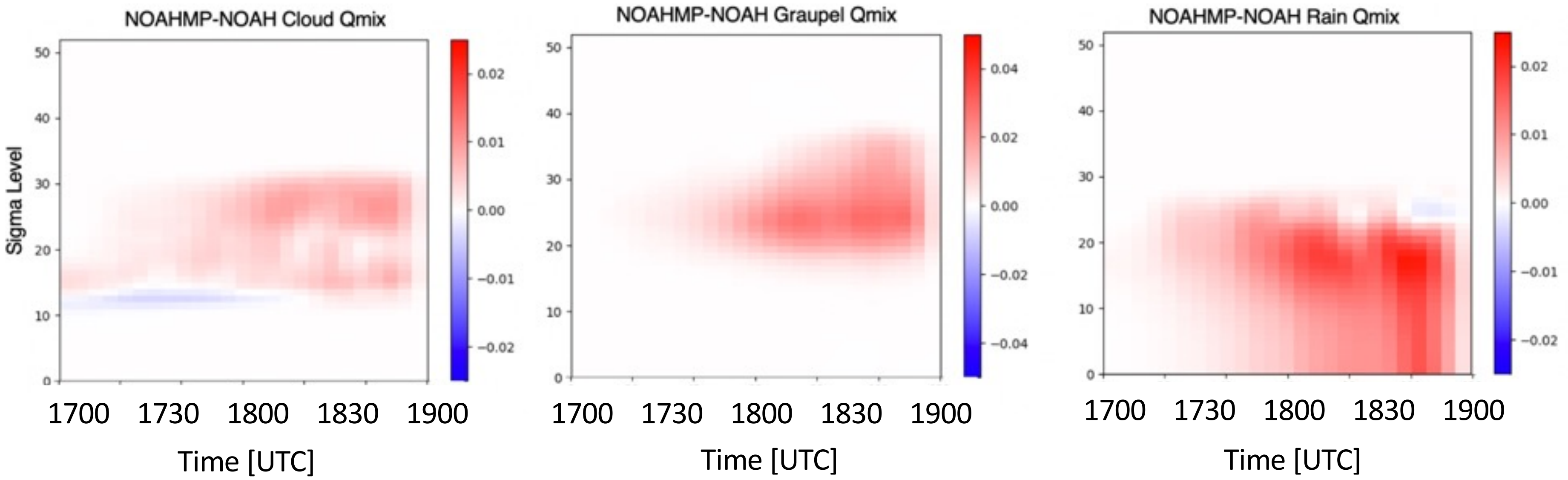
Impacts of Surface Energy Balance on Local Circulation
[Noah-MP – Noah]





Differences in surface radiative balance leads to differences in the local circulation

Impacts on hydrometeor mixing ratios in CI cloud objects
[Noah-MP – Noah]



Stronger updrafts and mass flux in the Noah-MP simulation led to substantially more cloud content, especially after 1800 UTC

Higher ice formation helps confirm the need for a latent heat boost to sustain cloud growth beyond CI detection

Summary of the Convective Initiation Study

- Differences in the land surface models impact the magnitude and spatial heterogeneity of the sensible and latent heating components of the surface radiation balance that in turn drive differences in local circulation patterns

- These differences then impact the characteristics of the updrafts, the spatial and temporal evolution of the hydrometeor mixing ratios, and the growth of the convective clouds

- Results also show that more research is necessary to improve the accuracy of land surface models

    - We are working on a NOAA project that is using surface sensible and latent heat flux measurements to examine the accuracy of UFS S2S forecasts