NUCAPS in gridded AWIPS format for Anticipating Convection

Joint Project between

NOAA JPSS, NASA SPoRT, STC, NWS, CIMSS, CIRA, GINA

Satellite soundings characterize the thermodynamic environment in 3-dimensions

- This training module will take you through the steps on how to use the Gridded NUCAPS product in AWIPS-II to improve situational awareness when diagnosing the pre-convective environment.
- We will discuss:
  - NUCAPS product overview
  - The value of gridded NUCAPS display*
  - Practical examples

Vertical structure and composition

Spatial patterns in ~2200km wide orbital swaths

*Mesoscale situational awareness / mid-level moisture / thermodynamic structure / tropopause height / spatial gradients / derived stability indices / height of freezing layers

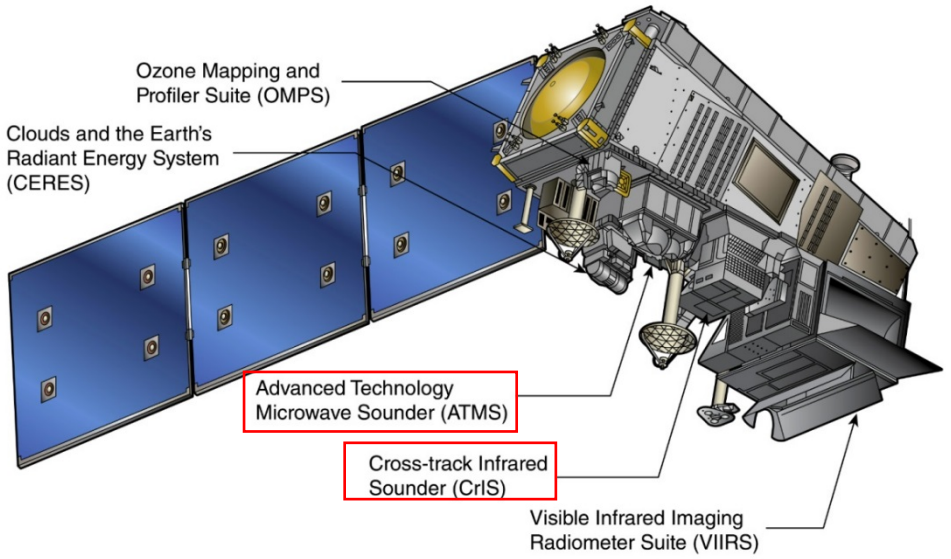
NUCAPS soundings from polar-orbiting satellites have the highest vertical resolution of any satellite measurement (including GOES)

NOAA-Unique Combined Atmospheric Processing System

- Combines hyperspectral **Infrared** (thousands of channels) and **microwave** measurements (20-30 channels)
  - Thousands of infrared channels allow better measurements of vertical column, from surface to top-of-atmosphere.
  - Combining **Infrared + Microwave** allows measurements in **Day + Night**, **Clear + Cloudy** (up to 90%).

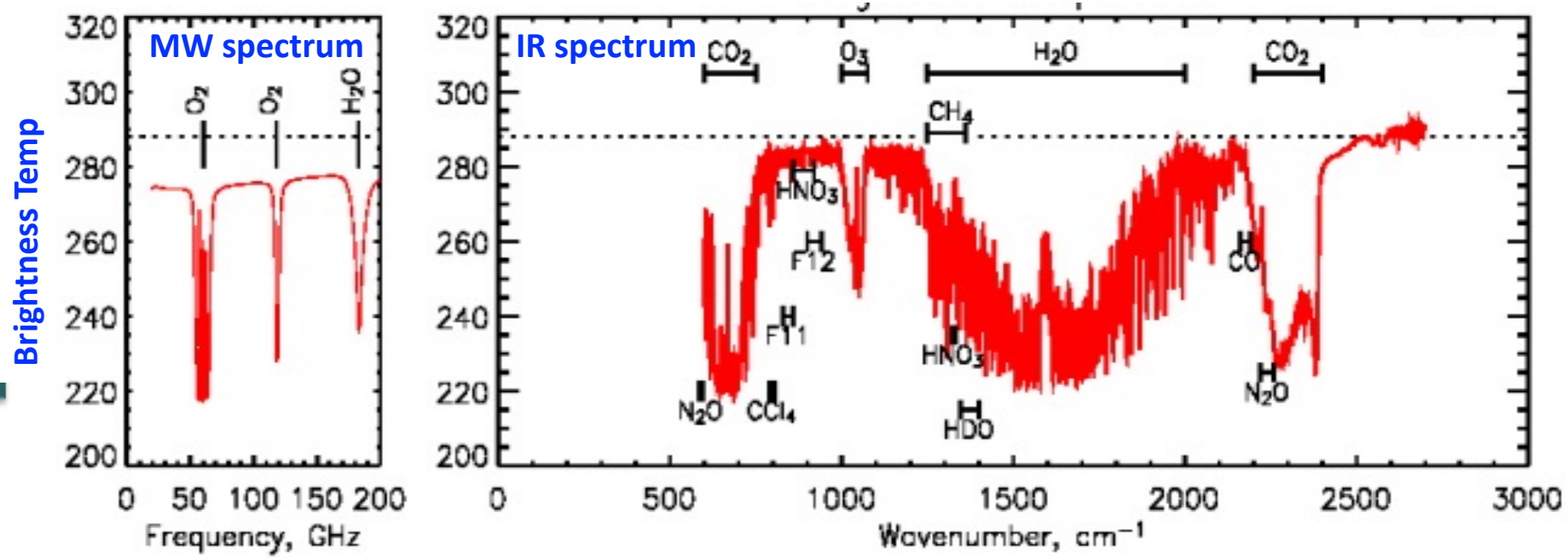
- Combines measurements from **4 x polar-orbiting satellites** to generate a 24-hour time-series of satellite soundings

- NUCAPS is a combined observation of multiple parameters (temperature, moisture, trace gas amount, cloud top pressure) that are thermodynamically consistent and characterizes the structure and composition of the 3-D atmospheric state



A NUCAPS sounding is retrieved from an integrated top-of-atmosphere IR+MW spectrum as a set of discrete parameters that are thermodynamically consistent

Initial profile statistically derived from MW (ATMS) and full IR measurement (all channels of CrIS)



Perform **cloud clearing** to remove cloud signal from IR radiance

Physical retrieval using both MW and a subset of cloud-cleared IR channels. This involves

- Sequential retrieval of T, q, CO, O3, CH4, O3, CO2, HNO3, SO2.
- Error checking, diagnostic tests, iteration to retrieve most **stable atmospheric state**

Which CrIS channels are used? 399 of them
- **24 for surface temperature**
- **87 for atmospheric temperature**
- **62 for water vapor**

Adjacent Channels are not used

Channels chosen are predominantly sensitive to one gas only

Produce final IR+MW NUCAPS soundings
at 100 layers
MW-only NUCAPS soundings available operationally but not in AWIPS yet

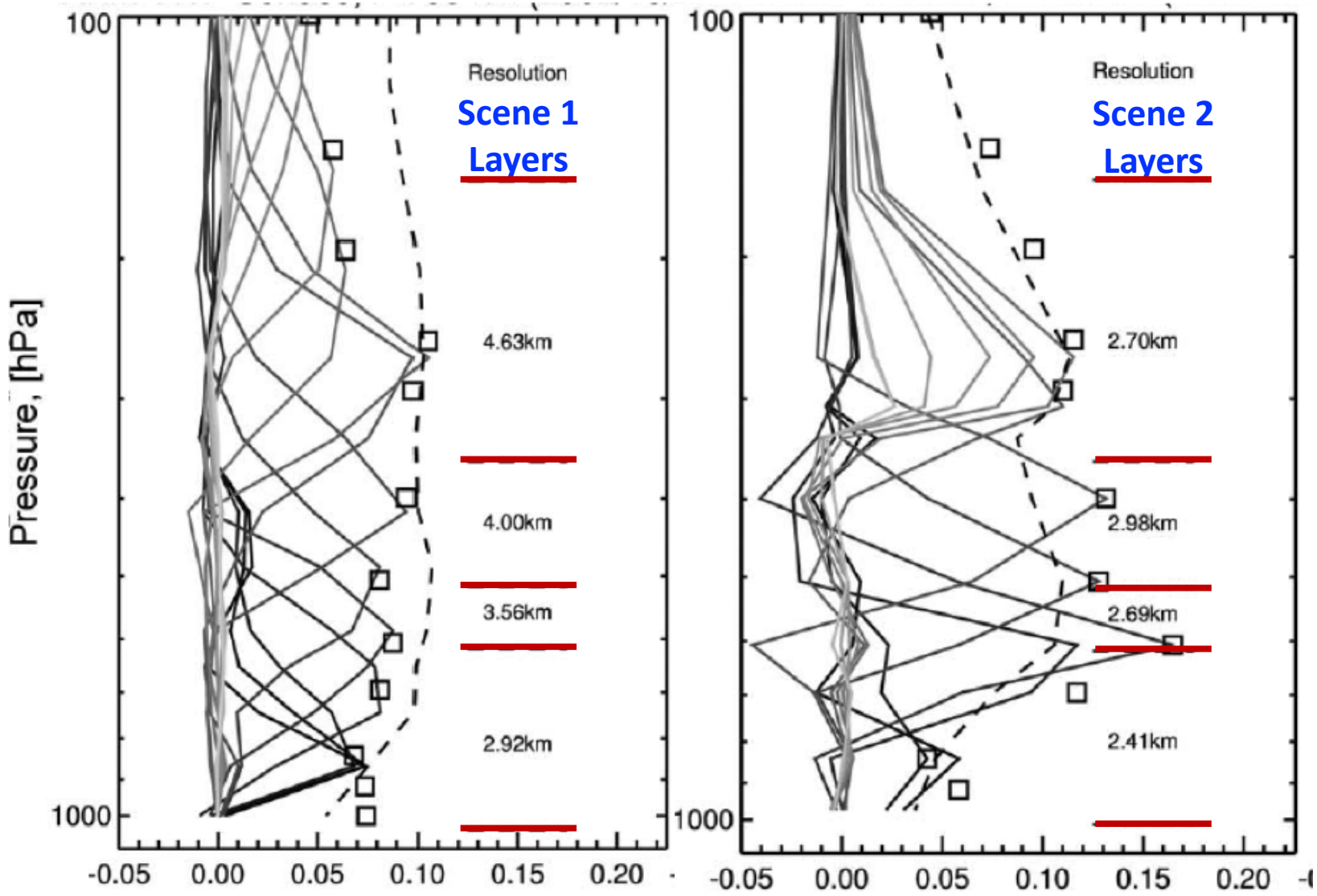
NUCAPS is a top-down observation of the vertical atmospheric column, the width of which is determined by the measured footprint from space

Effective Vertical Resolution of Satellite Soundings

NUCAPS retrieves temperature and moisture information as **thick layers stacked together to form a vertical atmospheric column** from surface to TOA

<u>How are the layers vertically distributed?</u>

… it varies slightly from scene to scene and is dependent on Earth surface temperature as well as local weather conditions



Vertical Resolution Estimates

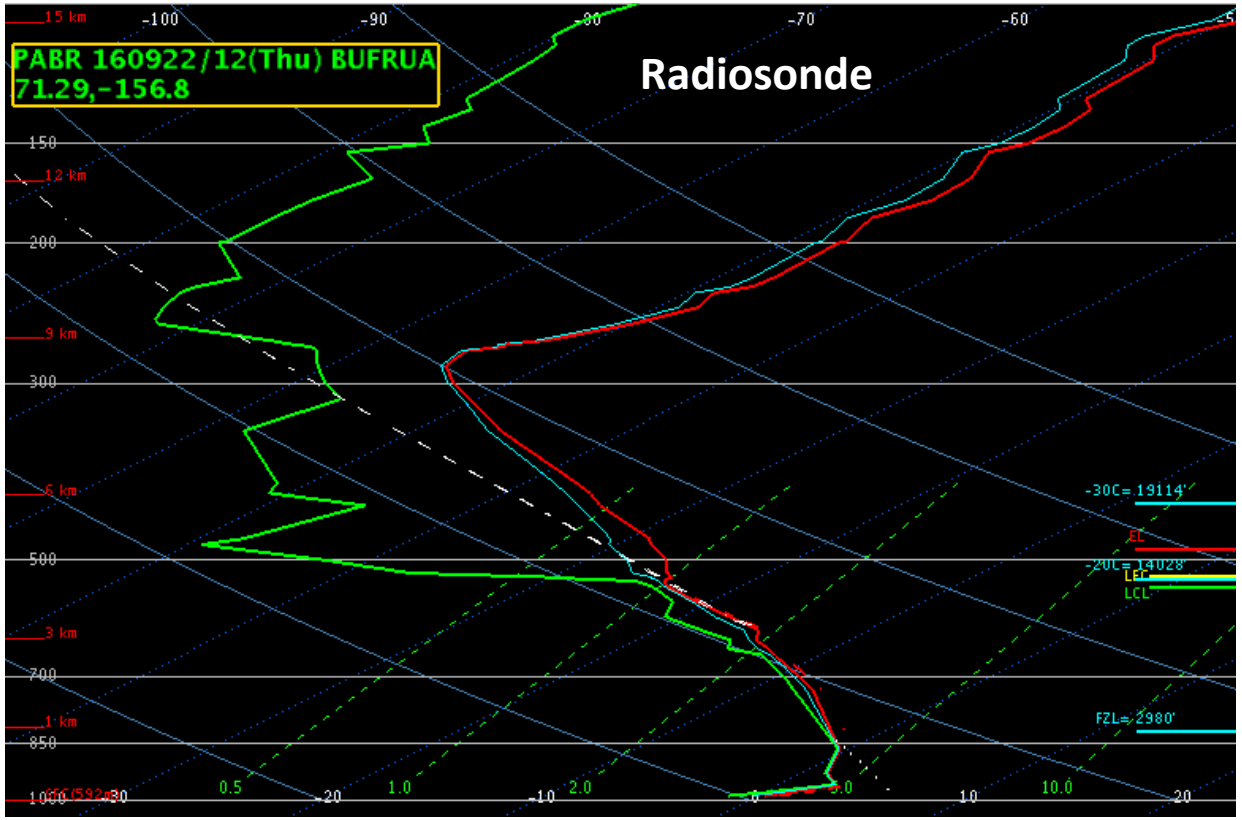
Images are from Maddy & Barnet, IEEE, 2008

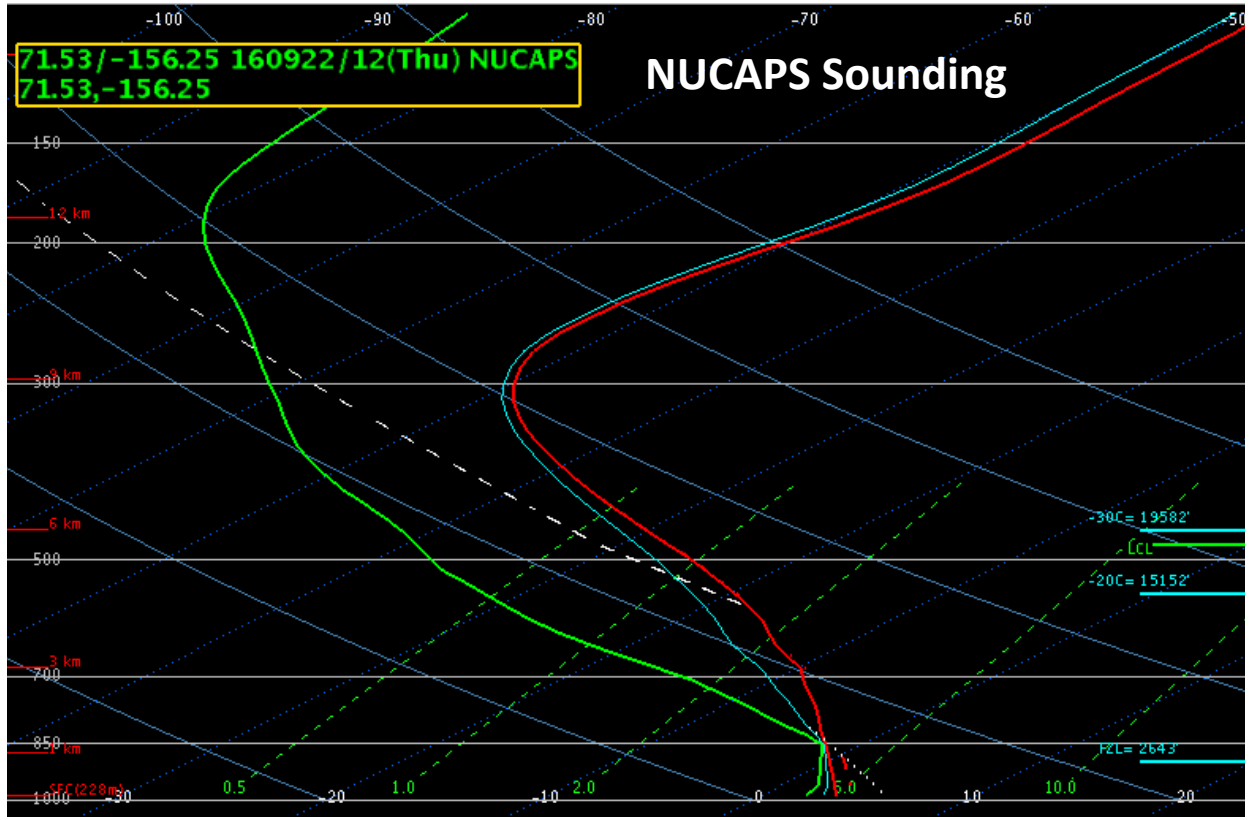
Effective Vertical Resolution of Satellite Soundings

So what does this mean in operations?

… compared to radiosondes, NUCAPS has a smoother appearance

… compared to GOES soundings, NUCAPS has high vertical definition





Barrow, Alaska

NUCAPS Strengths

- There are **thousands** of satellite soundings **day and night** to measure many types of evolving weather systems.
- NUCAPS soundings observe mid-level moisture, thermodynamic structure, tropopause height, spatial gradients, derived stability indices, height of freezing layers, fire weather indices, all to improve **meso- and synoptic scale situational awareness** and forecasting
- A NUCAPS sounding has information not only on Temperature and Moisture but **also on trace gas amounts** (CO, O3, CH4), cloud top pressure and various diagnostic indices all in one.
- NUCAPS soundings are available in **clear and partly-cloud scenes** (up to 90% cloudiness; see slide 10).
- NUCAPS soundings have been **validated extensively** and have high vertical accuracy and precision in the low, mid and high troposphere.
- All parameters in NUCAPS retrieval product are thermodynamically consistent, which makes comparisons between trace gas amounts, clouds and T/q profiles not only easy but also accurate.
- **Spatial + temporal coverage** over land and ocean, day and night, deserts and mountains, thus in many areas nearly impossible for radiosondes to reach.

NUCAPS Limitations

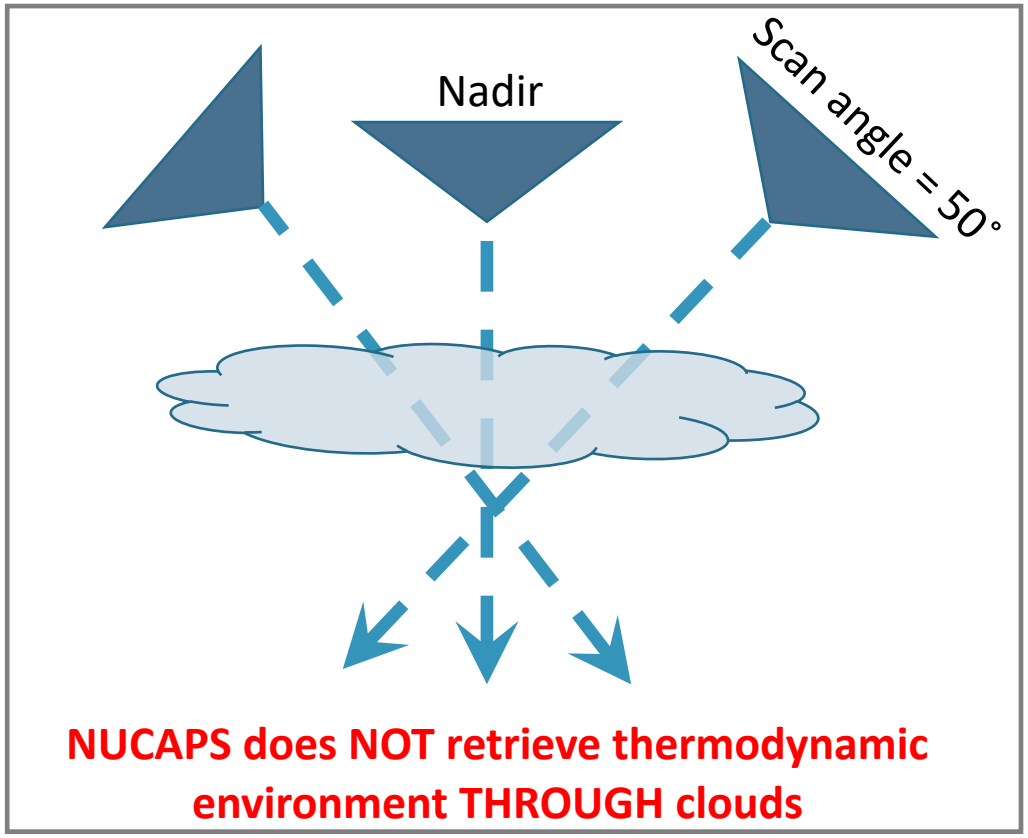
- Because NUCAPS is a TOP-DOWN measurement, it has its **highest uncertainty in the boundary layer**, which is furthest away from the instrument in space.
- Because of high boundary layer uncertainty and variability from scene to scene, NUCAPS soundings sometimes need to be adjusted to help forecasters interpret atmospheric instability.
- NUCAPS observes the atmospheric state as **thick vertical layers** that together form a broad **columnar measurement**. Thus, care should be taken when comparing to radiosondes, which are point-source measurements strung together along the balloon path.
- NUCAPS soundings fail when the measurement footprint is covered by a uniform cloud field (see slide 11).
- A NUCAPS sounding in partly cloudy scene removes cloudy signal before retrieving atmospheric state. So take care to interpret these soundings as they **do NOT measure the thermodynamic state *through* the clouds but *around* them**.
- The NUCAPS algorithm combines a cluster of IR and MW measurements to retrieve a satellite sounding of the clear-sky atmosphere past clouds. This means a **course NUCAPS footprint size** (~50km at nadir).

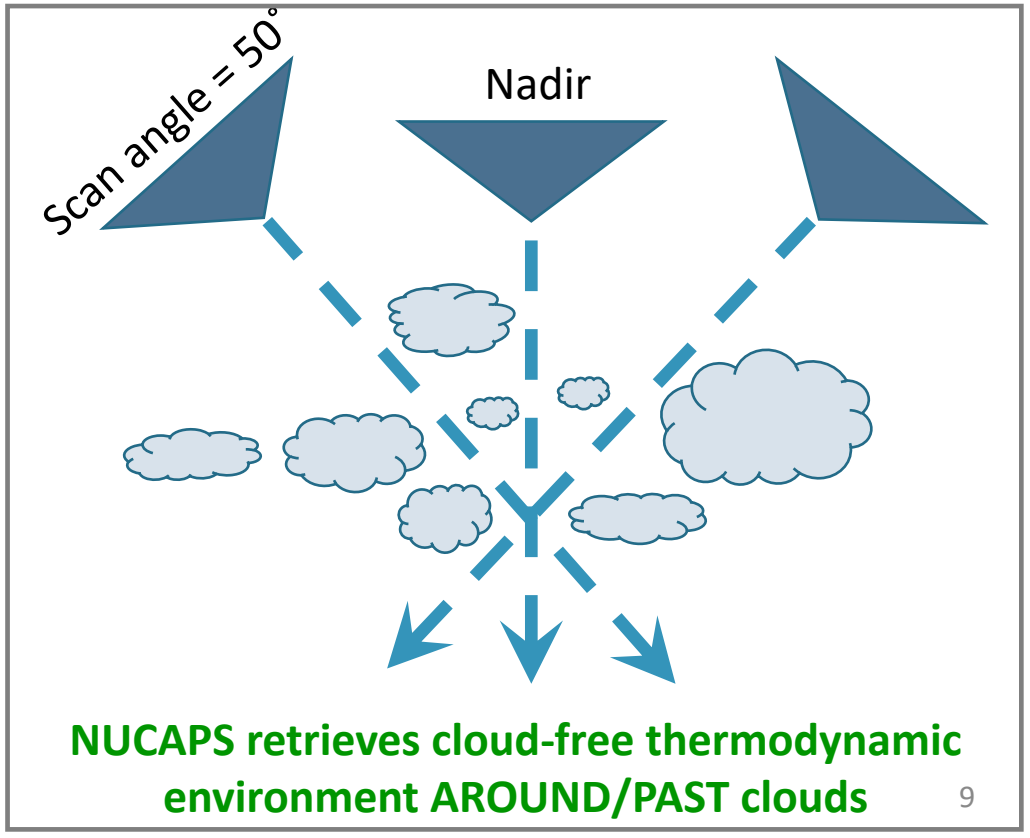
NUCAPS soundings in cloudy atmospheres

To an IR Sounder a cloud is an obstacle, not an opportunity!

The probability that a NUCAPS footprint is completely cloud-free is ~5% (that is very low!)

So, NUCAPS performs **cloud clearing** to allow retrievals in partly-cloudy scenes so that there can be more sounding observations of evolving weather systems.



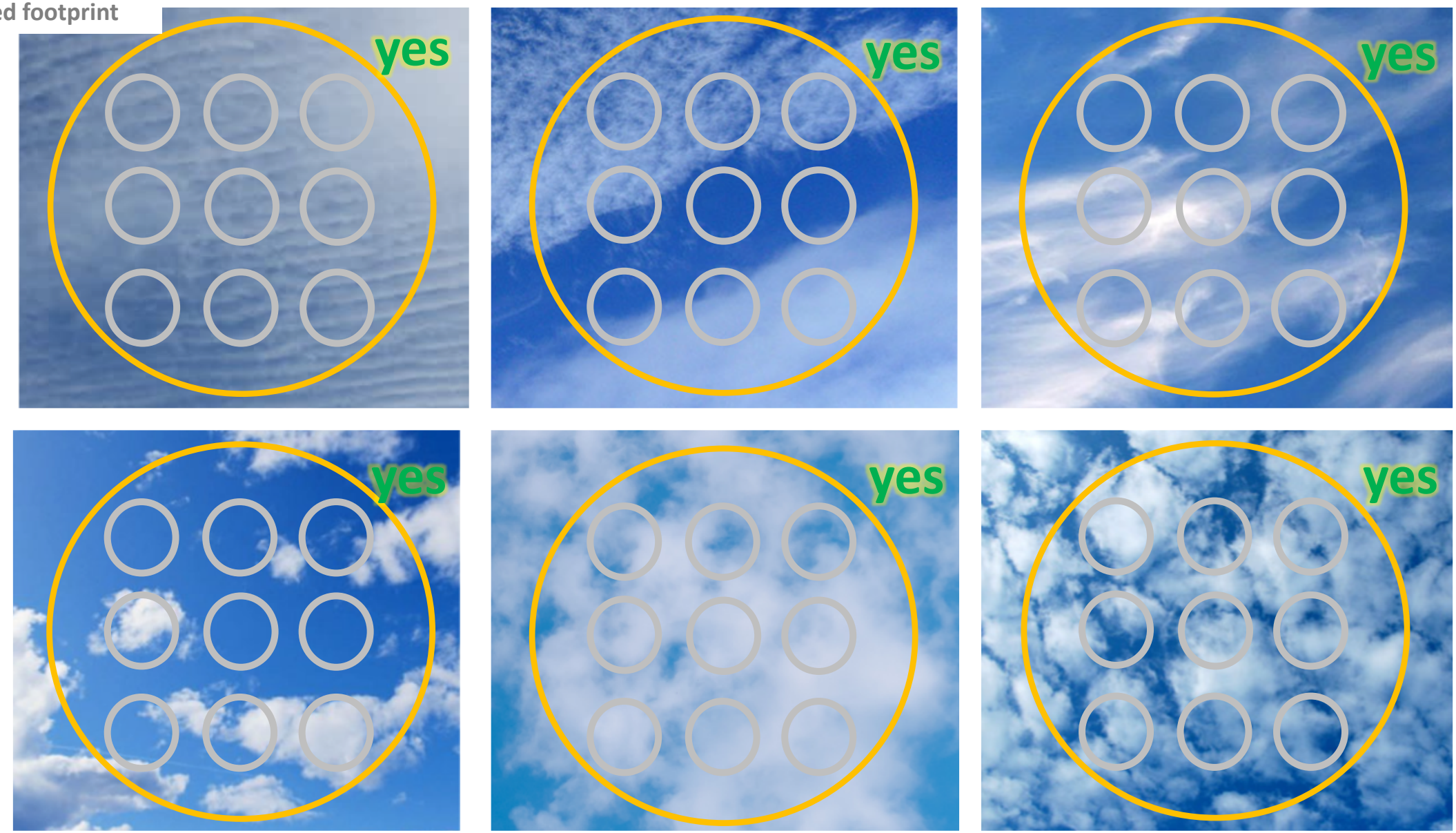


Cloud Clearing **succeeds** when NUCAPS footprint has **cloud variability**; i.e. a cluster of IR footprints over broken cloud fields

NUCAPS footprint

Infrared footprint

NUCAPS retrieve soundings if there is an infrared radiative pathway past clouds



The clear-sky radiative pathway PAST clouds can be determined using **a cluster of 3x3** infrared footprints with variable cloud fractions.

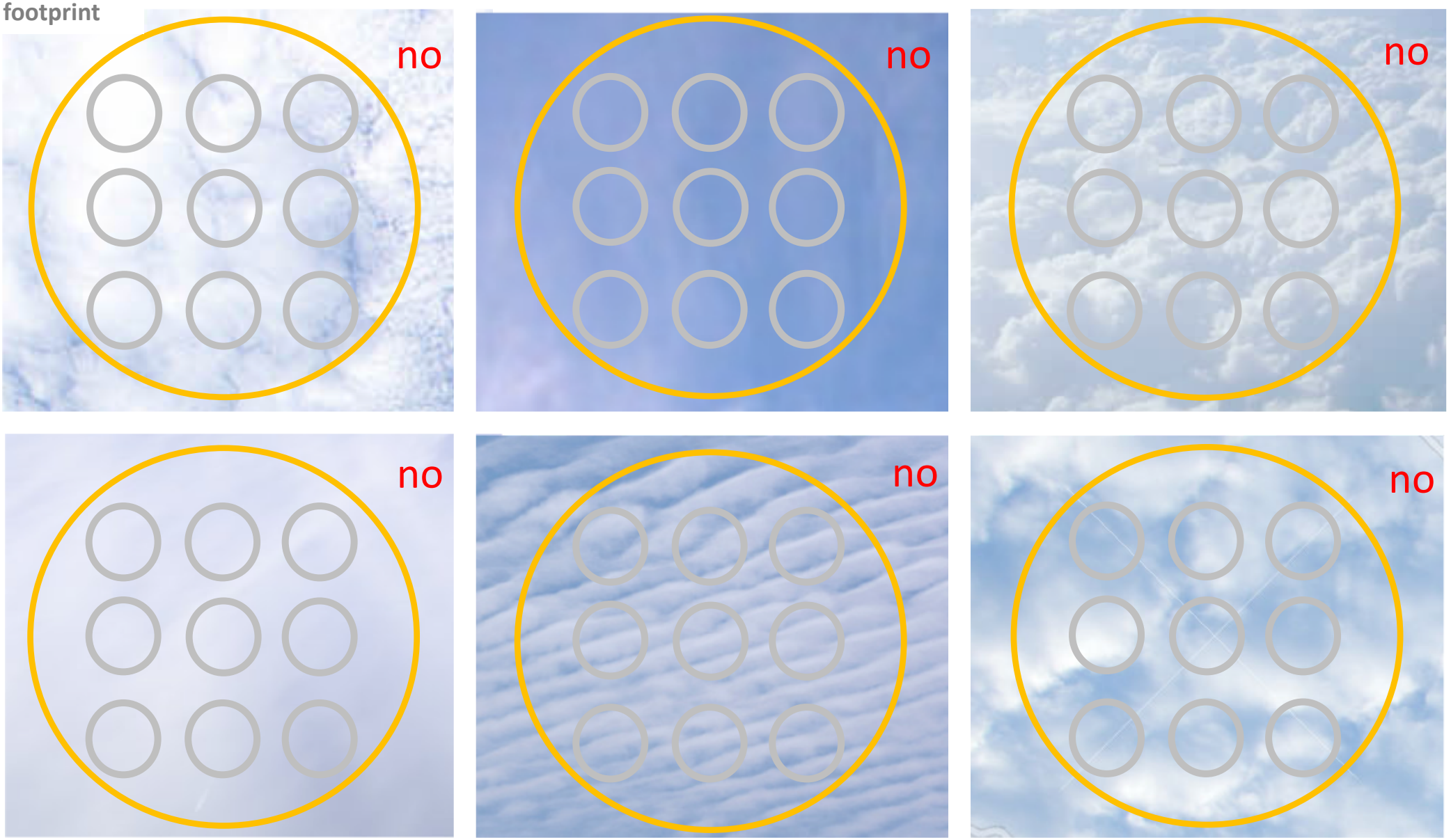
NUCAPS soundings are successfully retrieved from clear-sky or cloud-cleared radiance measurements

Cloud Clearing **FAILS** when NUCAPS footprint is **uniformly cloudy**, i.e. a cluster of IR footprints over a uniform cloud deck

NUCAPS footprint

Infrared footprint

NUCAPS cannot retrieve soundings if there is no radiative pathway past clouds

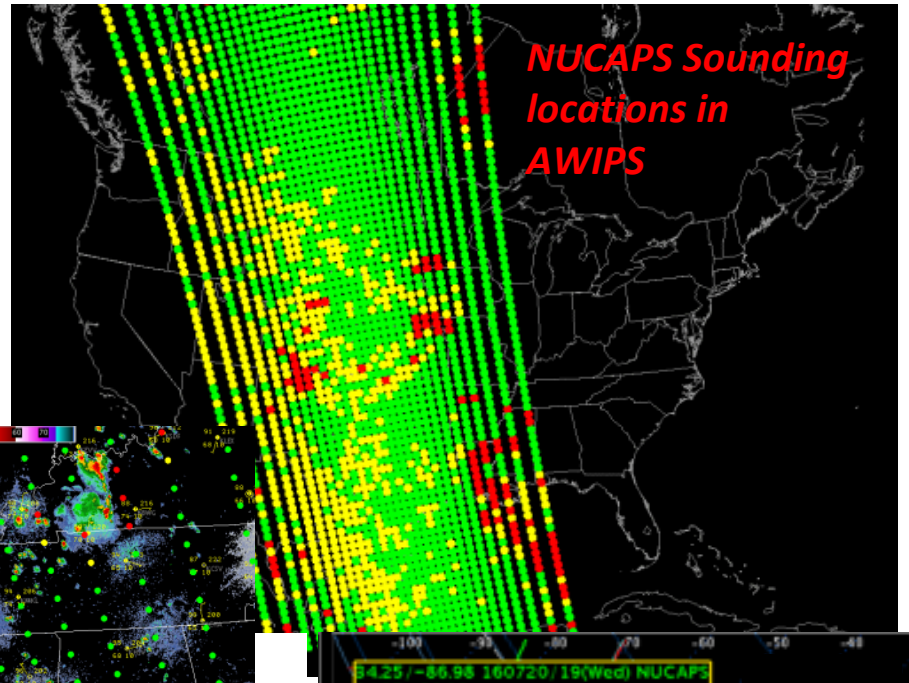


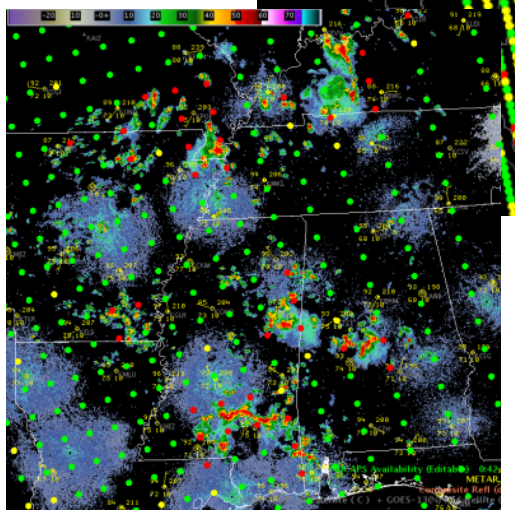
NUCAPS soundings CANNOT be retrieved from cloudy measurements of the radiative the pathway through clouds.

This is why optical thickness (cirrus versus stratocumulus) is irrelevant to NUCAPS.

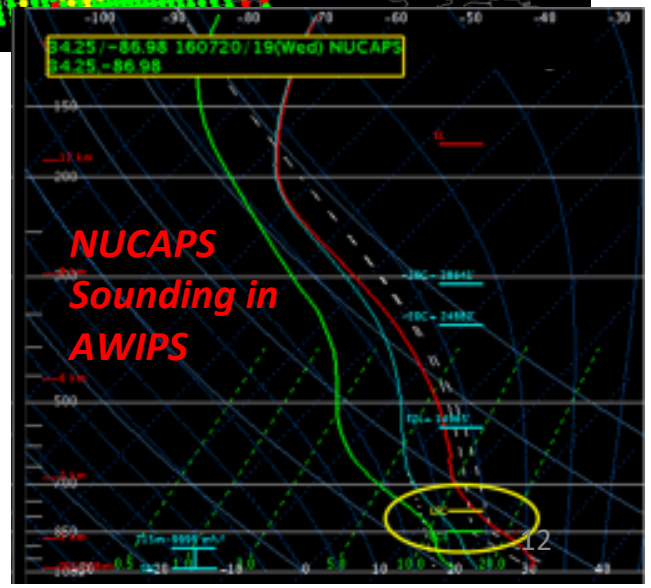
Current Operational NUCAPS Visualization

- NUCAPS has been available in AWIPS-II since 2014 and can be visualized as:
  - **Skew-T plots** with red/yellow/green quality control flags (this is available to AWIPS-II terminals)
  - Since 2016 as AWIPS grids to allow for **plan view and cross-section display**, which have great value in decision processes (this is being developed and will become available to all AWIPS-II terminals in 2019)
- NUCAPS allows forecasters to observe the 3D extent of the atmosphere with spatial and temporal regularity to enable improved situational awareness at meso- and synoptic scales.

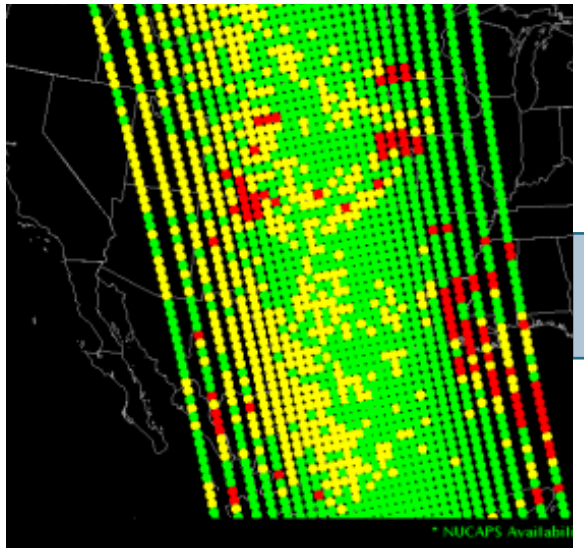


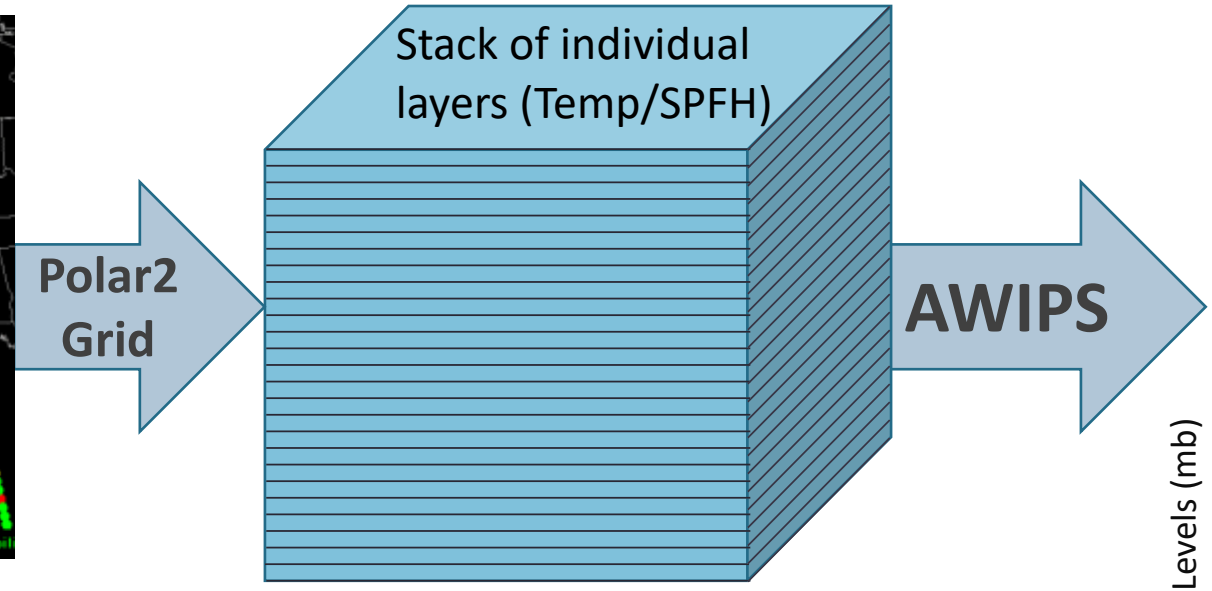


NUCAPS Sounding locations overlaying radar in AWIPS

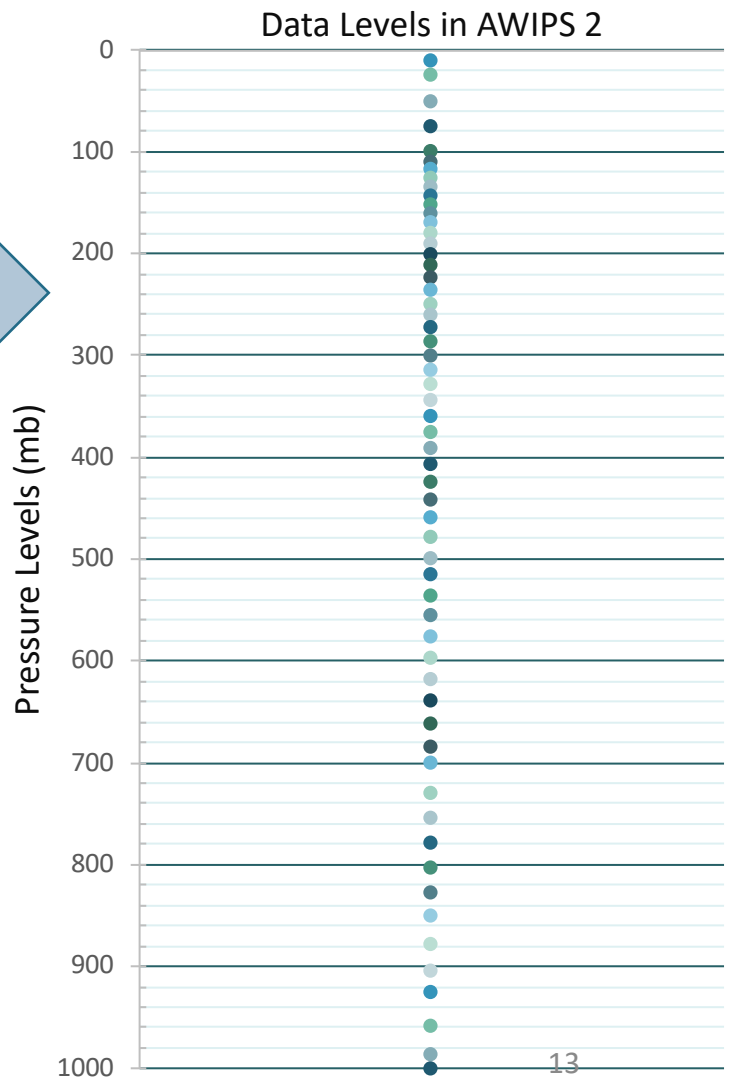


Gridded Product Overview





NUCAPS Data Levels Output from Polar2Grid



NUCAPS Soundings:
Need to click on each 'dot/point' to review the vertical information

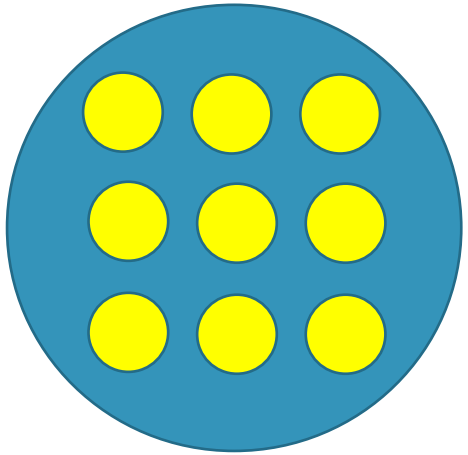
- *Pros: Can choose specific locations*
- *Cons: A lot of individual interrogation*

- 58 levels are output using Polar2Grid from the 100 layers output by NUCAPS.
- Ingested into AWIPS on a uniform model grid, so AWIPS will interrogate the information in the same way it handles model data allowing for plan view and cross sections

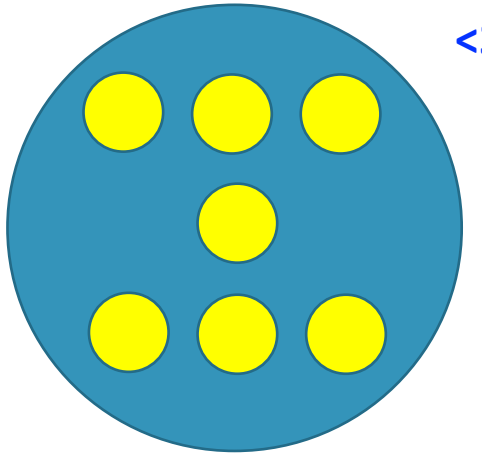
NUCAPS. data delivery:

Operational (CLASS/SBN) vs Direct-Broadcast (CSPP)

90-240 min latency



FOV = field of view (yellow)
FOR = field of regard (blue)



<30 min latency

Operational NOAA CrIS/ATMS footprints

9 x CrIS FOVs inside 1 x ATMS FOR

Point-based NUCAPS Soundings in AWIPS is delivered via operational SBN stream

Direct Broadcast NOAA CrIS/ATMS footprints

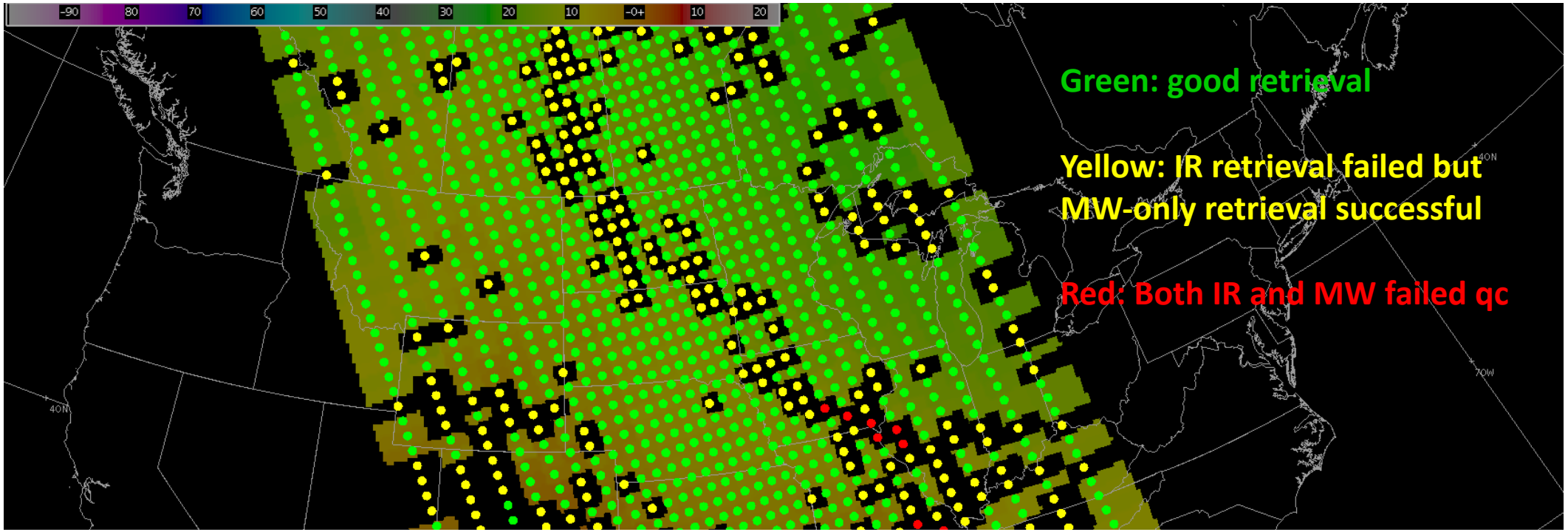
7 x CrIS FOVs inside 1 x ATMS FOR

Gridded NUCAPS and Reduced Latency Soundings (& Modified Soundingg) in AWIPS are delivered via CSPP/DB stream

Two footprints (#4 and #6) are removed from real-time DB stream to decrease data latency

IMPACT: We can expect to see a mismatch in quality flags and retrieval quality at the edges of cloud fields between the SBN point–based NUCAPS Soundings and gridded NUCAPS due to fewer footprints with which to calculate cloud cleared radiances

Reduced Latency NUCAPS Soundings overlaid on Gridded NUCAPS



- ***New this year:*** consistent QC between Reduced Latency Soundings and gridded product since both are derived from the CSPP (direct broadcast) data stream which has 7 instead of 9 fields of view (previous slide).
- ***Gridded NUCAPS:*** polar2grid regrids NUCAPS to 12km from ~50km at nadir (~150km at edge of scan).
  - NO INTERPOLATION. All this means is that a single retrieval footprint is now represented by ~25 (~225) identical grid cells.
  - This breaks footprint into smaller parts and gives it a zig-zag edge but the benefits are that (1) it preserves a realistic footprint size towards edge of scan, and (2) allows a one-to-one comparison with point-based

Displaying Data & Recommended Fields

- ***See weekly NUCAPS SME's for Volume Browser or Procedure Instructions***

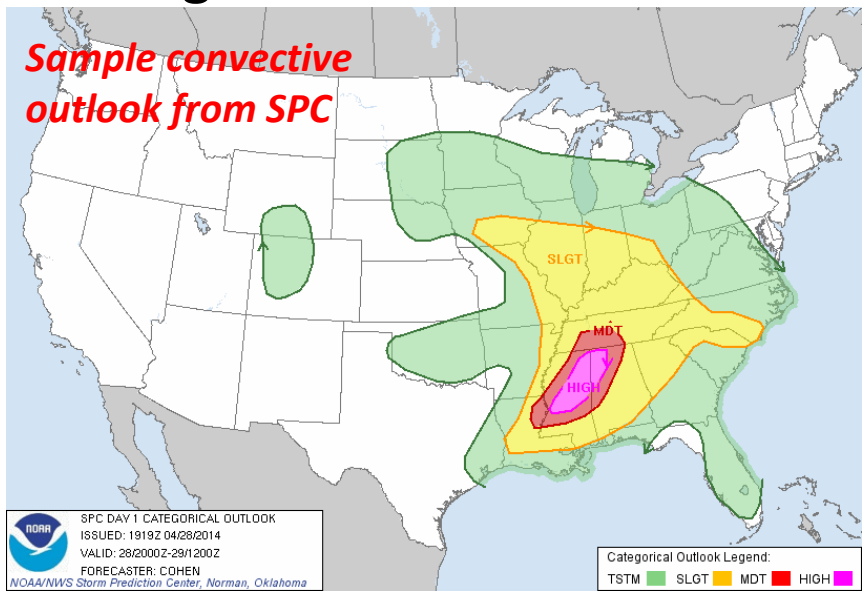
- Can view ***Temperature, Moisture, and Stability Indices*** on ***single level*** or ***over a layer***
  - ***Choosing a level display***

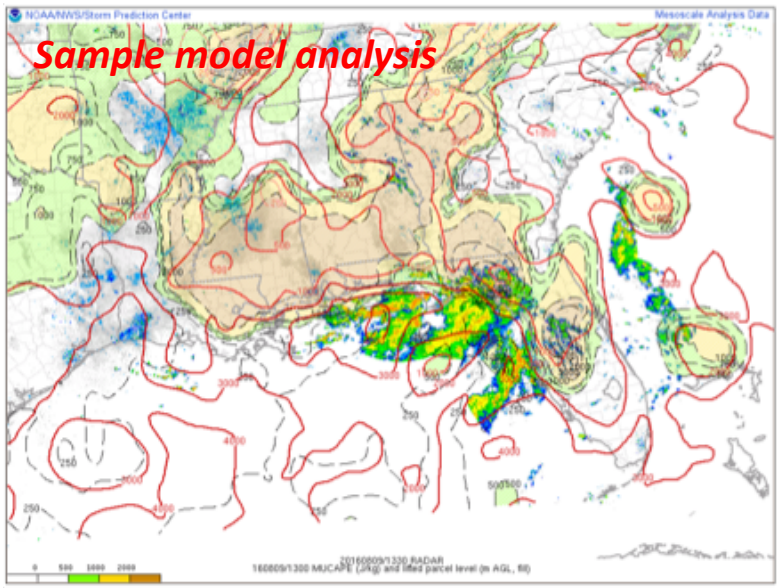
    Volume Browser → NUCAPS-CONUS → choose field → Misc → Gridded NUCAPS → choose level → right click on display field to Change to Img → load
  - ***Choosing a layer display***

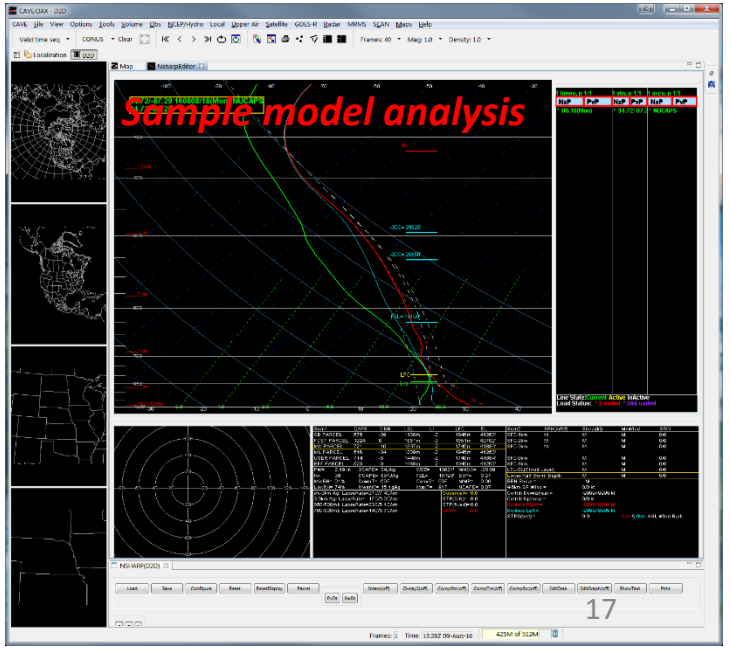
    Volume Browser → NUCAPS-CONUS → choose field → Pres → Standard Layers→ choose layer → right click on display field to Change to Img → load

Forecast Challenge: Diagnosing Pre-Convective Environment

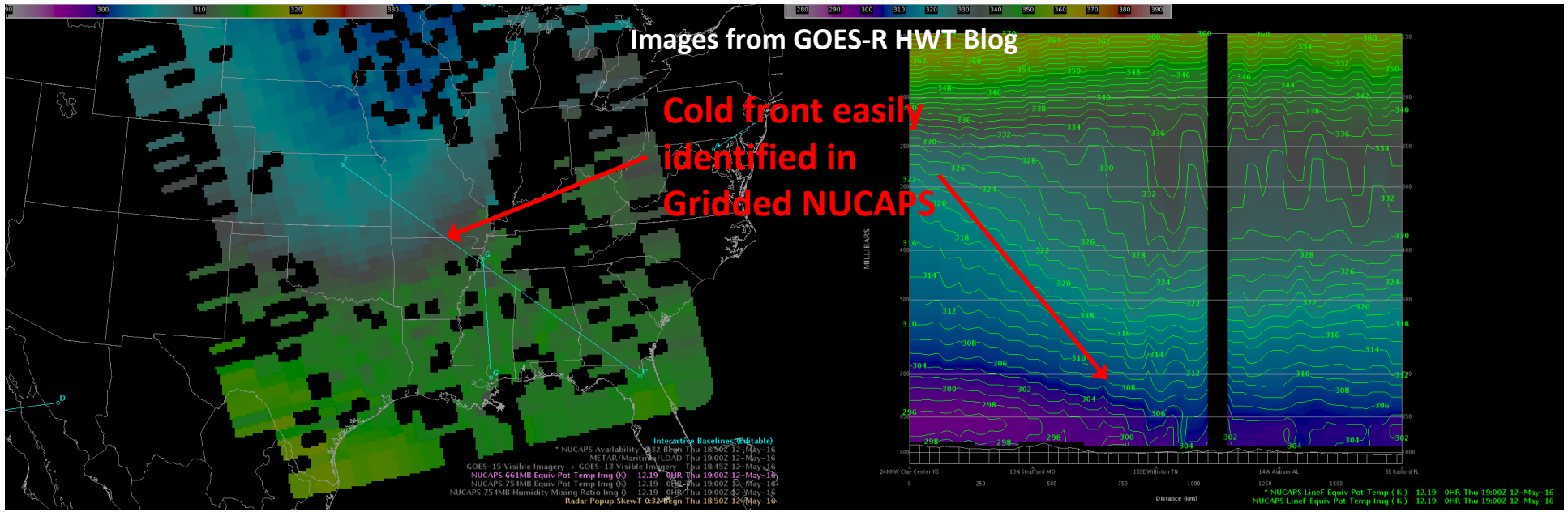
- The vertical distribution of temperature and moisture in the lower atmosphere determines convective potential
- Forecasters use a combination of in situ observations, satellite data, and models to determine the location of boundaries and areas of instability
- Ability to view plan view and cross sections of NUCAPS data in a beta version were demonstrated at the 2016/17 Hazardous Weather Testbed Experimental Warning Program





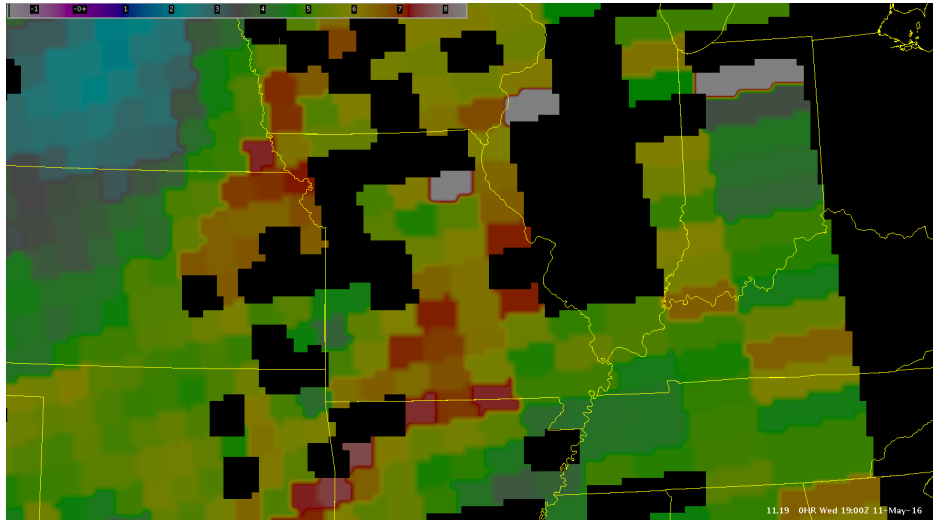


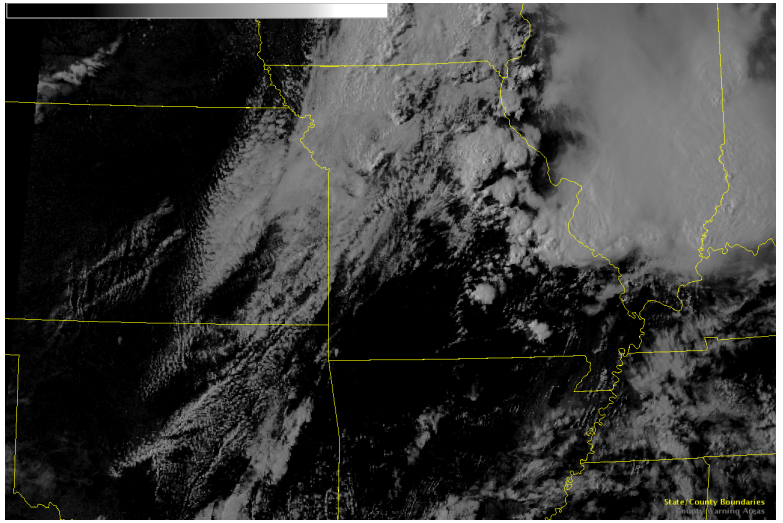
Gridded NUCAPS Convection Application



“We recently gained the ability to create cross sections through the NUCAPS swaths. This will be helpful for diagnosing phenomena such as boundaries and convective instability. The first image below is a plan view display of theta-e at 660 mb across the region. Obvious is the much cooler, drier air behind the cold front (low theta-e) with moist, warmer air ahead of it to the east (high theta-e). Also plotted is a line, denoting the location for which the cross-section (image below) was taken, through the cold front. The cross-section depicts theta-e vertically through the atmosphere. This provides another perspective on the cold front, which is obvious in the image.”

Gridded NUCAPS Convection Application





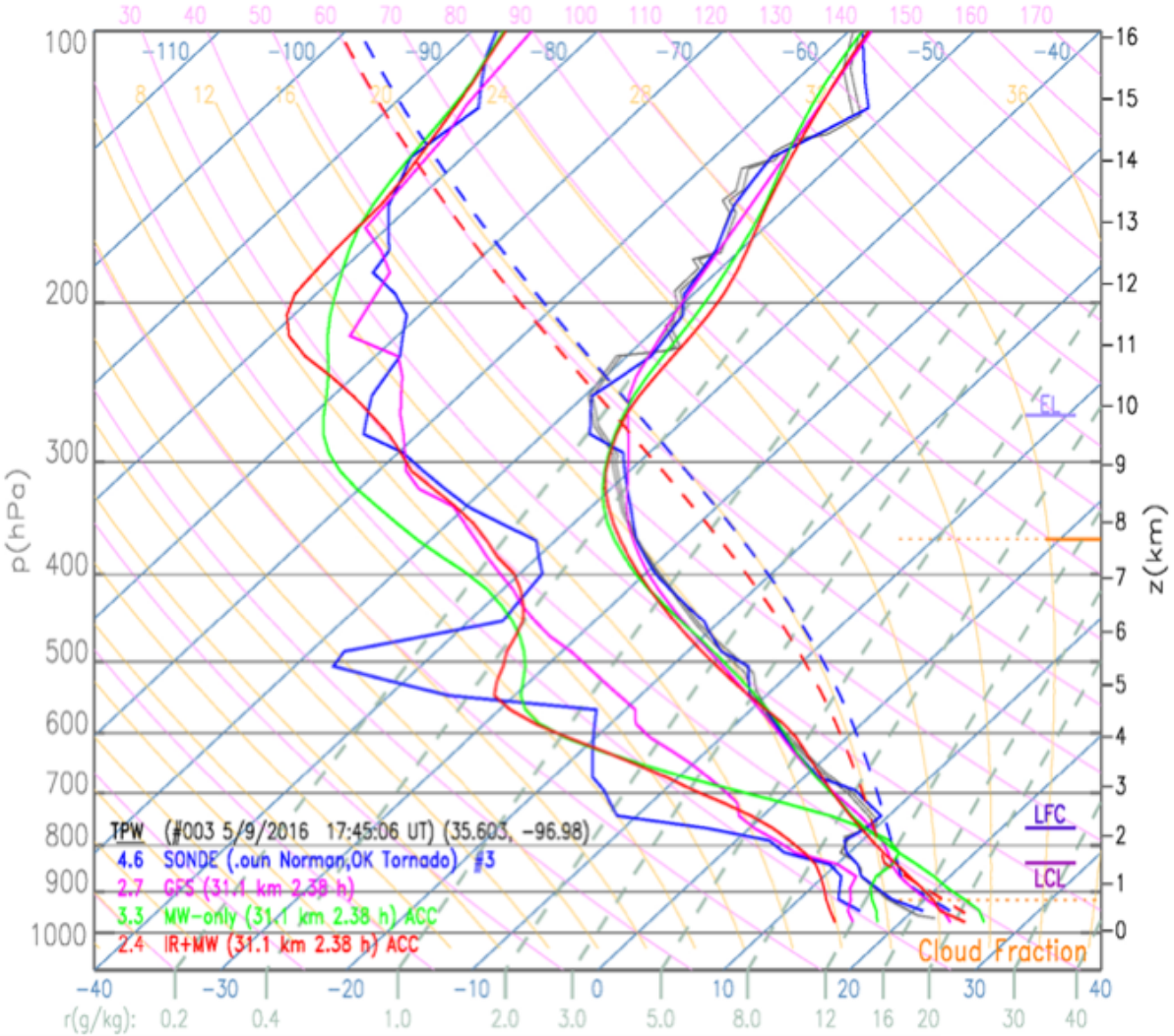
Images from GOES-R HWT Blog

“We took a look at a NUCAPS plan view image of mid-level moisture (754 mb mixing ratio) from 19Z. Image shown below. Areas of higher moisture were apparent over south-central Missouri in our SGF CWA, and over the St. Louis metro area.

Several hours later, we noted that convective activity was focused in these general areas. The few cells that developed over our CWA were over the south-central part of the state. Much more significant convection triggered over the St. Louis area. –JP”

9 May 2016

- Observed soundings taken at OUN 12/18 UTC
- NUCAPS Sounding (Red) captured the mid-level dry air signature during 19-20 UTC overpass
- Convective parameters (red in table) were within ~20 % of model CAPE and observations
- NUCAPS provided additional soundings over a large area and between special/synoptic observations
- Tornado occurred near Moore, OK 2215 UTC

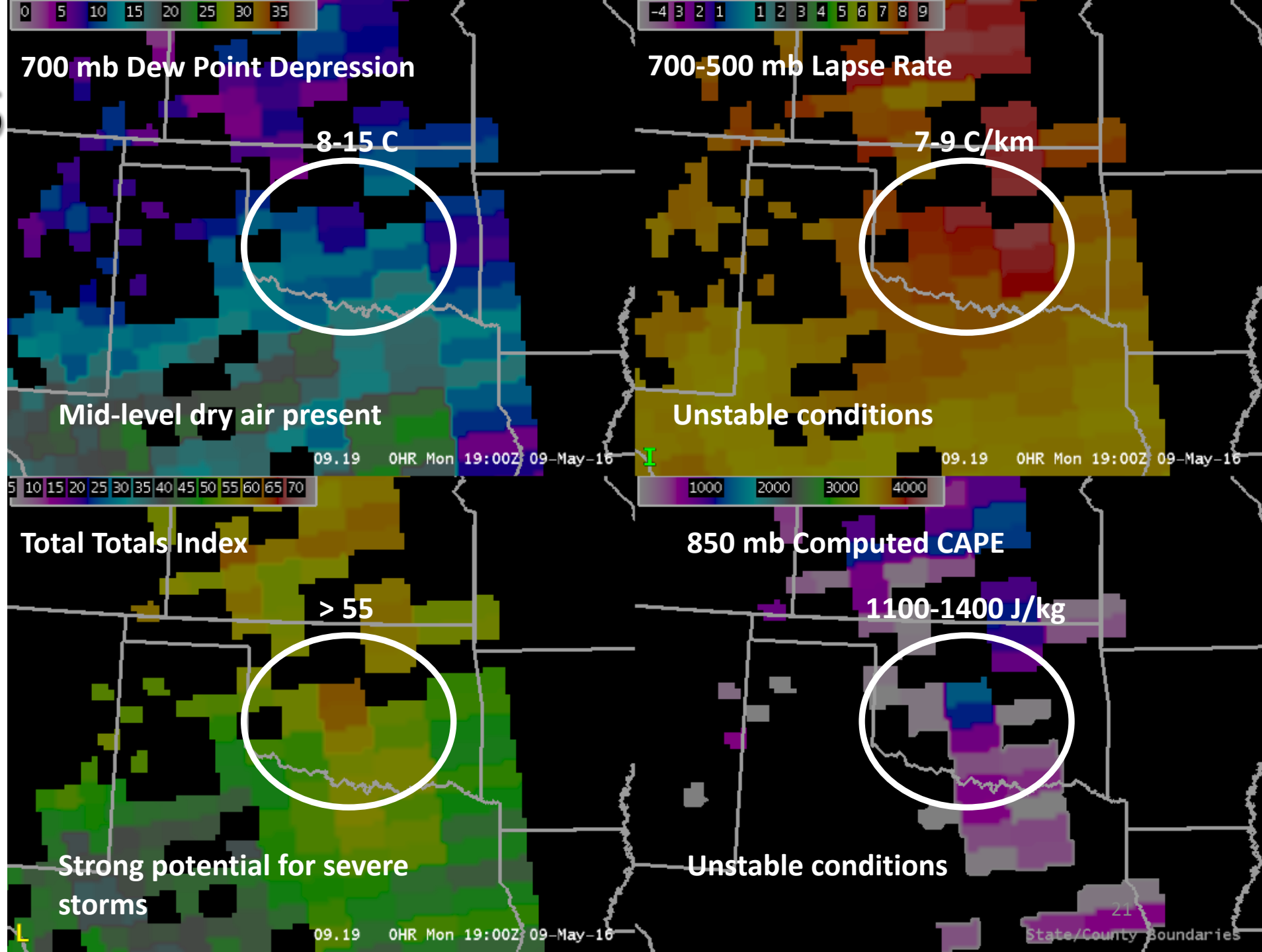


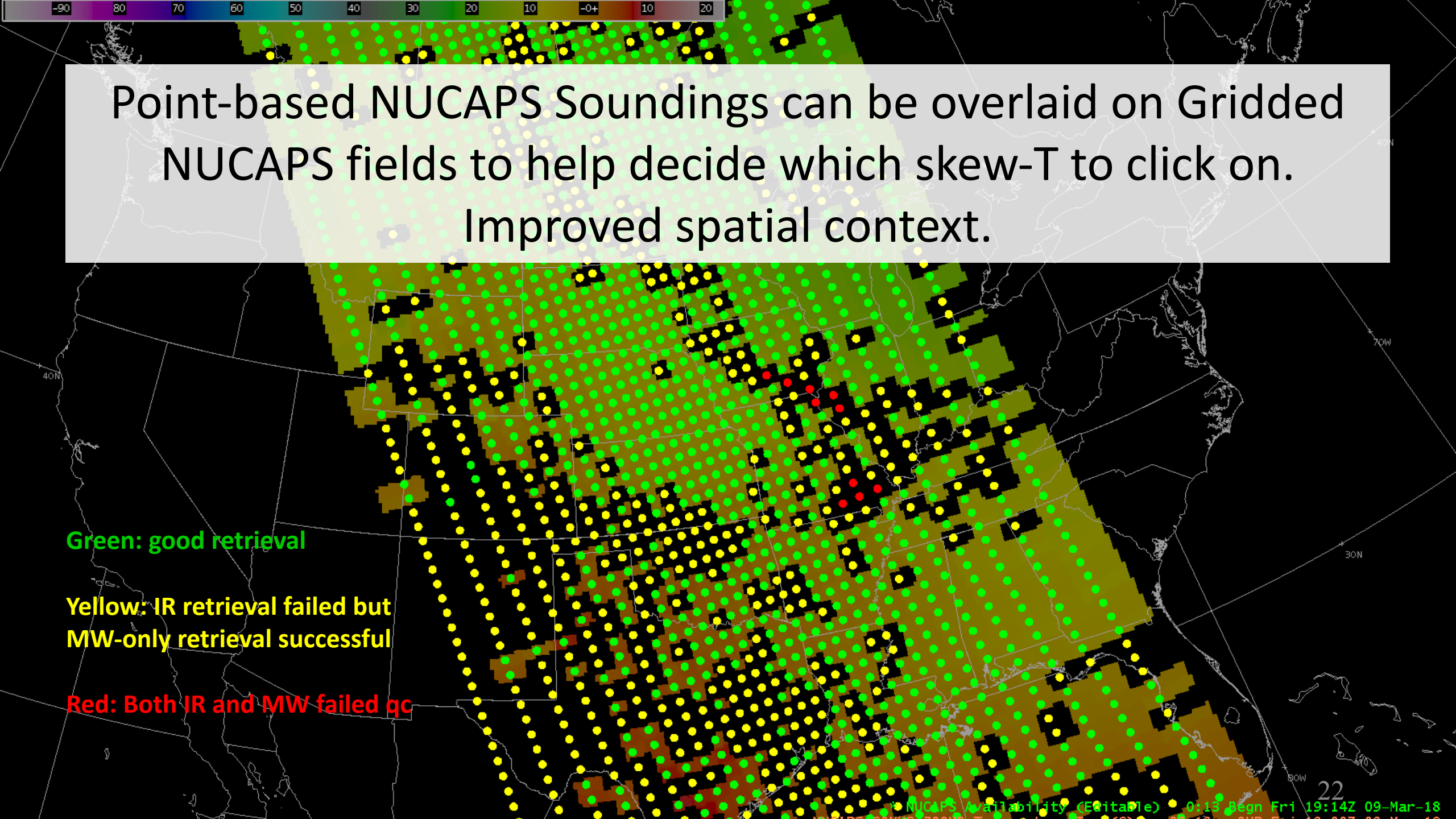
typ	scan	FOR	(g, FOR)	r(km)	dt(h)	time	lat	long	CAPE	CIN	LCL	EL	LFC
GFS	144	29	(36, 119)	31.1	2.38	20.13	35.78	-96.71	1939	-26	849	253	785
MIT	144	29	(36, 119)	31.1	2.38	20.13	35.78	-96.71	3591	-15	845	229	814
RET	144	29	(36, 119)	31.1	2.38	20.13	35.78	-96.71	1570	-74	836	266	765
SND	---	--	(---,---)	----	-----	17.75	35.60	-96.98	1914	0	877	241	877

9 May 2016

- Gridded NUCAPS example to evaluate the pre-convective environment in OK and TX where severe weather was anticipated on this day

- Gridded NUCAPS overpass 19-20 UTC indicates
  - Mid-level dry air present
  - Unstable conditions
  - Strong potential for severe weather




-90 80 70 60 50 40 30 20 10 -0+ 10 20
Point-based NUCAPS Soundings can be overlaid on Gridded NUCAPS fields to help decide which skew-T to click on. Improved spatial context.
Green: good retrieval
Yellow: IR retrieval failed but MW-only retrieval successful
Red: Both IR and MW failed qc
40N
70W
30N
80W
NUCAPS Availability (Editable) 0:13 Begn Fri 19:14Z 09-Mar-18

NUCAPS in AWIPS – Things to think about...

- Radiosondes measure moisture through clouds, NUCAPS measures moisture around clouds
- NUCAPS can retrieve super-saturation (no limit on 100% RH). May see RH values well above 100% in the gridded product which will impact how AWIPS calculates certain parameters such as dew point and stability indices
- Data below the surface is masked out in the gridded product
- NUCAPS resolution is 50 km near the center but closer to 150 km near the swath edge however the product is gridded to a uniform 12 km grid for AWIPS
- NUCAPS can resolve only 4-6 layers of water vapor and 6-10 layers of temperature but data is output on the 100 layers used by the radiative transfer model. As a result profiles are smooth despite the number of levels available
- There are 58 levels available in AWIPS and some levels were forced to standard levels for consistency with the forecast process and to allow AWIPS to calculate stability indices (1000, 925, 850, 700, 500, 300, 250, 200, 100)

Summary

- NUCAPS Soundings and Gridded NUCAPS can be used to diagnose temperature, moisture, and stability characteristics of the pre-convective environment.
- NUCAPS Soundings provide soundings between routine radiosonde observations
- Gridded NUCAPS allows the forecaster to view variables on either plan view or cross-sections
- NUCAPS retrieves atmospheric information around clouds
- The best quality data is retrieved under clear to partly cloudy conditions

Developer questions to Forecaster

- Would you be interested to know how vertical resolution (or degree of smoothing) changes from scene-to-scene?
- Given what you've learned about satellite soundings, is there any diagnostic, thermodynamic or quality control metric that you would like to visualize as a means to aid your real-time problem solving?
- Would you be interested in MW-Only NUCAPS retrieval? It provides additional measurement and it can possibly be used to fill the IR+MW product gaps
- Does NUCAPS (IR+MW) provide enough information (e.g., despite data gaps and coarse spatial resolution) to make sense of the pre-convective environment?
- Other than the thermodynamic parameters (T/q) what other NUCAPS retrieval parameters (trace gases, surface and cloud properties) would you find valuable?

Thank you

Have questions about NUCAPS products in AWIPS?

Contact Emily Berndt emily.b.berndt@nasa.gov

Have questions about NUCAPS quality or how to interpret it?

Contact Nadia Smith nadias@stcnet.com