AN OVERVIEW OF NUCAPS SOUNDINGS RESEARCH TO OPERATIONS ACTIVITIES TO SUPPORT OPERATIONAL FORECASTING CHALLENGES

Emily Berndt and Brad Zavodsky

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Alaska Center for Climate Assessment and Policy

HYPERSPECTRAL INFRARED SOUNDERS

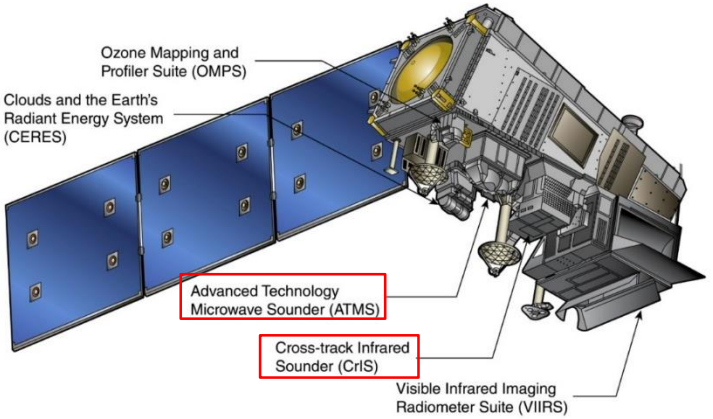
- NUCAPS – NOAA Unique Combined Atmospheric Processing System
- CrIS – Cross Track Infrared Sounder (1305 Channels)
- ATMS – Advanced Technology Microwave Sounder (22 Channels)
- Onboard Suomi/NPP and NOAA-20
- Overpasses between standard radiosonde launch times

  Passes over East Coast: 05z/17z

  The Plains: 07z/19z

  West Coast: 11z/23z

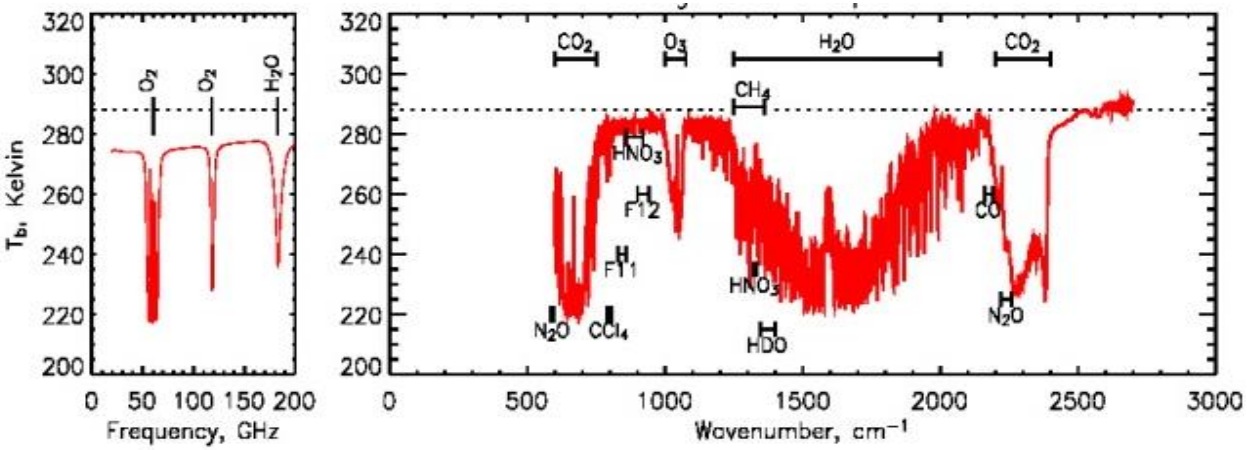
  Alaska: Multiple



- Takes advantage of a much larger number of channels (as compared to current GOES, HIRS, legacy TOVS sounders) to better resolve vertical structure in the atmosphere
  - Measure temperature and water vapor with height as well as ozone, other trace gases, and cloud information (e. g. cloud top fraction, cloud top pressure)
  - Most accurate in the upper-levels under clear conditions
  - Infrared and microwave measurements are paired to allow for measurements in partly cloudy regions
  - Measurements are degraded in regions of thick clouds

HOW IS A NUCAPS SOUNDING RETRIEVED?

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

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

Physical retrieval using both MW and a subset of cloud-cleared IR channels. This involves
- Error checking, diagnostic tests, iteration
- Sequential retrieval of T, q, CO, O3, CH4, etc.
- Quality flags

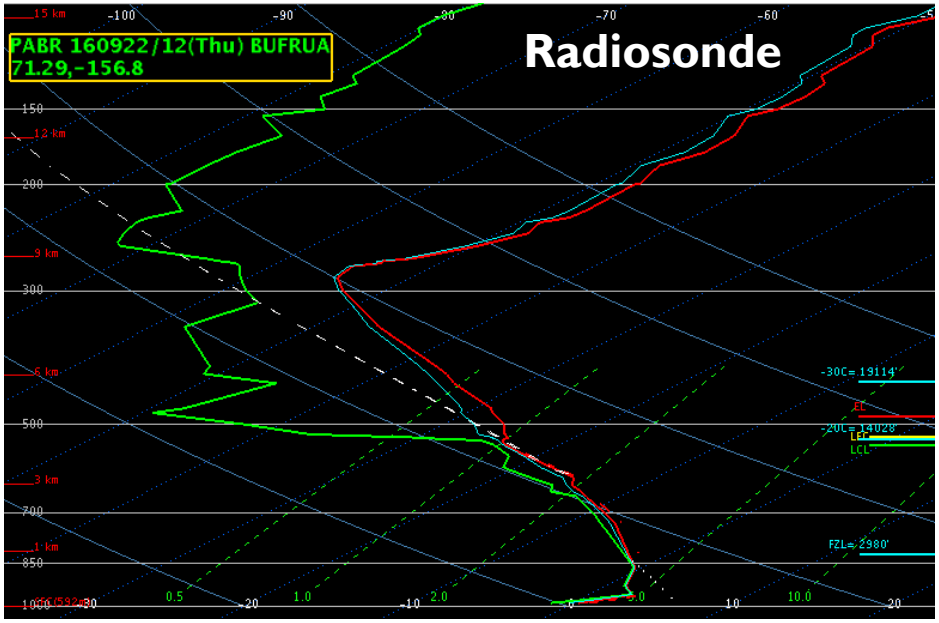
Produce final IR+MW NUCAPS soundings at 100 layers

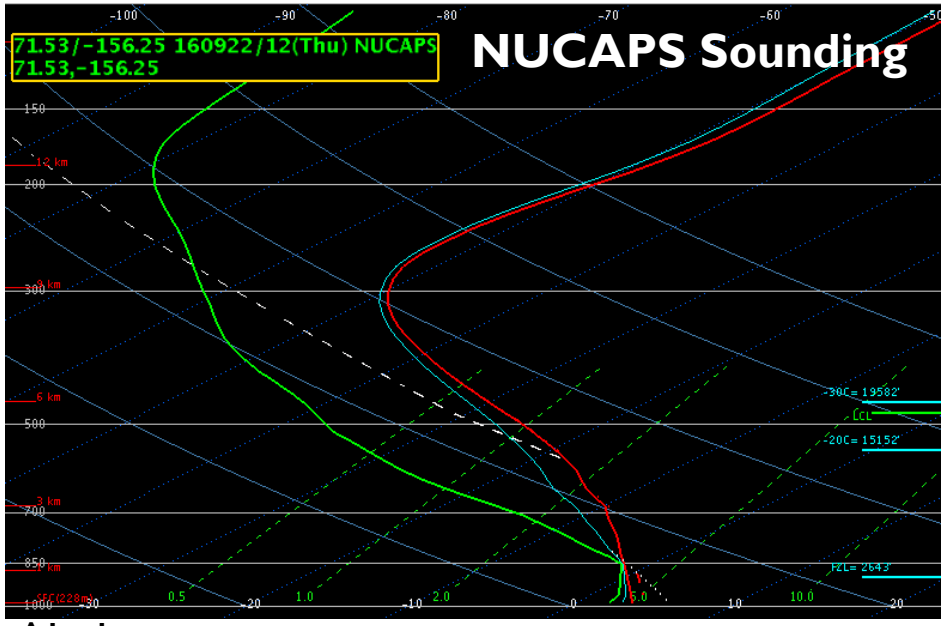
MW-only NUCAPS soundings available operationally but not in AWIPS yet

EFFECTIVE VERTICAL RESOLUTION OF SATELLITE SOUNDINGS

- CrIS and ATMS can resolve:
  - 4-6 layers of water vapor
  - 6-10 layers of temperature
- How are the layers vertically distributed?

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





Barrow, Alaska

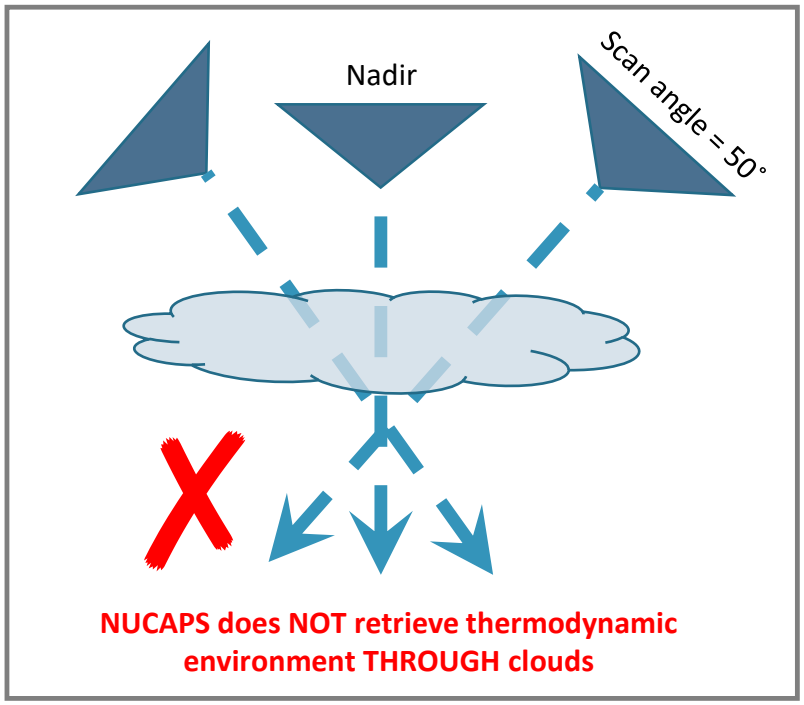
NUCAPS LIMITATIONS

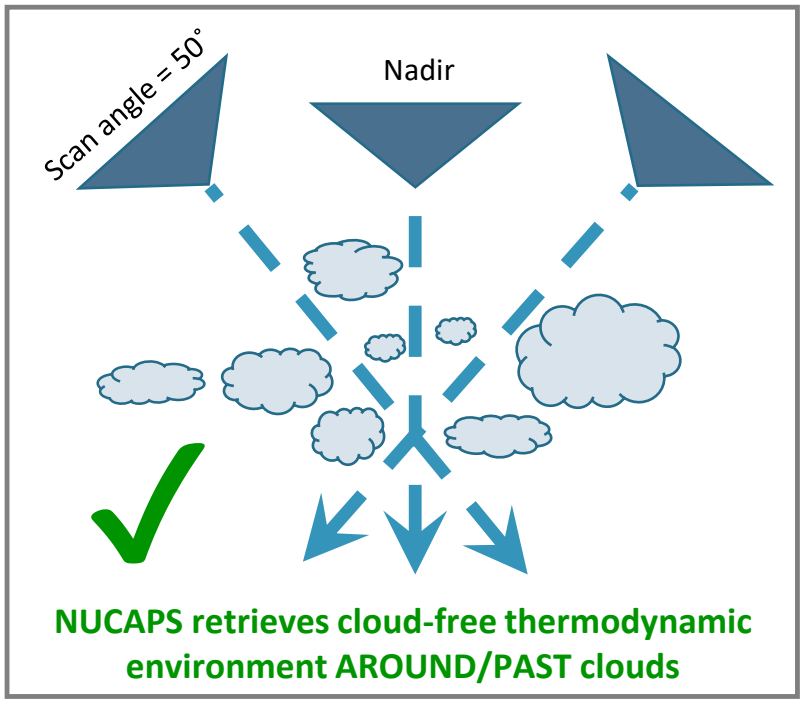
- The amount/quality of retrievable information varies from scene to scene depending on local weather conditions
- Infrared observations are sensitive to surface temperature
  - Land vs ocean
  - Day vs night
  - Local conditions
- No single parameter (T, q) is retrieved without interference from others (T, q, trace gases)
- Cloud cover and edges of clouds
  - Success in cloud cover up to 90%
  - Does not retrieve atmospheric conditions inside/through clouds
  - NUCAPS retrieves atmospheric conditions from clear-sky pathway around clouds
  - Cloud clearing removes the radiative effects of clouds and preserves the clear-sky portion of the foot print or emission signal that reaches the top of the atmosphere

WHAT ABOUT CLOUDS

SPORT

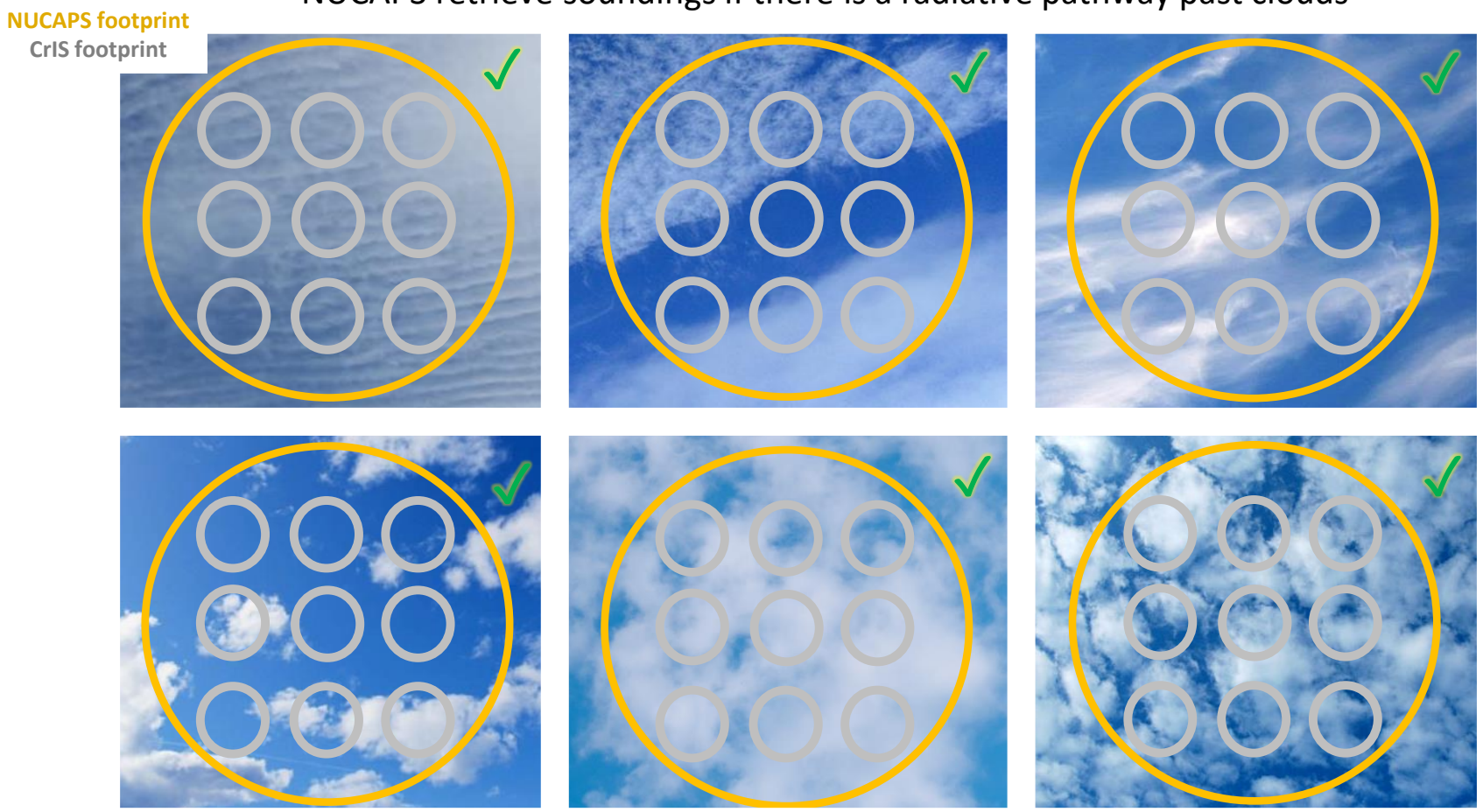
- To an IR Sounder (CrIS) a cloud is an obstacle, not an opportunity!
- The probability that a NUCAPS footprint is cloud-free is 5%
- NUCAPS performs "cloud clearing" to increase global yield of soundings, thus soundings are retrieved under most cloud/surface conditions. NUCAPS have spatial + temporal consistency, it also has soundings of atmospheres nearly impossible for radiosondes to reach





Cloud Clearing **succeeds** when NUCAPS footprint has **cloud variability**;
i.e. when the CrIS footprints have variable cloud fractions

NUCAPS retrieve soundings if there is a radiative pathway past clouds

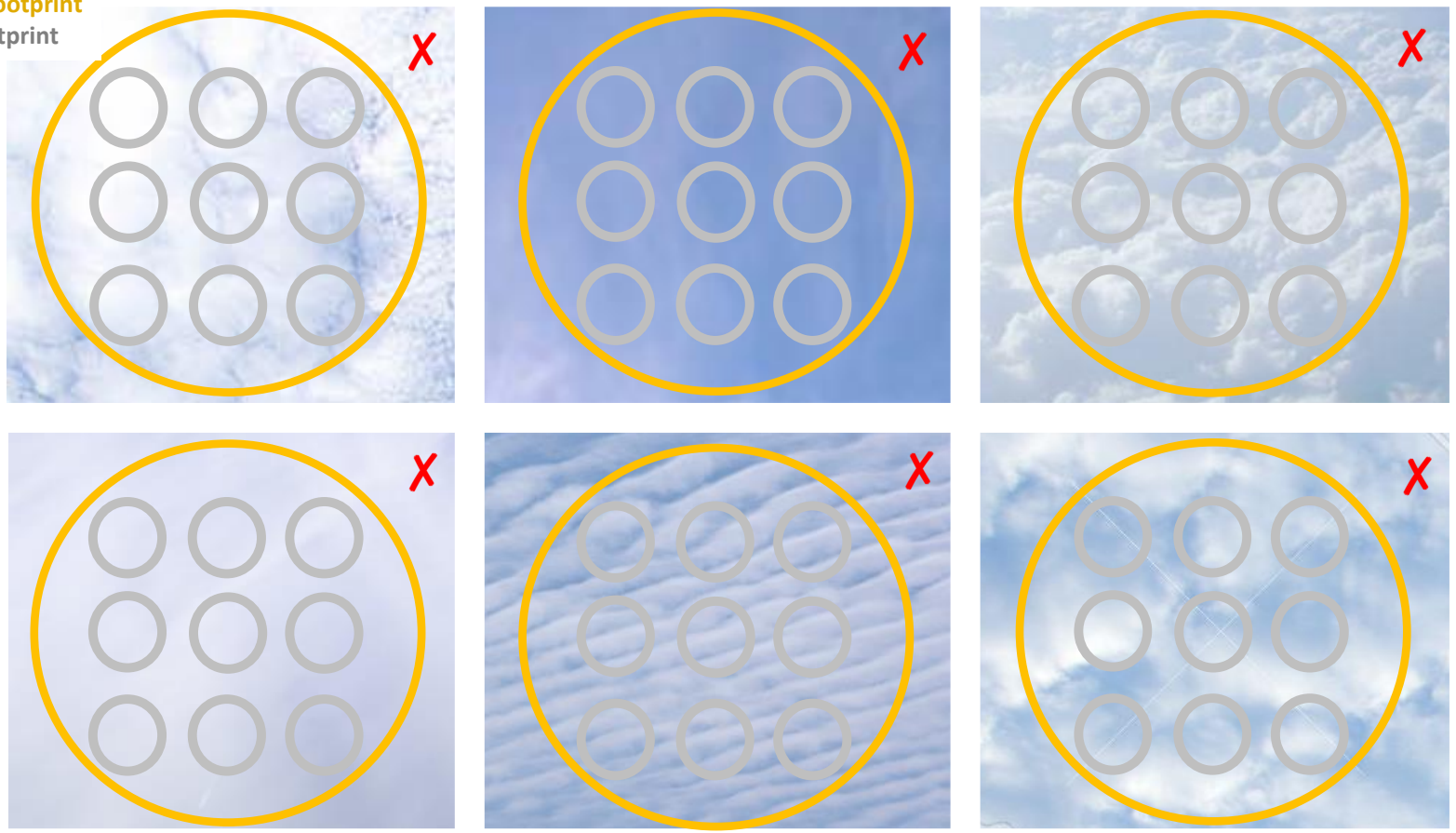


- The clear-sky radiative pathway PAST clouds can be determined using a cluster of 3x3 CrIS footprints with variable cloud fractions.
- NUCAPS soundings are successfully retrieved from clear-sky or cloud-cleared radiance measurements

Cloud Clearing **FAILS** when NUCAPS footprint is **uniformly cloudy**; i.e. when each CrIS footprint has the same cloud fraction

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

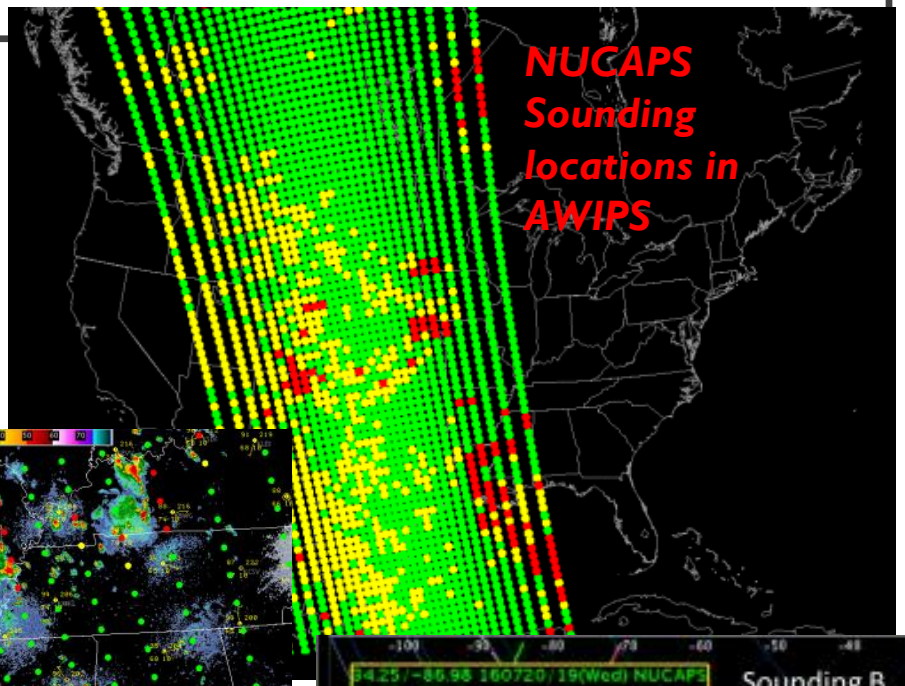
NUCAPS footprint
CrIS footprint

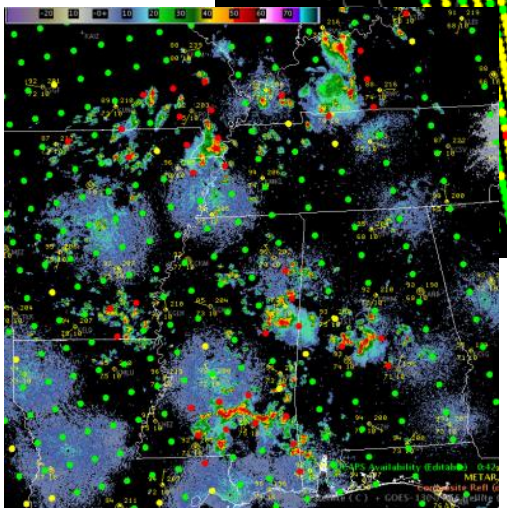


- NUCAPS soundings CANNOT be retrieved from cloudy measurements of the radiative the pathway through clouds.
- This is why optical thickness (cirrus versus stratocumulus) is irrelevant to NUCAPS.

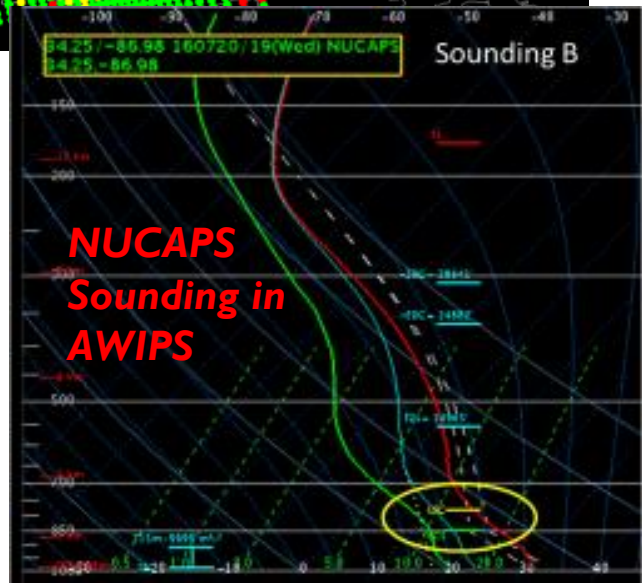
Current Operational NUCAPS Visualization

- NUCAPS is the NOAA Operational Retrieval algorithm for SNPP CrIS/ATMS and Metop IASI/AMSU T and q profiles
- Capabilities for displaying individual Skew-T plots are available in the latest versions of AWIPS II with quality control flags
- Skew-Ts are valuable for some forecast challenges, and ***visualizing the data in plan view or cross section may be more useful for others***
- NUCAPS allows forecasters to observe the 3D extent of the atmosphere
- Helpful where conventional observations are sparse





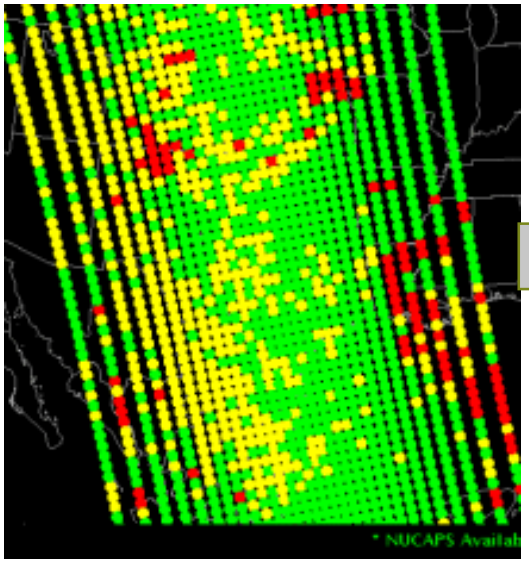
NUCAPS Sounding locations overlaying radar in AWIPS



Images by Kris White (NWS HUN/SPoRT)

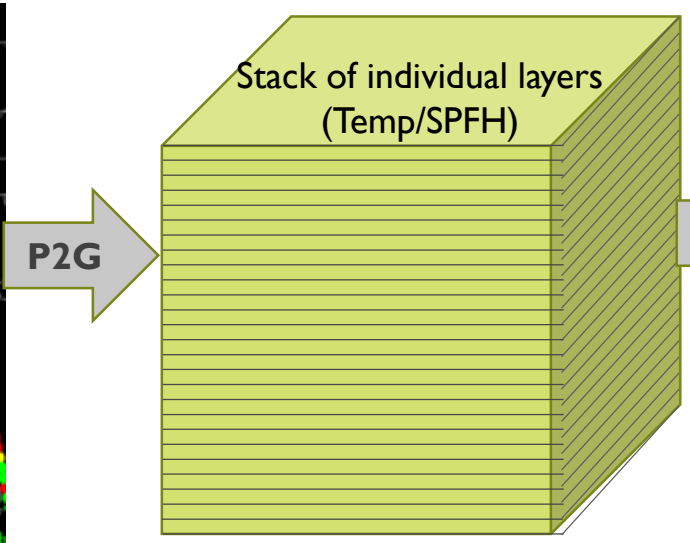
GRIDDED PRODUCT OVERVIEW

- CIMSS has modified its polar2grid software package to include readers for NUCAPS
- SPoRT obtains Direct Broadcast data, runs polar2grid, and converts output to gridded binary (GRIB2) format for ingest into AWIPS II
- GRIB2 files are pushed to NWS partners in real-time



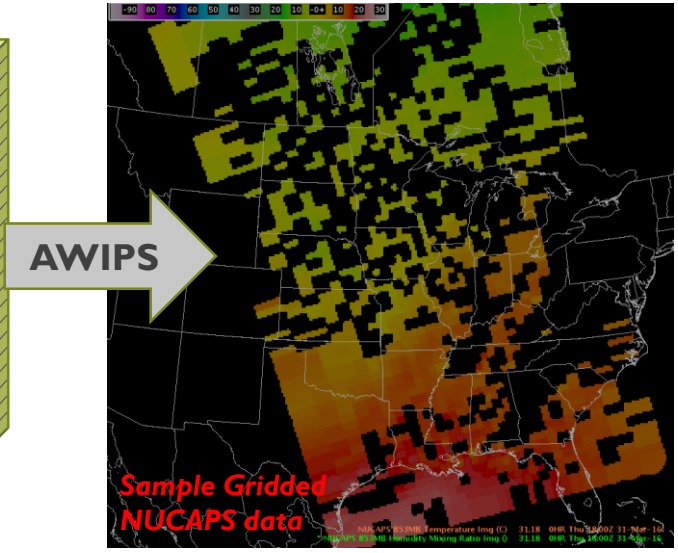
NUCAPS Soundings:
Need to click on each 'point' to review the vertical information

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



A subset of 58 layers are output using Polar2Grid from the 100 layers output by NUCAPS.
The grib2 file only contains:

- Temperature, Specific humidity
- Surface pressure and temperature
- Topography

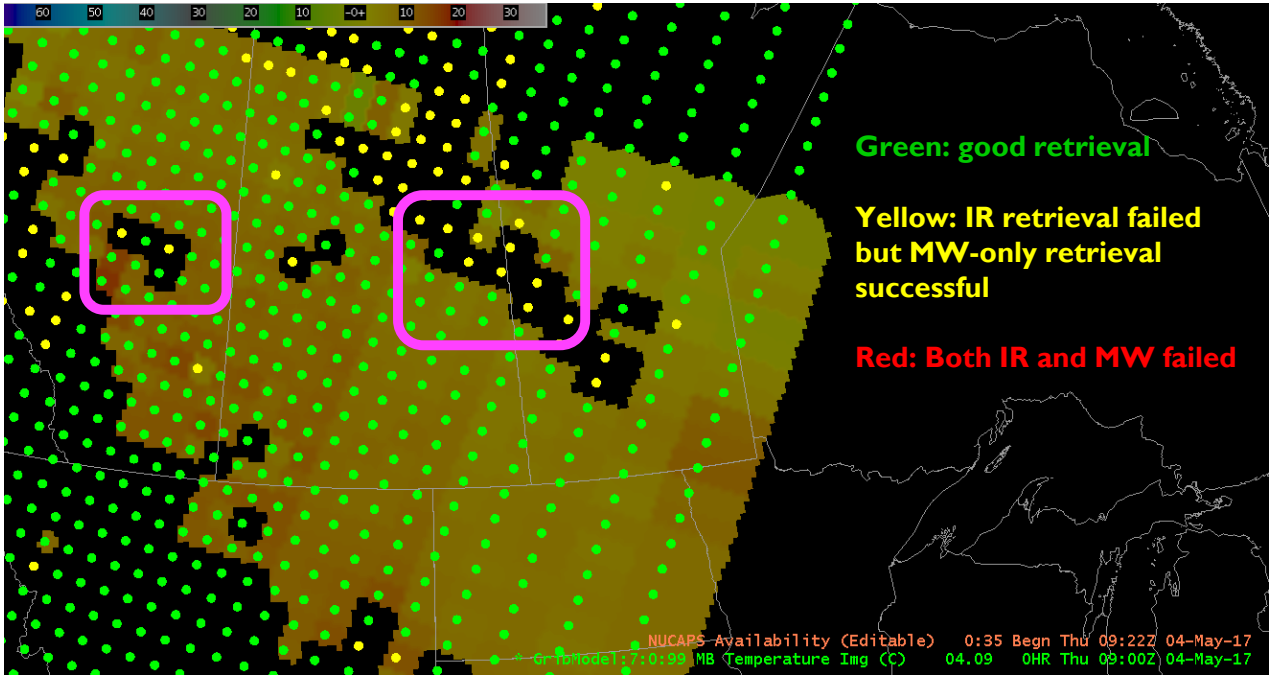


Ingested into AWIPS on a uniform model grid, so AWIPS will interrogate the information in the same way it handles model data.

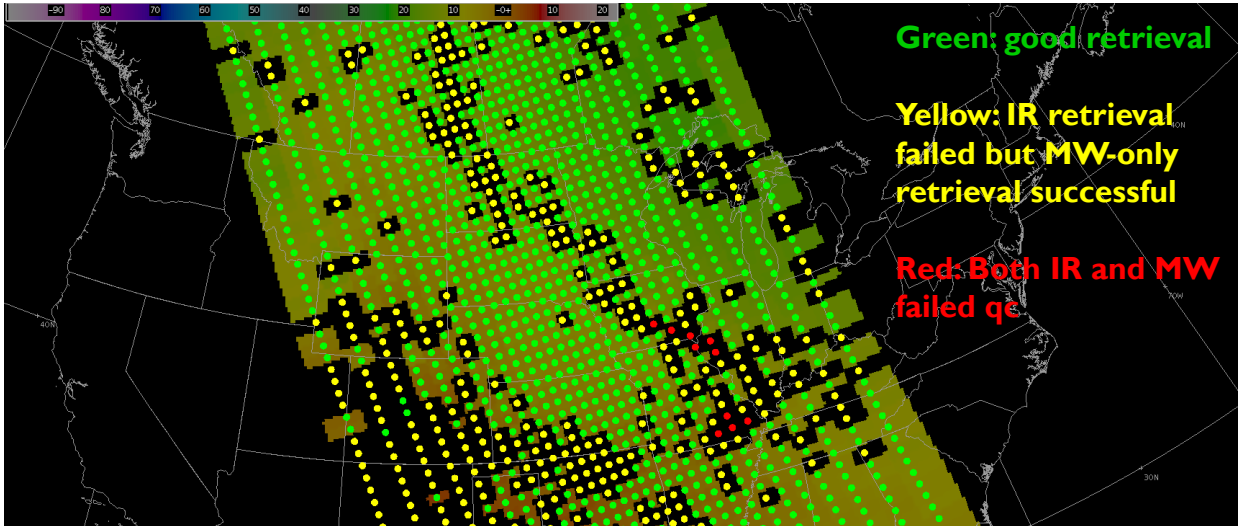
- Plan view and cross sections
- Temperature, moisture, and stability indices.

LIMITATIONS/CONS

- Gaps in gridded data due to cloud cover and failed retrievals
- Discrepancies between NUCAPS Sounding output and Gridded NUCAPS (i.e. CAPE values differ)
- Mis-match in quality flags and retrieval quality at cloud edges between operational and direct broadcast processing (only 7 of 9 CrIS FOVs processed via direct broadcast)
- Individual retrievals are not preserved (i.e. gridding results in multiple 10-12 km grid boxes inside each NUCAPS footprint
- Infrared observations are sensitive to surface temperature
  - Land vs ocean
  - Day vs night
  - Local conditions



REDUCED LATENCY NUCAPS SOUNDINGS

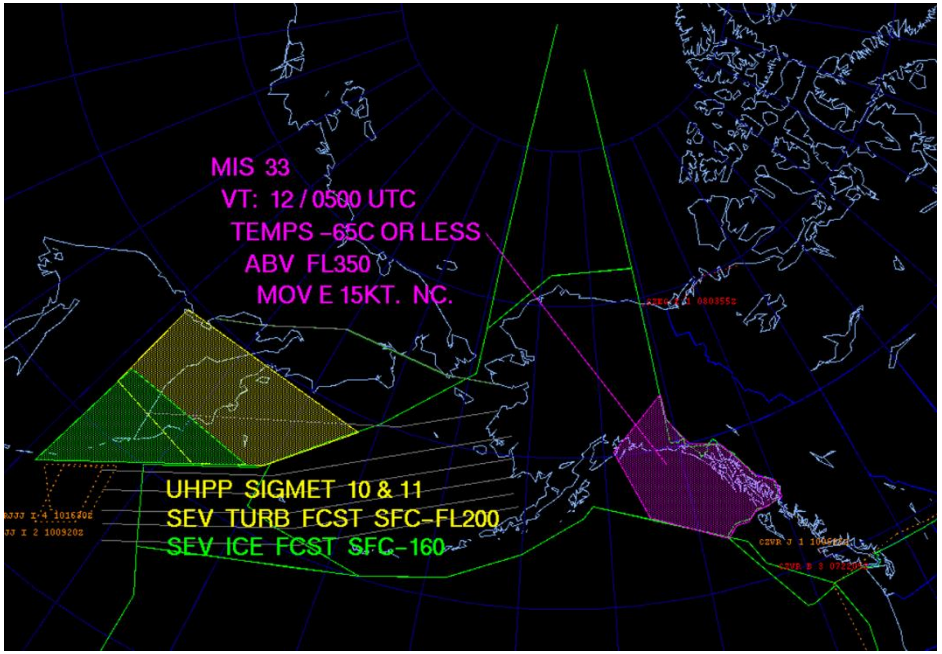


- ***New this year:*** consistent QC between Reduced Latency Soundings and gridded product over CONUS since both are derived from the CSPP (direct broadcast) data stream which has 7 instead of 9 fields of view (previous slide)….could be implemented in Alaska
- ***Gridded NUCAPS:*** polar2grid regrids 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 NUCAPS product.

FORECAST CHALLENGE: COLD AIR ALOFT

- Gridded NUCAPS was initially developed to address Cold Air Aloft
- Cold Air Aloft (≤ -65°C) events can freeze airliner fuel and regularly occur at flight levels in the arctic
- Center Weather Service Units (CWSU) provide Meteorological Impact Statements (MIS) to Air Traffic Controllers to direct flights around the 3D air features
- In data sparse Alaska, forecasters have relied on analysis and model fields and limited radiosonde observations to guess the 3D extent of the Cold Air Aloft
- Use of satellite observations provides an opportunity for forecasters to observe the 3D extent of the Cold Air Aloft in real-time

Alaska CWSU domain (green line) and warning guide for 11 January 2017. Purple hatched area is an advisory for Cold Air Aloft



Example text product disseminated by Alaska CWSU for Cold Air Aloft; valid 14 November 2015

```
FAAK20 KZAN 121458
ZAN MIS 01 VALID 121500-130300
...FOR ATC PLANNING PURPOSES ONLY...
COLD AIR ALOFT
FROM 185NE SCC-65NE ORT-55SW ENN-110NW BRW-185NE SCC
TEMPS -65C OR LESS FM FL350-400. AREA MOVG NE 40 KTS.
CMW NOV 14
```

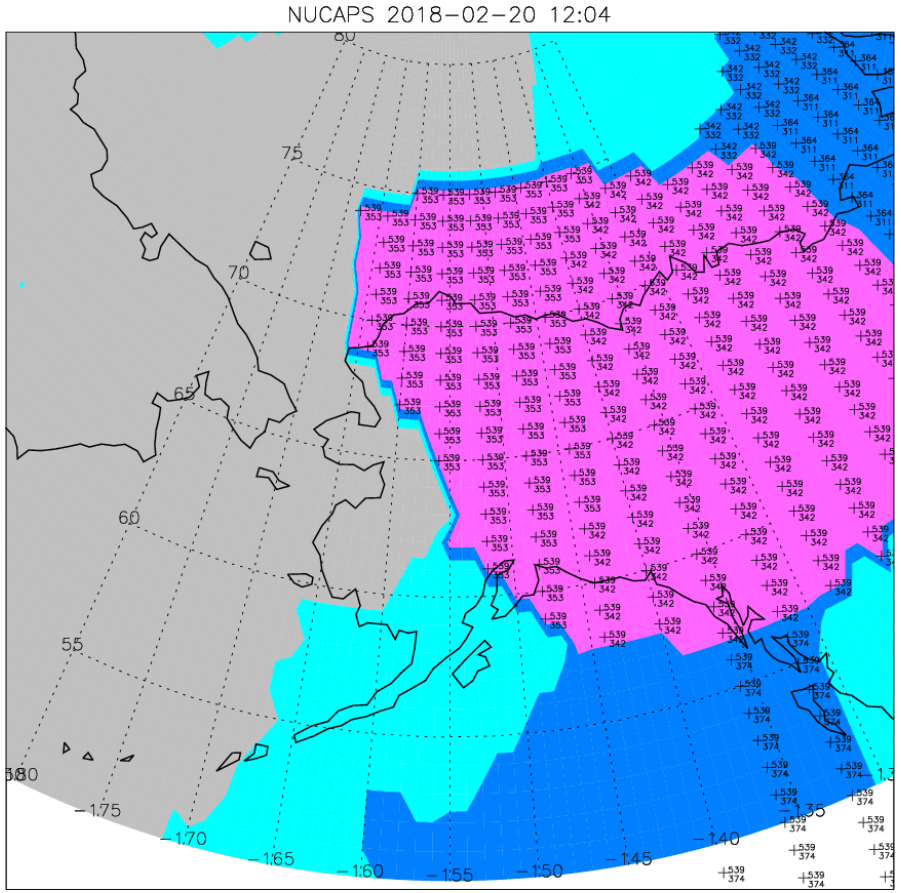
Lat/Lon Extent of Cold Air from soundings, aircraft reports, model

Vertical Extent of Cold Air from soundings/aircraft reports/model

Motion determined from model data

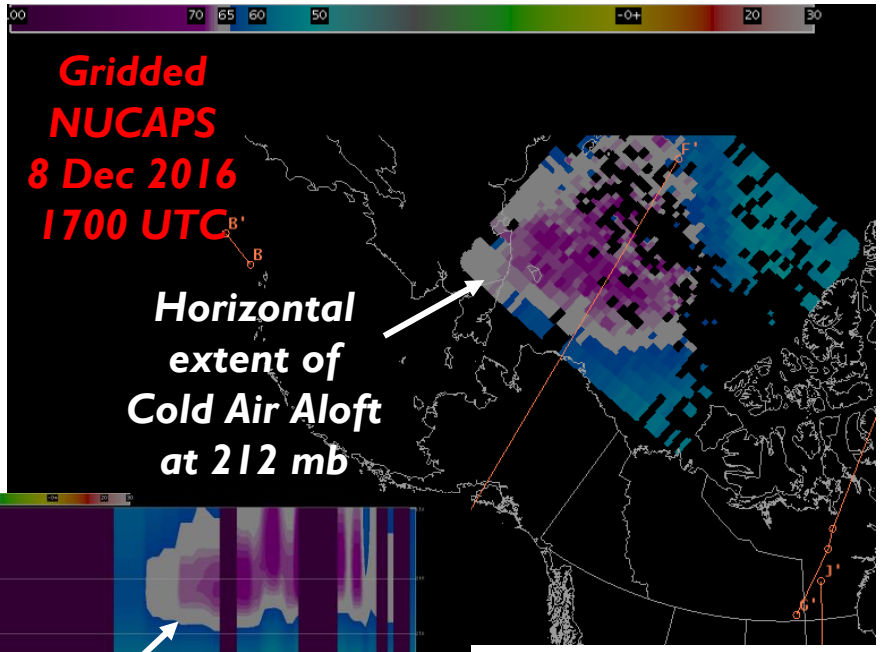
WHY IS CAA IMPORTANT

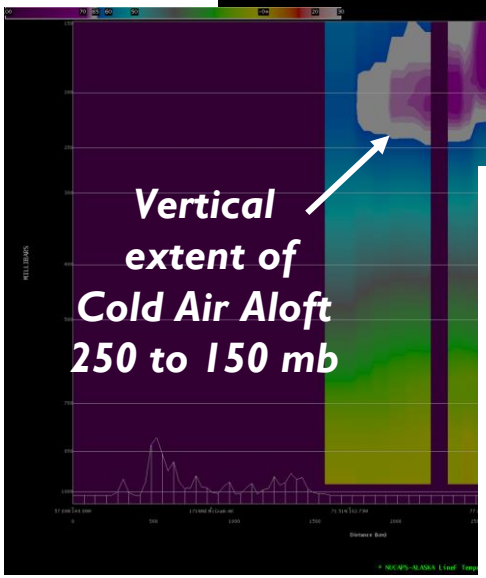
- British Airways Flight 038 Boeing 777 crash on approach at London Heathrow Airport on 17 January 2008
- Fuel freezing points vary from -40°C to -60°C, but water in fuel can freeze at higher temperatures (below -10°C); either results in a loss of engine performance due to restricted fuel flow
- CAA mitigating factors include aircraft design, fuel type, initial fuel temperature, fuel quantity, aircraft speed, and flight route
- The ZAN CWSU CAA forecast/warning threshold is an air temperature of -65°C outside the aircraft
- CIRA developed the first display concept:
  - http://rammb.cira.colostate.edu/ramsdis/online/cold_air_aloft.asp
  - Displays CAA heights in units of flight level (hundreds of feet)
  - Polar-orbiting satellite data and GFS model output



PRODUCT DEMONSTRATION

- Forecasters at the Anchorage CWSU evaluated the Gridded NUCAPS during the 2016-2017 Winter
- Goal was to provide data to improve Cold Air Aloft analysis and increase confidence when issuing operational MIS statements use by the FAA and airlines.
- Preparation for the demonstration included:
  - In person visit to the CWSU to cover training material
  - A specific color curve to outline the coldest air
  - A procedure to allow forecasters to quickly toggle through the vertical layers
  - Short videos to demonstrate installation and use of the data





FAAK20 KZAN 082312
ZAN MIS 01 VALID 082312-090600
...FOR ATC PLANNING PURPOSES ONLY...
FROM 575NNW BRW-510NNE BRW-175NE SCC-BRW-200W BRW-572N BRW
COLD AIR ALOFT
TEMPS -65C OR LESS FM FL310-FL340. MOV E 15 KT. INTSF.
GMW DEC 16

FORECASTER FEEDBACK

- 2/2/17 6:00a **Some Operational Impact, High Confidence:** "NUCAPS images on the WEB site were about 5 degrees C too cool over the eastern Bering and western Alaska compared to 12Z raobs and the NAM/GFS. **NUCAPS 12Z image on AWIPS at 212 mb was right on though with temperatures and with the models and observations**." –unnamed AK CWSU forecaster

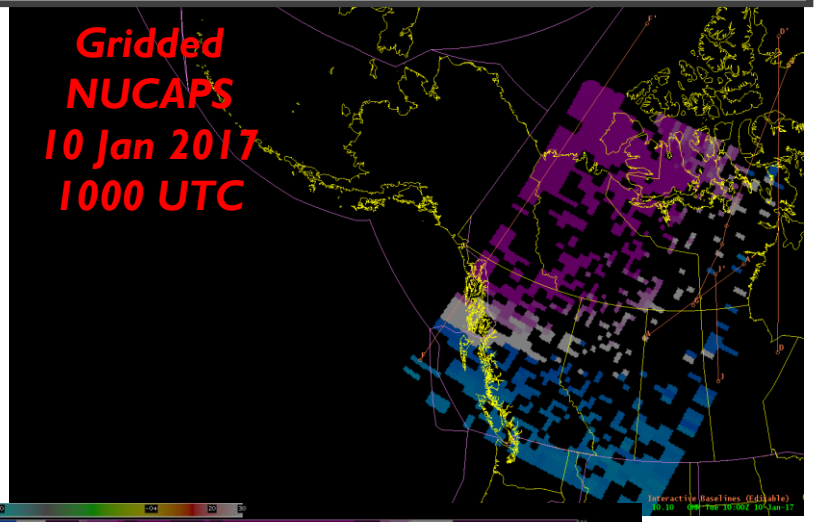
- 2/24/17 8:00p **Very Large Operational Impact, High Confidence:** "**Both the GFS and gridded NUCAPS showed an area of CAA moving into the central Aleutian's**, with the GFS being slightly better tonight in bringing in colder values in the same area depicted by both models. 25/00Z soundings did not help since the CAA was moving up from the south after 00Z." – Gail Weaver, AK CWSU

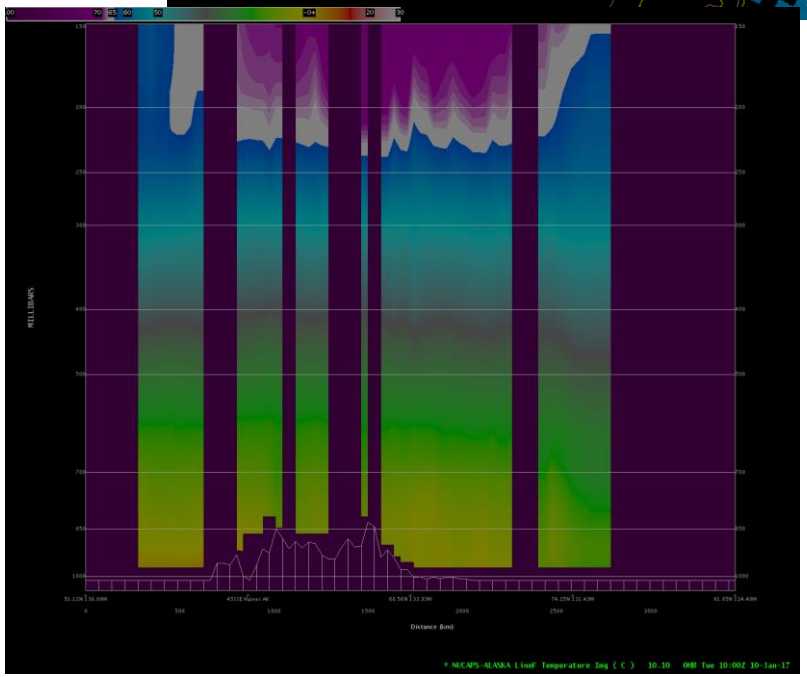
- 2/28/17 2:00p **Very Large Operational Impact, High Confidence:** "I used the Gridded NUCAPS CAA heights today since the new area of CAA did not include any upper air sounding sites (it was located over the Bering Sea). The GFS model seemed to be weaker and depicted a smaller area of CAA than the NUCAPS, so **I had more confidence in the NUCAPS data today**." –Gail Weaver, AK CWSU

- 3/1/17 **8:00a** **Very Large Operational Impact, High Confidence:** "GFS model data showed temps near -65C over the northern Bering Sea this morning. SYA and SNP 12Z raobs did show -65C right around FL330, but it was only about 500 feet deep. The NAM was slightly colder than the GFS in the area between and north of SYA-SNP to the FIR boundry. **Based on the SNPP-NUCAPS it showed a deeper layer, nearly 5000 feet, from FL350-FL400 in this area that was not sampled by the raobs. *Due to the models trending colder the next 12-24 hours I decided to issue a MIS for Cold Air Aloft based on the Gridded NUCAPS data. I felt very confident in the NUCAPS data based on the surrounding raobs, model data, timing, and intensity of the data represented in these graphics.*** " –unnamed AK CWSU forecaster

POST 2017 ASSESSMENT

- Forecasters identified several events that occurred during the 2016-2017 evaluation and plan to compare the Gridded NUCAPS to soundings and AMDAR data and present results at AMS
- AGU presentations to highlight Cold Air Aloft and HWT work
- Forecasters requested the Gridded NUCAPS include data on flight levels
- Another Cold Air Aloft demonstration with the CWSU this Winter 2017-2018
- Transition of processing to GINA to reduce Gridded product latency

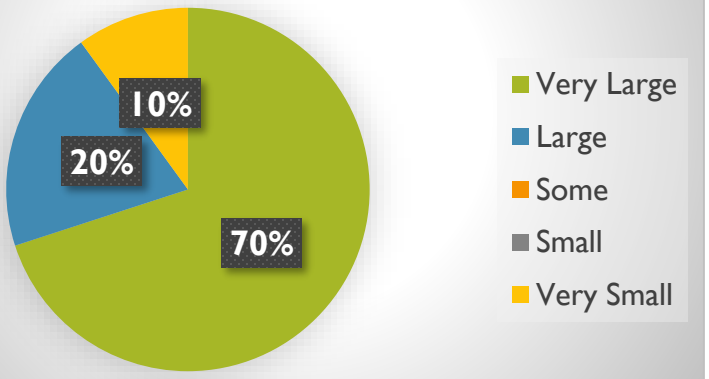




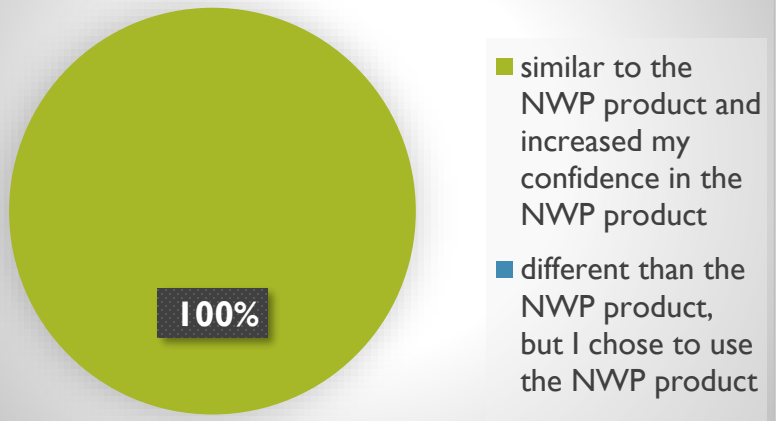
2018 WINTER ASSESSMENT

- January – March 2018
- Large scale late February event pivotal in raising awareness of CWSU CAA MIS beyond intended customer
- *"The only way the pilots hear about our weather products is when they fly through our airspace and the ZAN controllers pass on our weather products to them." - GW*

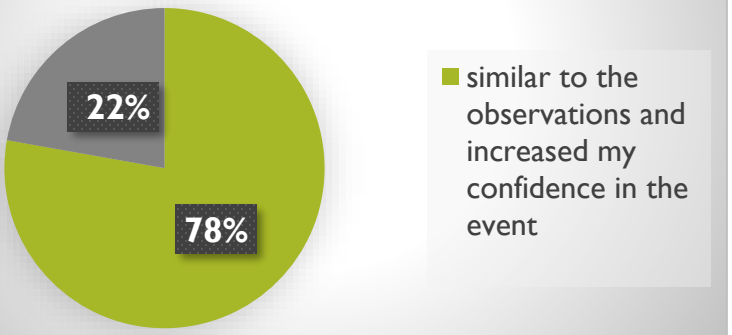
Rank the impact of the Gridded NUCAPS on decision to issue or not issue a forecast product



When compared to NWP data, the Gridded NUCAPS data were



When compared to additional remote sensing or in-site observations, the Gridded NUCAPS data were



14 FEBRUARY EVENT

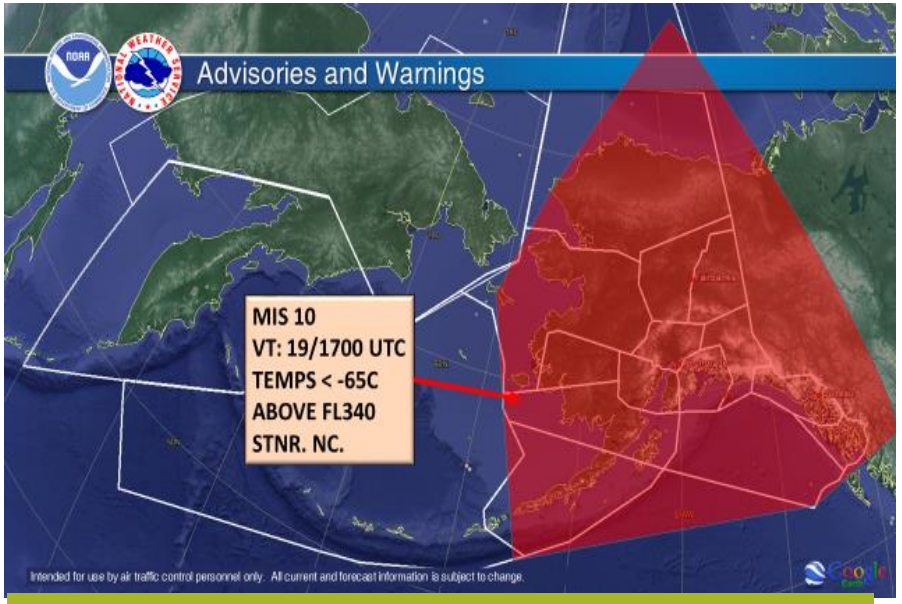
- CWSU Forecasters noticed a FEDEX aircraft traveling from MEM to ANC descended from FL360 to FL300 due to a freeze warning on their temperature indicator (PIREPS)
- The CWSU CAA MIS was valid for temps < -65C above FL340 in the same area
- ***This was one of the rare times the forecasters received feedback on aircraft in ZAN airspace changing their altitude due to CAA***

"I used NUCAPS pop-up soundings for this MIS. The NUCAPS temp times and the cross-sections in the Volume Browser weren't lining up properly for when I needed the data." - GW

"Gridded NUCAPs data and soundings were in excellent agreement this morning with CAA over much of the state." - CW

18-22 FEBRUARY EVENT

- CWSU noticed aircraft changing altitude to avoid CAA as evidenced in PIREPS
- ***"EVA667 B744 at ORT230043 at 1035Z (2/18/18) went from FL400 to FL340 due to very cold air aloft (M70). At the time, ZAN MIS 08 product was available to the aircraft." – Stephen at Anchorage ARTCC***
- For instances when there was a NUCAPS outage the forecasters were able to use MIRS data on the CIRA webpage
  - ***Overall, the MIRS CAA boundaries match up well will model data and sounding data, and also the boundaries used in MIS 16. I have attached MIS 16 for your SA.***
  - ***Comparison of 22/00Z sounding data with the 21/2130Z MIRS data shows a differences of about 1,000 to 4,000 ft depending on location and level in the atmosphere***



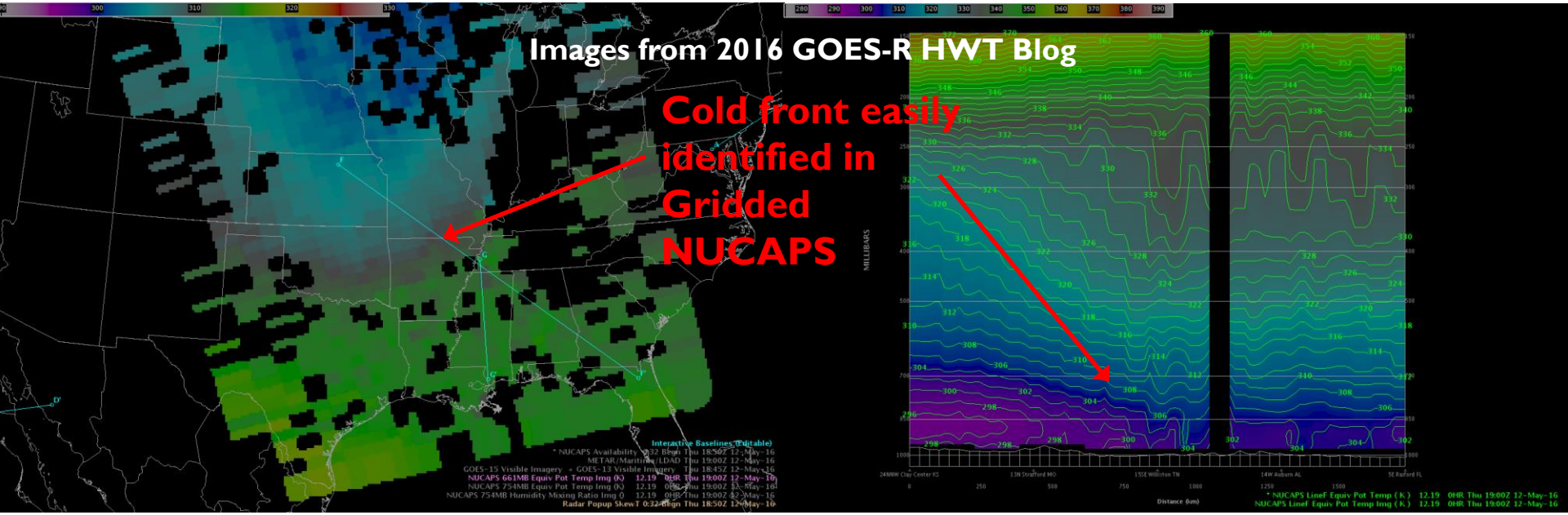
"NUCAPs data was unavailable in AWIPs this morning. The Alaska SNPP-MIRS matched well with the NAM and RAOBs. The only issue with the MIRS was the bases of the cold air were generally shown above FL410 while RAOBs indicated the cold air above FL340." -CW

"Latest NUCAPS Soundings availability on AWIPS was 20/1321Z. This data was way to latent to use for the 21/0500Z CAA MIS." -GW

"NUCAPS trends matched NWP trends of the CAA area moving to the southeast over the Panhandle and out of our airspace by 23/06Z." -GW

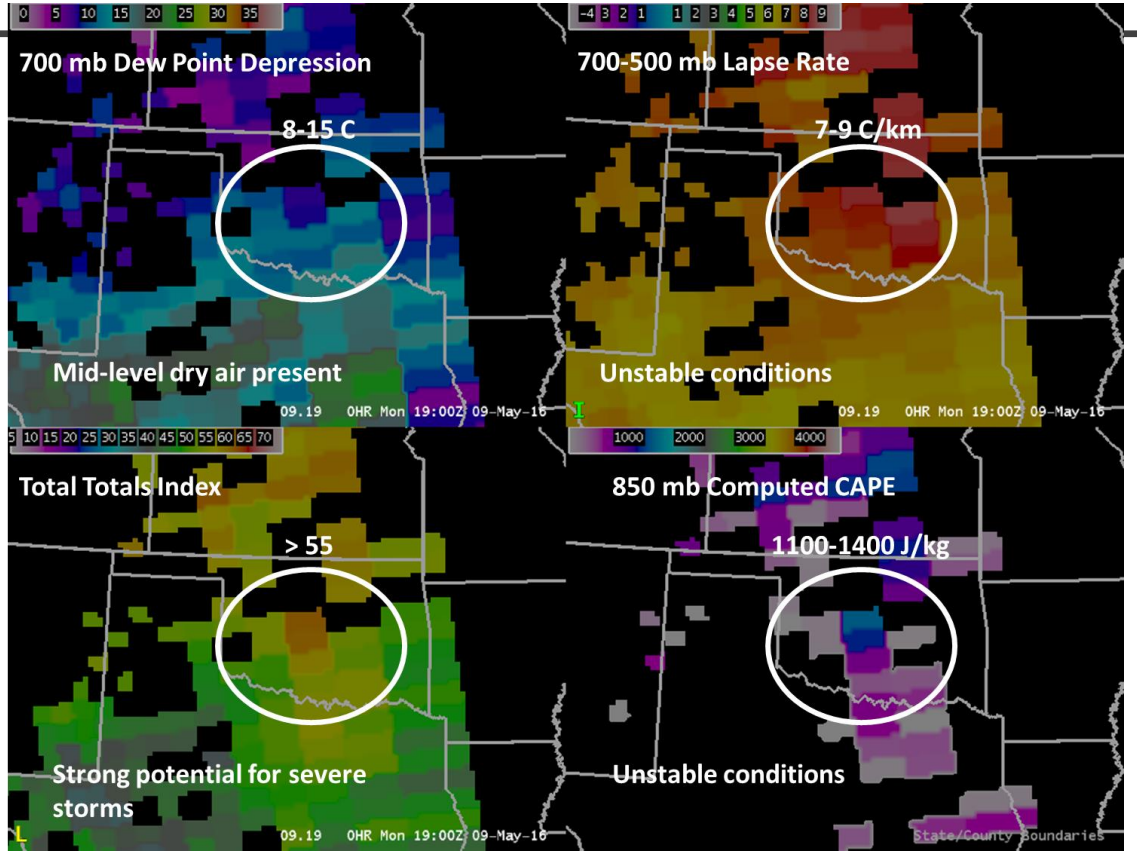
FORECAST CHALLENGE: PRE-CONVECTIVE ENVIRONMENT

- 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 were demonstrated at the 2016 and 2017 Hazardous Weather Testbed Experimental Warning Program
- Goal was to assess product utility for another application



HWT DEMONSTRATION

- Preparation for HWT:
  - CIMSS updated Polar2grid to output all pressure levels and surface variables and mask values below the surface
  - Some levels were forced to standard levels to allow AWIPS to calculate stability indices
  - Several AWIPS procedures were developed
  - More robust training slides and Quick Guide

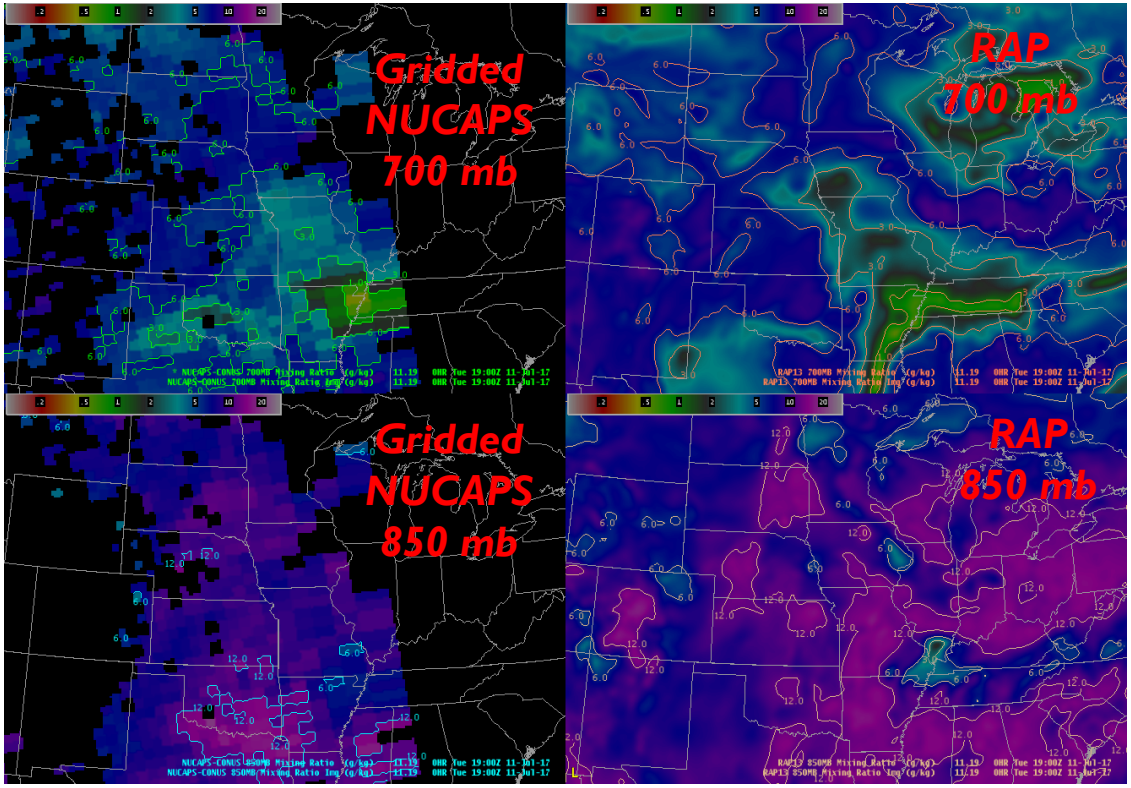


- During 2017 a wider variety of fields were available in AWIPS:
  - Temperature, Potential Temperature, Virtual Temperature
  - Dewpoint, Dewpoint Depression, Mixing Ratio, Relative Humidity, Theta E, Saturated Theta E, Specific Humidity
  - CAPE, CIN, Lapse Rate, Vertical Totals, Total Totals, Showalter Index, K Index, Cross Totals

FORECASTER FEEDBACK

"At 700 mb (top two panels with NUCAPS on left and RAP on right), it looks like both are generally showing a dry tongue stretching up from Tennessee across Missouri. They are also both in good agreement on the mixing ratios over our new forecast area of FSD. **Overall, very impressed how well NUCAPS matches up with the latest model data at 700mb."** – HWT forecaster 11 July 2017

"Looking a bit farther lower at 850mb (lower panels), it looks like mixing ratios overall are slightly less than what the RAP is indicating… **Thus, confidence may be a bit better at levels at or above 700mb, but not so good for 850mb or lower."**

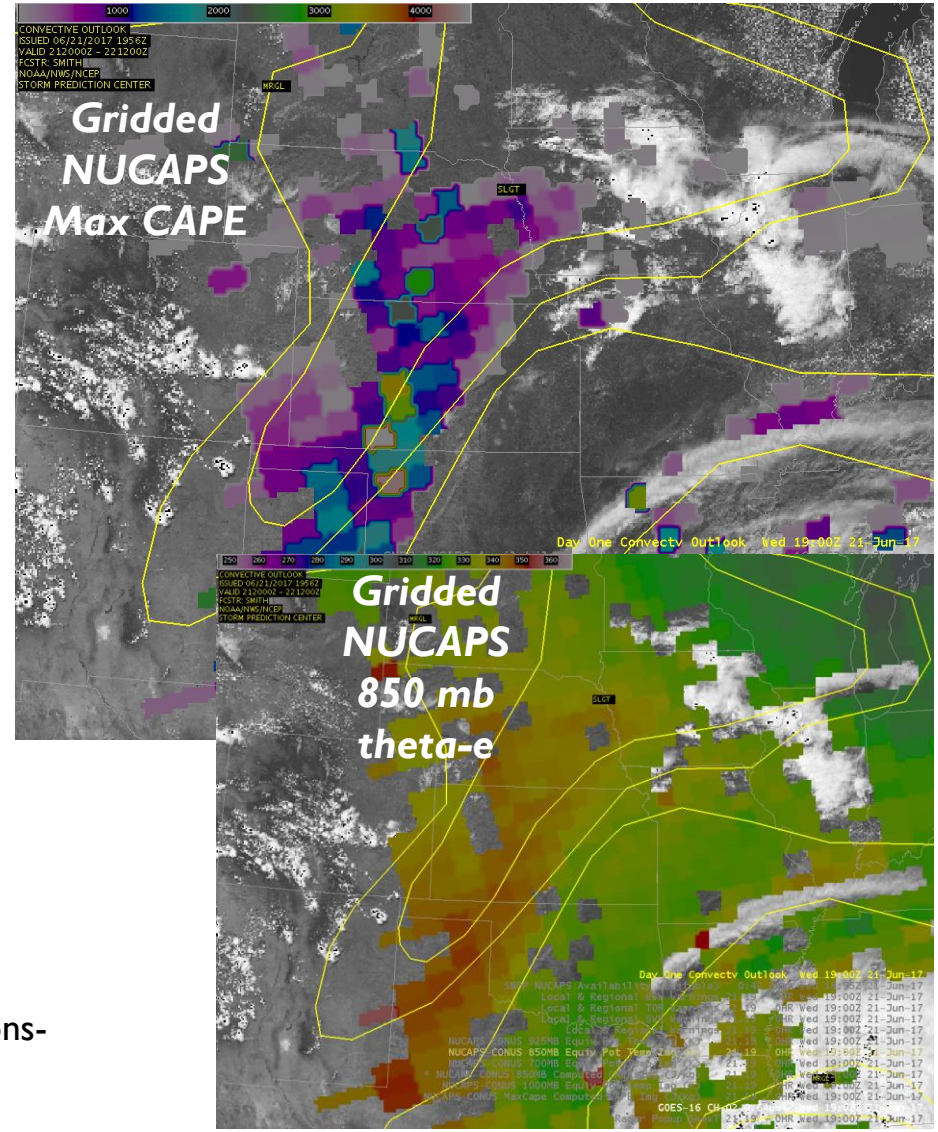


http://goesrhwt.blogspot.com/2017/07/nucaps-mixing-ratio.html

FORECASTER FEEDBACK

Notice that the axis of max CAPE values is very close but a little to the east of the Slight Risk area, **suggesting perhaps that the better axis of instability lay just to the east of the Slight Risk. Also, the 850 mb theta-e analysis from the NUCAPS gridded data likewise indicated this eastward shift.**

Convection did subsequently develop in western Kansas during the afternoon… Although data from NUCAPS are a few hours old now, the earlier data indicated sufficient instability to keep convection development ongoing downstream and that increased intensity is possible as it moves into a region of higher instability. - Kris White HWT 2017



http://goesrhwt.blogspot.com/2017/06/nucaps-observations-in-w-kansas-for-21.html

NEXT STEPS

- **"Gridded NUCAPS" enables greater situational awareness by enabling quick and easy visualization of spatial patterns**. Plan views of NUCAPS can be overlaid on imagery such as those from ABI on GOES-16. This product also allows easy comparison with model fields. Despite the success of this 2017 demonstration, there is much to be done to improve the quality of this product in AWIPS.
- Improve availability of derived fields such as freezing level, lapse rate, CAPE
- Simplified menu/list of derived products
- Only produce fields on standard levels
- Improve flight level visualization for aviation hazards
- Better consistency in values between soundings and gridded product
- Explore other applications such as fire weather, icing, turbulence, winter weather
- Explore use/applicability of microwave soundings
- Provide feedback to AWIPS developers to baseline Gridded NUCAPS and improve visualization in AWIPS

SUMMARY

- Gridded NUCAPS was developed to allow for 3-D interrogation of the atmosphere and specifically to diagnose areas of Cold Air Aloft
- Data sparse regions such as Alaska now have a reliable data source to diagnose Cold Air Aloft over a vast domain which lacks conventional observations
- Forecasters have provided feedback that Gridded NUCAPS has a positive impact on identifying Cold Air Aloft events and increases confidence when issuing Meteorological Impact Statements
- Gridded NUCAPS was evaluated at HWT to explore its use for diagnosing the pre-convective environment
- Forecasters found utility in spatial patterns and gradients, while specific values were not as valuable, especially at lower levels of the atmosphere.
- More work is necessary to improve derivation and representation of stability indices and provide a more simplistic menu
- Collaborating with AWIPS developers to baseline Gridded NUCAPS and improve visualization in AWIPS
- Improvements in latency of both Soundings and Gridded products are under development
- Check out the Aerospace America Feature Article "Danger In the Air"

Thank you to Contributors:

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