An assessment of the NUCAPS product at the 2018 Hazardous Weather Testbed Spring Experiment

Prepared for the NOAA/JPSS Proving Ground and Risk Reduction (JPSS) Sounding Initiative

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Executive Summary

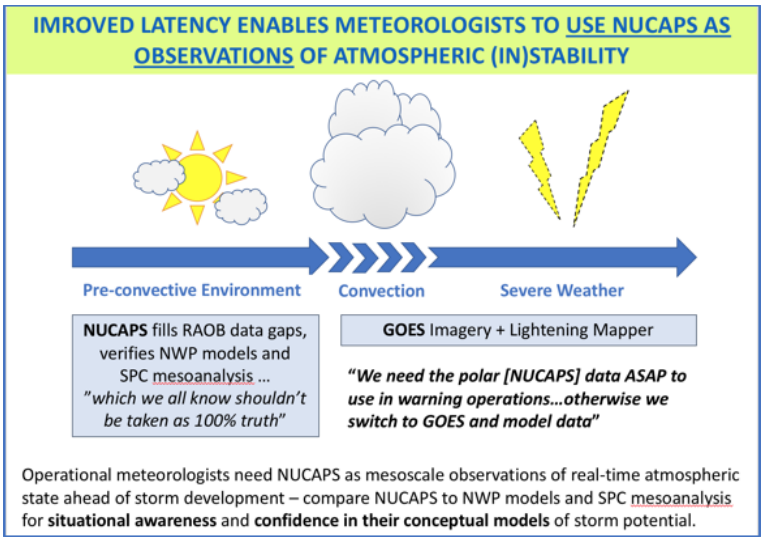
- ❏ Forecasters use NUCAPS products to analyse the preconvective environment. This is a nowcasting application that exists in the Spring/Summer months for a few hours in the early afternoon. The S-NPP and NOAA-20 overpasses around 2 pm local time serves this application well. The MetOp-A/B overpasses mid-morning falls outside the window of interest for this application.
- ❏ Forecasters require NUCAPS to be available within AWIPS-II less than 60 min after each satellite overpass. With a latency of 90-240 min, the operational pathway for S-NPP NUCAPS products via SBN into AWIPS-II does *not* meet this requirement.
- ❏ We tested a new delivery pathway with CSPP NUCAPS from S-NPP via direct broadcast stations with a 40-60 min latency and conclude that NUCAPS latency is critically important to its application in nowcasting operations.
- ❏ Product visualization affects the type and amount of information accessible to forecasters at the time of decision making. Forecasters need different modes of visualization to fully exploit NUCAPS products – thermodynamic profile diagrams (skew-T) and horizontal/vertical gradients (gridded fields). The development of high quality NUCAPS visualization products in AWIPS-II as well as interactive web-based tools is a priority.
- ❏ The value of NUCAPS in operations will improve when forecasters can access training modules and visualization of NUCAPS product uncertainty as it varies diurnally, horizontally (scene to scene), and vertically (surface to top of atmosphere).
- ❏ Forecasters need access to a higher frequency of NUCAPS soundings. Work must be done to streamline the AWIPS-II ingest and display of NOAA-20 in tandem with S-NPP.
- ❏ Preconvective nowcasting is one application for NUCAPS soundings. Many more applications exist in operational weather forecasting that can include but are not limited to turbulence, flash flooding, hurricane cyclogenesis and air quality.

INTRODUCTION

This document highlights what we have learned about NUCAPS application at the Hazardous Weather Testbed 2018 Spring Experiment. We make **5 recommendations** to guide the The goal was not product validation; the goal was product evaluation in severe weather nowcasting application. Specifically, we evaluated the importance of (and requirements for) product latency as well as the quality of information forecasters have available about the NUCAPS product in AWIPS-II. We refer the reader to the NUCAPS team strategy and Bibliography for more information. Our primary focus was on NUCAPS from the SNPP platform because it measures the top of atmosphere at 01:30 pm local time thus coinciding with the onset of atmospheric instability ahead of convection. NUCAPS from NOAA-20 was not operational at the time of this evaluation.

Why do forecasters need observations? As long as there are multiple NWP models and human forecasters at the helm there will be a need for observations to distinguish *what is actually happening* from *what was forecasted to happen*. Well-characterized and trusted observations help forecasters verify the truth and guide them towards more accurate and timely watches and warnings.

What do forecasters use NUCAPS sounding observations for? To improve situational awareness of atmospheric instability and potential for storm development. See Appendix A for a summary of forecaster feedback on how they use NUCAPS in real-time forecasting. The graphic below illustrates how a forecaster's data needs evolve with the weather.



The HWT Spring Experiment focuses on evaluating satellite data products that characterizes severe weather as convective potential, hail or wind threat, flash flooding, etc. In the Spring and Summer months convection typically occurs late afternoon. NUCAPS soundings from the SNPP and NOAA-20 platforms make timely measurements of the pre-convective environment and helps forecasters understand storm potential.

NUCAPS Soundings from the two MetOp-A/B platforms characterizes the atmosphere at 9:30/10:30 am local time and falls outside the domain of interest for Summertime storms. **We propose that NUCAPS Soundings from the MetOp-A/B platforms be tested for applications that have a diurnal cycle and can benefit from night-time and mid-morning observations, e.g. Mesoscale Convective Systems (MCSs).**

RECOMMENDATION #1: The latency of operational SNPP NUCAPS products must be improved for it to have value in nowcasting applications

The NWS requirement for NUCAPS in AWIPS-II is to not exceed 60-min after satellite overpass. Meeting this latency requirement is critically important if NUCAPS is to be useful in NWS operational decision-making (Appendix B).

NUCAPS soundings via the SBN/NOAAPORT arrives in AWIPS-II 90-240 min after SNPP overpass, which is too late. Forecasters use NUCAPS sounding observations to help characterize the pre-convective environment, which has a limited time window. Once convection starts, forecasters attention switch to observations about lightning, clouds and rainfall.

At the 2018 HWT Spring Experiment, we tested a new, low latency pathway that saw NUCAPS delivered to AWIPS-II within 60 min of SNPP overpass, thus meeting forecaster requirements for the first time. This low latency pathway was made possible by using a network of Direct-Broadcast (DB) stations and CSPP software tools. For the first time, forecasters could evaluate NUCAPS in the pre-convective environment as weather evolved. Previously (Wheeler et al. 2018), forecasters could only use NUCAPS in post-analysis.

To realize full capacity/capability of SNPP in tandem with NOAA-20 for pre-convective forecasting we recommend mitigating the latency issues of SNPP by streaming DB data over the SBN. As a result of the reduced latency project for 2018 HWT, SSEC (Liam Gumley) has established processing of AWIPS-compliant files from all available DB sites. Each week at HWT forecaster focused solely on the DB SNPP NUCAPS with little attention on the Operational NUCAPS stream due to its high latency (arriving after convective initiation). When asked whether forecasters would use SNPP NUCAPS at their home office they indicated that they would only if the latency requirements is met.

RECOMMENDATION #2: NUCAPS visualization in AWIPS-II can be improved to fully exploit product value in operational decision-making

- At HWT, there were instances where NUCAPS Sounding granules were ingested but not displayed. It was difficult to determine whether the issue was a result of the modifications to the plug-in or an existing problem in AWIPS-II (see blog post and blog post).
- The NUCAPS plug-in routinely give errors about duplicate records. Need to consult an AWIPS-II developer to solve this issue.
- Appendix C gives an overview of the ideas forecasters had for improving access to information in NUCAPS products by changing display options. Forecasters operate in a high pressure environment and need easy access to relevant information that improves their understanding in real-time. Much remains to be done to improve the quality of NUCAPS visualization in AWIPS-II.

RECOMMENDATION #3: NUCAPS uncertainty needs to be better understood and communicated to improve real-time interpretation

- NUCAPS quality varies vertically from surface to top-of-atmosphere. In the boundary layer, NUCAPS soundings sometimes display a dry, cool bias, but not always. The NUCAPS sounding product has been validation against radiosondes and its global accuracy is well known, statistically. However, much remains to be done to understand its quality in practice.
- Forecasters are moving beyond focusing on the BL and start to appreciate the accuracy and value of information in the mid to upper troposphere. We developed a number of AWIPS in close collaboration with forecasters as a set of best practices (see blog post) to evaluate NUCAPS in new ways. Much remains to be explored here.
- The accuracy of NUCAPS sounding observations also vary horizontally from scene to scene as temperature changes. With the Gridded NUCAPS product now being developed for AWIPS-II operational release (due date Spring 2019), we need to find ways to better communicate and visualize spatial and vertical uncertainty. See Appendix D for examples.

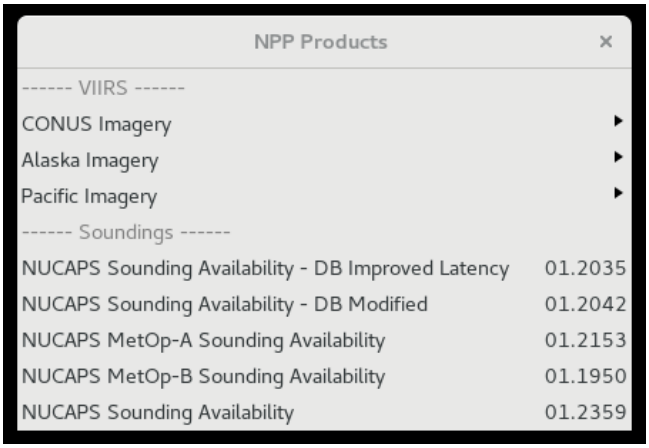
RECOMMENDATION #4: The thinned NUCAPS netcdf file format that is sent over SBN/ NOAAPORT to AWIPS-II needs to be updated to maximize operational efficiency and value

See Appendix E for a detailed outline of the NUCAPS SBN file format and recommendations for improvement. Addressing this recommendation is a priority because **the new AWIPS-II Gridded NUCAPS product that is being developed** (with scheduled release in Spring 2019) **depends on it.**

RECOMMENDATION #5: The AWIPS-II menu for NUCAPS must be evaluated and re-designed to accommodate JPSS products from multiple platforms and orbits

Forecasters require access to a higher frequency of sounding observations to better understand dynamic atmospheric processes. Asked what they'd like to see in future, forecasters said "*Improving the temporal availability*", "*More frequent satellite passes*", "*Hopefully the NOAA-20 satellite will provide additional and more timely data*", "*Additional satellites that could provide additional NUCAPS data would be great"*. It is thus a priority to grant forecasters access to NUCAPS from all operational platforms, namely MetOp-A, MetOp-B, SNPP and NOAA-20.

But, work is required on the AWIPS-II menu to allow easy access to NUCAPS soundings from multiple platforms. Currently, it is not possible to combine NUCAPS soundings from multiple satellites or sources under the same menu item because this results in a cluttered display (see **Appendix F**) that causes great confusion and severely impair product interpretation.



At HWT the NUCAPS Sounding datasets were separated into different menu items (left). This was possible by modifying the NUCAPS plug-in. This plug-in modification cannot be implemented on operational AWIPS-II unless a discrepancy report (DR) or request for change (RC) is submitted by end users to Raytheon.

We must reach community consensus on the design of the NUCAPS menu in AWIPS-II.

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APPENDIX A – How was NUCAPS utilized in your analysis today?

Forecaster responses to the 2018 Spring Experiment questionnaire.

"I used gridded NUCAPS mid-level lapse rates to verify my initial analysis of the atmosphere. I compared NUCAPS to HRR/GFS/NAM and SPC Mesoanalysis. NUCAPS was the closest to the SPC Mesoanalysis, which added confidence to my perception of severe threat and which areas to watch."

"NUCAPS gradients are helpful for situational awareness prior to convective development"

"NUCAPS was used during the pre-storm environment and comparisons of sounding derived parameters with SPC mesoanalysis showed good agreement. This increased my confidence in its use in an operational environment."

"A swath of NUCAPS soundings came in from a 1941 UTC pass… and showed high CAPE and modest mid-level lapse rates, thus supporting my idea of sub-severe convection"

"I had a chance to use NUCAPS to monitor the air mass in front of the squall line and found it to be a useful tool in the forecast process. It identified steep lapse rates and some mid-level drying that contributed to the high wind threat"

"NUCAPS helped verify gradients and severe weather concerns"

"I used NUCAPS to show instability and overall moisture in the mid- to upper troposphere"

"NUCAPS matched up well with RAP model soundings"

"I used NUCAPS to sample the boundary layer inflow into the shortwave trough"

"I was able to analyze the pre-convective thermodynamic environment using NUCAPS"

"Used NUCAPS to view the environment ahead of the supercell"

"NUCAPS was utilized to assess the environment during the afternoon just prior to convective initiation. A special 19 UTC sounding was launched and NUCAPS thermodynamic values matched well, lending confidence to the product"

"NUCAPS is useful as a pre-storm analysis tool…to determine convective potential"

"NUCAPS gave me confidence in the wind threat"

"NUCAPS showed environments that were becoming more moist and unstable, which would lead to SPS or SVR late in the forecast shift"

"I like being able to see the environment from the top down…A whole different perspective"

"It was used to asses the pre-storm environment, as well validate (or not) model data."

"I looked at the environment ahead of developing storms."

“I didn't use it today. I was watching for it, but by the time the data was available, we were looking at active thunderstorms.”

“NUCAPS was used to aid in assessing the pre-storm environment.”

“Given we jumped right into the warning scenario today, NUCAPS was not used heavily. I was able to pull up a modified NUCAPS sounding during the event to provide some situational awareness.”

“NUCAPS was used during the pre-storm environment and comparison of sounding derived parameters (both reduced latency and modified) with SPC mesoanalysis showed good agreement. This increased my confidence in its use in an operational standpoint. Today's environment of interest, however, was relatively cloud-free at the onset and of course this is not always the case. Would love to see how accurate the sounding-derived parameters are even if they are sensed with a thick cirrus and/or mid deck ongoing.”

“I used this before the storms fired up. This was helpful to see how the atmosphere was working up to a severe weather day.”

“Utilized NUCAPS soundings to asses thermal/moisture profile changes outside of radiosonde launch periods and/or to compare with forecast Soundings.”

“Looking at NUCAPS gridded products layered with derived cirrus imagery to help verify gradients and severe concerns”

“NUCAPS was used in the early afternoon to gauge the thermodynamic environment and convective potential as the cu field was growing. NUCAPS profiles were analysed from central Iowa, where instability was still quite low, to southern Iowa where instability was moderate, to just south of the border where instability was quite high. The air mass to the south would be advancing into our area, indicating to us that storms would have plenty of instability to be severe. NUCAPS captured the drying in the upper levels that was moving in from the southwest.”

APPENDIX B – Motivation for Recommendation #1

The latency of operational SNPP NUCAPS products must be improved for it to have value in nowcasting applications.

A subset of responses to the 2018 Spring Experiment questionnaire asking forecasters to identify the most pertinent property of NUCAPS for future applications.

“*The lower the latency time between the satellite pass and ingest of the soundings into AWIPS, the more likely I would be to use NUCAPS*”

“*More timely. Right now it is too slow and too late*”

“*Having products in as close to real-time as possible is very helpful when assessing a rapidly changing convective environment*”

"*Reducing data latency in a warning environment is extremely important*"

"*Direct broadcast was very useful. When monitoring environmental changes before storms develop, the more recent the data, the better*"

"*Soundings closer to the expected development time of convection is very useful*"

"*I could see a real advantage to being able to get the data more quickly to the forecasters to pinpoint areas of potential convective development*."

"*NUCAPS needs to be offered as soon as possible to the forecasters. The faster we can translate that data and incorporate it into our severe forecast mindset, the better the public will be as we will have real data, not model derived, top-down that is not available anywhere else*."

"*Liked having it available much quicker after the pass and also helped diagnose the hail threat*."

"*We need the JPSS data ASAP in order to use it in warning operations. If we need to wait hours, we won't use it because we will instead use GOES and model data*."

"*Timing is everything when using NUCAPS for convection*."

"*Lower latency of NUCAPS is vital in increasing the utility of the profiles.*"

"Having products in as close to real-time as possible is very helpful when assessing a rapidly changing convective environment"

"The DB data can cut the latency in half and really makes a big difference on days when a prior analysis is in the cards."

"Direct broadcast was very useful. When monitoring environmental changes before storms develop, the more recent the data, the better."

"By the time we would normally get the NUCAPS sounding, the atmosphere would have changed quite a bit, but the quicker turn around was a huge benefit"

"Since this was the east coast there may have been better timing of the sounding with onset of convection (earlier in the event and closer to time of initiation)."

"I was able to pull some data from NUCAPS today. However, given the widespread cloud cover, there were limited data points available to choose from. I relied primarily on the DB [Direct Broadcast] sounding points but did find that the corrected DB [Direct Broadcast] points added value to the initial soundings."

APPENDIX C – Motivation for Recommendation #2

The quality and type of NUCAPS display in AWIPS-II must be improved to maximize product value in operational decision-making

- ➢ Quantitative Read-Out Values: Instead of a visual display, NUCAPS retrieval values can be loaded as cursor read-out values. This enables forecasters to add quantitative information to a qualitative display of GOES RGB imagery.

- ➢ Spatial Gradients: We experimented visualizing gridded NUCAPS without QC as the DB NUCAPS data often had many failed soundings (yellow and red dots). Once switched off, forecasters could visualize NUCAPS gridded products as continuous fields. They claimed it was much easier to pick out spatial patterns and found it easy to mentally filter out the bad values. The green-yellow-red dots can be overlayed on NUCAPS gridded fields to verify where the failed retrievals are (figure C.1).

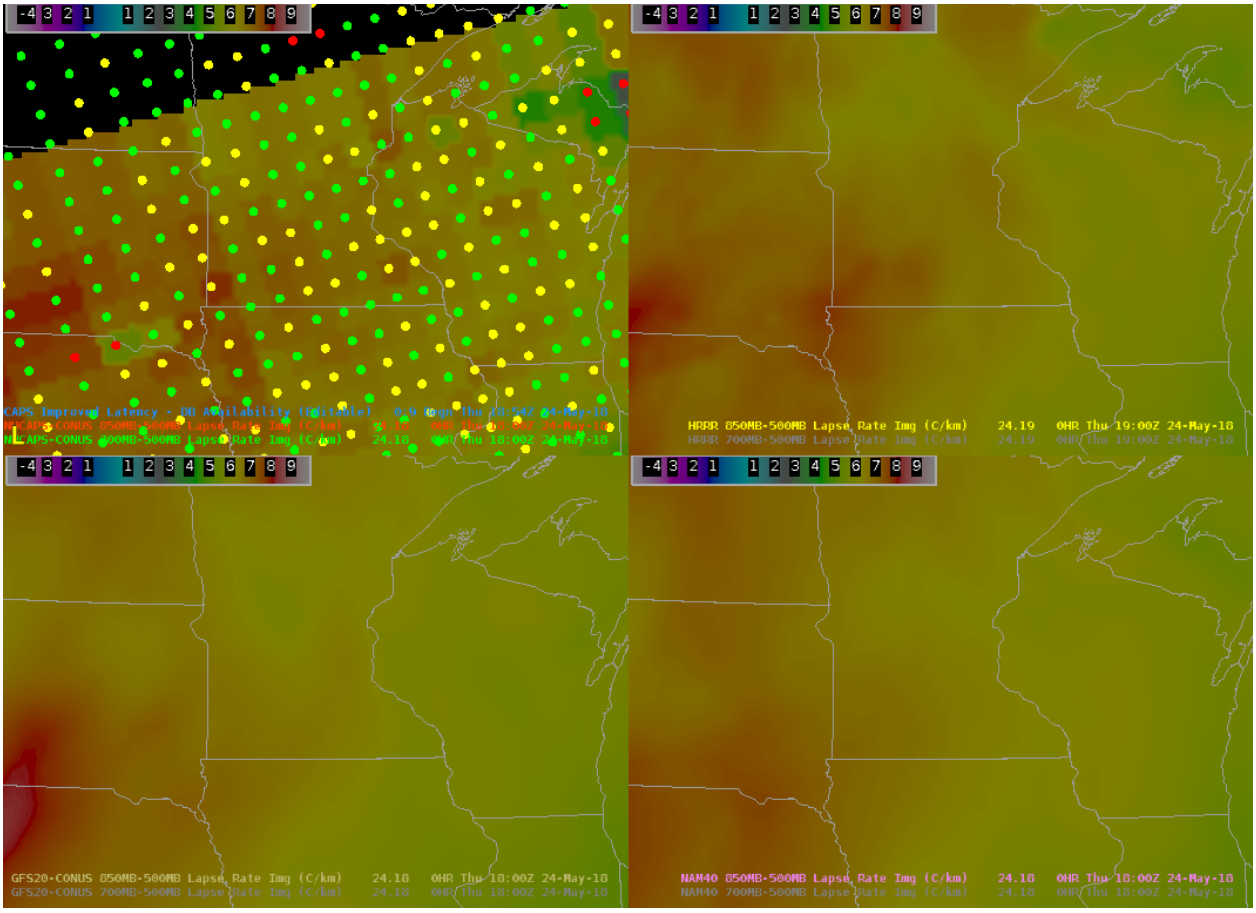

Figure C.1: NUCAPS lapse rate (top left) for a 850-500mb layer compared well with model fields (top right, bottom left and right) and accurately observed the elevated mixed layer (EML).

Visualizing NUCAPS as continuous gridded fields enables forecasters to evaluate spatial gradients of convective indices. Data gaps (due to failed observation) impair interpretation. This a **new application** of polar-orbiting sounding data in AWIPS-II. Previously the focus was on feature identification (cold air aloft) and interrogation of individual soundings (skew-T plots). In pre-

convective analysis, forecasters benefit from access to NUCAPS gridded fields that depict spatial gradients.

➢ Care must be taken to avoid confusion due to version differences in NUCAPS from different platforms and pathways. Figure C.2 highlights the confusion that ensues when the exact same area is observed with NUCAPS from different versions.

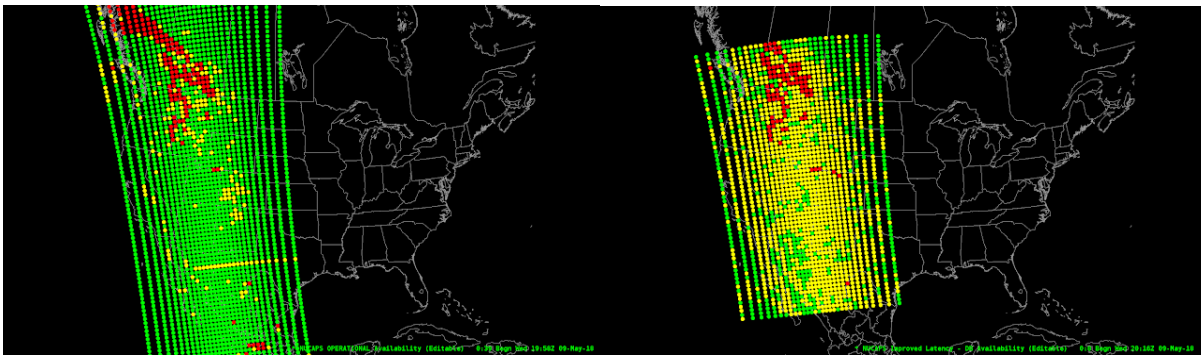

Figure C.2: Comparison of different NUCAPS versions at 19Z on 5 May 2018. Operational NUCAPS via SBN on full spectral resolution CrIS SDRs (left) compared to direct-broadcast CSPP NUCAPS on nominal spectral resolution CrIS SDRS (right).

APPENDIX D – Motivation for Recommendation #3

NUCAPS uncertainty needs to be better understood and communicated to improve real-time interpretation

Here we present an example where two adjacent NUCAPS soundings are both marked as yellow dots (i.e., IR retrieval did not converge, but MW retrieval succeeded) but when a forecaster click to view them, they display two very different types of profiles (figure D.1). It is clear to the eye that they have different error sources. Currently there is no clear explanation available to help forecaster interpret this. Without a clear understanding of the error sources that affect product quality, forecaster cannot develop trust in NUCAPS products. We have work to do to better characterize product uncertainty as it varies over space, time and height.

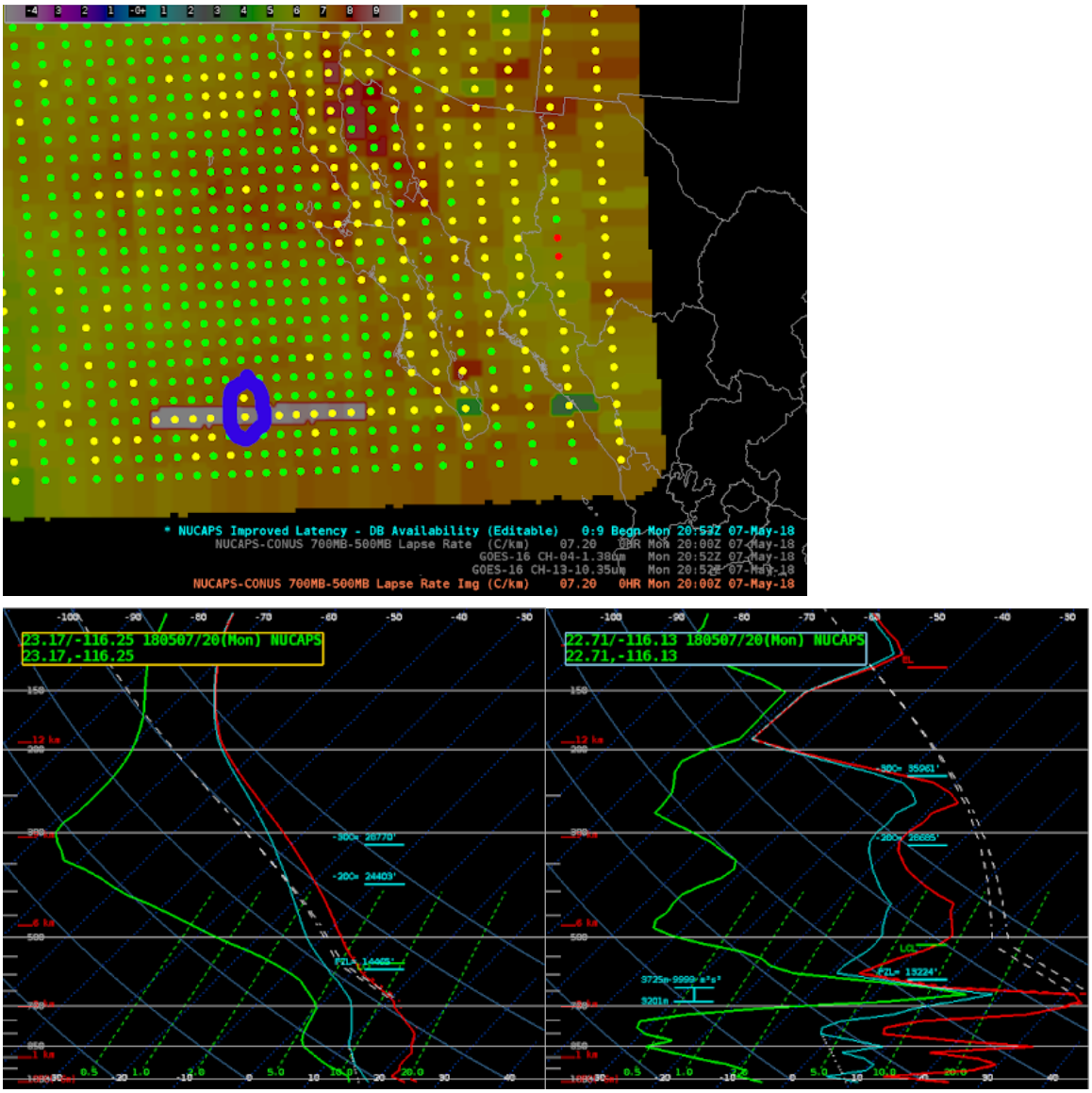

Figure D.1: Two adjacent NUCAPS soundings marked “yellow” but one sounding (left) looks OK and the other (right)

APPENDIX E – Motivation for Recommendation #4

The thinned NUCAPS netcdf file format that is sent over SBN/NOAAPORT to AWIPS-II needs to be updated to maximize operational efficiency and value

Addressing this recommendation is a priority because **the new AWIPS-II Gridded NUCAPS product that is being developed** (with scheduled release in Feb 2019) **depends on it**.

➢ *Overview of the NUCAPS SBN File Format as of August 2018*

Dimensions:
- Number_of_CrIS_FORs-120 = 120
- Number_of_P_Levels-100 = 100
- Number_of_Stability_Parameters-16 = 16

Variables (array dimension in parentheses):

short **Ascending_Descending** (120)

int **CrIS_FORs** (120)

float **Latitude** (120)

float **Longitude** (120)

int **Quality_Flag** (120) – first three values are used to assign green, yellow, red colors, t**he rest of the values (4, 8, 9, 16, 17, 24, 25) are redundant.**
- 0 = accepted
- 1 = reject_physical
- 2 = reject_MIT
- 4 = reject_NOAA_reg
- 8 = reject_iMIT
- 9 = reject_phy_and_iMIT
- 16 = reject_iNOAA
- 17 = reject_phy_and_iNOAA
- 24 = reject_iMIT_and_iNOAA
- 25 = reject_phy_and_iMIT_and_iNOAA"

float **Skin_Temperature** (120) – retrieved surface temperature

float **Surface_Pressure** (120) – GFS modeled surface pressure

double **Time** (120)

float **Topography** (120)

float **View_Angle** (120) – not aware of this field being used in AWIPS-II.

float **Effective_Pressure** (120 x 100) – value of pressure layer that is derived from Pressure levels. Can easily be calculated on AWIPS-II side from Pressure field. **There is no need to send this large array over SBN**.

float **H2O_MR** (120 x 100) – profiles of water vapor mixing ratio [ppb] derived from the retrieved H2O profile field in [molec/cm2] units.

short **Ice_Liquid_Flag** (120 x 100) – 0=water, 1=ice. Instead of this being an ice/water mask (120) it is a 2-D array of profiles with 0 values. This parameter is **not ingested into AWIPS-II and it contains no information**.

float **Liquid_H2O_MR** (120 x 100) – derived profiles of Liquid water mixing ratio [g/g]. This parameter is **not ingested into AWIPS-II** and can easily be derived in AWIPS-II from the retrieval field H2O [molec/cm2] if forecasters need it in future.

float **O3_MR** (120 x 100) – profiles of ozone mixing ratio [ppb] derived from the retrieved O3 profile field in [molec/cm2] units

float **Pressure** (120 x 100) – The standard 100-level pressure profile used for every NUCAPS retrieval. This array thus contains **120 x identical 100-level pressure profiles**, which is a waste of bandwidth.

float **SO2_MR** (120 x 100) – Sulfur Dioxide mixing ratio [ppb] profiles. This retrieval field is **not ingested into AWIPS-II**.

float **Temperature** (120 x 100) – Retrieved temperature profiles [K], one of the primary fields used in AWIPS-II. This is **the only NUCAPS profile directly retrieved from radiances in this SBN file**. All other profile parameters are derived from retrieved parameters not included here. Need to rethink this.

float **Stability** (120 x 16) – Derived stability indices about convective potential. These values are **not ingested into AWIPS-II** but instead calculated directly from the temperature and moisture profiles by NSHARP in AWIPS-II

➢ *Recommendations for an update to the NUCAPS SBN File Format*

The product file update we recommend here will enable the new Gridded NUCAPS product being developed for AWIPS-II (release date: Feb 2019) and it will reduce the overall size of the product file with a streamlining of its content.

1. **REPLACE FIELDS**

int **Quality_Flag** – replace with subsets from **Ispare_Field** (120 x 129) and **Rspare_Field** (120 x 262) to allow availability of tailored uncertainty metrics to improve product value and ensure correct interpretation in real-time applications.

float **H2O_MR** [ppb] – replace with **H2O** (120 x 100) layer column density [molec/cm2] to allow vertical interpolation to standard NWP levels for easier comparisons in AWIPS-II and total column integration.

float **O3_MR** [ppb] – replace with **O3** (120 x 100) layer column density [molec/cm2] to allow vertical interpolation to standard NWP levels for easier comparisons in AWIPS-II and total column integration.

2. REMOVE FIELDS

float **Effective_Pressure** (120 x 100)

short **Ice_Liquid_Flag** (120 x 100)

float **SO2_MR** (120 x 100)

float **Stability** (120 x 16)

3. ADD FIELDS

float **CO** (120 x 100) – in units [molec/cm2] to enable wildfire applications

float **Cloud_Top_Pressure** (120 x 8) – to indicate pressure layer at which clouds were cleared. This will help forecasters interpret soundings correctly and use more easily with cloud products from GOES platforms.

float **Cloud_Top_Fraction** (120 x 8)

APPENDIX F – Motivation for Recommendation #5

The AWIPS-II menu for NUCAPS must be evaluated and re-designed to accommodate JPSS products from multiple platforms and orbits

The AWIPS-II NUCAPS plug-in does not display data orbit by orbit but instead combines all the orbits from a given time period into a single display. As NUCAPS from different platforms are introduced the display will become cluttered with data that can span a two to three hour time period, making analysis very difficult.

Figure F.1 gives an example of what such a cluttered display may look like. NUCAPS is one of the few JPSS products in AWIPS-II. Unlike products from geostationary platforms, NUCAPS products arrive in AWIPS-II an orbit at a time. AWIPS-II needs to be configured to not combine products from different orbits in the same display because this will cause great confusion as soundings from different times are plotted next to each other.

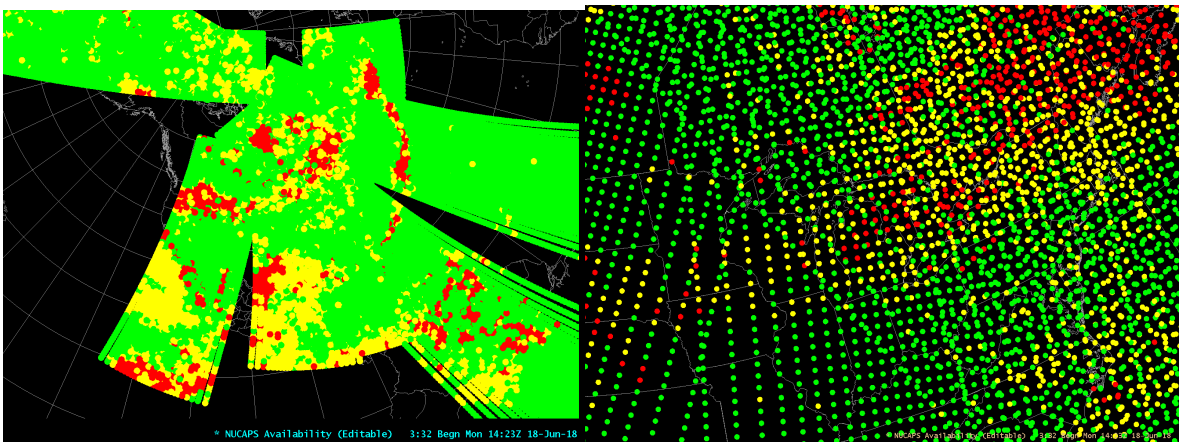

Figure F.1: AWIPS display with Operational NUCAPS, MetOp-A/B, and DB Soundings viewed with the current baseline AWIPS Plug-in and menu. Right: Zoomed in AWIPS display showing overlapping NUCAPS Soundings that span a 3 ½ hour time period.