Gridded NUCAPS Operational Assessment by NASA/SPoRT for Winter 2020/21

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Overview (goal and methodology)

In this assessment, SPoRT sought to evaluate the impact of Gridded NUCAPS sounding products to improve the operational forecaster's efficiency in upper air analysis of cyclones and associated hazards in data void regions and times. Often there are large voids of upper air observations in both space and time. ROABs are only twice daily and typically are relegated to over-land locations. The use of satellite soundings provides a relatively dense retrieval of observations compared to RAOBs, particularly for marine areas, and they occur just as frequently if not more than RAOB soundings. However, NUCAPS soundings differ from RAOBs (e.g., area vs point, dense spatial network) and can be gridded for assessment of horizontal spatial gradients. Therefore user assessment of the Gridded NUCAPS was needed to further test integration of NUCAPS soundings in operations. Specifically, this assessment will examine the winter season application of Gridded NUCAPS in operations for issues such as analysis of temperature and moisture gradients associate with cyclones, in both the vertical (profiles) and horizontal (cross sections), comparison with model forecasts, anticipation of upper atmosphere regions likely to experience aviation hazards, and qualitative analysis of cyclone strength trends. While the focus of the assessment was Gridded NUCAPS plan view displays, some feedback was given related to the vertical soundings

Gridded NUCAPS from the JPSS satellites is a 2-D view of many vertical sounding retrievals on/within a single level or layer, and it also provides the user the ability to examine cross-sections of the atmosphere, similar to current practices with model forecasts. It was created to more efficiently view spatial variations in temperature and moisture fields instead of requiring the user to view large numbers of individual soundings within the satellite swath. Ozone-derived products such as total column ozone and ozone anomaly, as well as tropopause level are also available for assessing the synoptic-scale environment. NUCAPS soundings and consequently, Gridded NUCAPS has been demonstrated as an observational tool in providing information between RAOB launch times and within data void regions (Weaver et al. 2019; Esmaili et al. 2020). Gridded NUCAPS can also be used as a model-independent comparison to short-term NWP forecasts to assess validity of the model solution at that time (Berndt et al. 2020). In this type of comparison quantitative values and spatial gradients between a model and Gridded NUCAPS can be examined, but only at the time of the satellite pass which is relatively infrequent compared to other satellite observations such as GOES-16/17. Fortunately, the imagery from GOES-16/17 includes channels related to temperature and moisture. Therefore, the more frequent GOES imagery has been shown to be complemented by the traditional ROAB and new Gridded NUCAPS data (Esmaili et al. 2020).

For this assessment the forecasters are already receiving NUCAPS data from NOAA-20 (i.e. JPSS-1) in their system and SPoRT provided access to the same data from S-NPP via an established LDM feed. An AWIPS baseline plugin in the forecasters local system transforms the NUCAPS sounding data into a gridded product (i.e. 'Gridded NUCAPS') for use with other plan view datasets. Due to the COVID-19 pandemic and altered work environment in operations, the approach of this assessment was slightly modified from the traditional SPoRT approach in order to be less intrusive to their work process. Given the desire for daily use of Gridded NUCAPS on shift (similar to RAOB usage) and the altered work environment, the request for daily feedback was not realistic. Instead, the target was determined to be weekly summary feedback or overall feedback at the end of a string of shifts. Assessment participants included those NWS WFOs in Alaska, the Weather Prediction Center, as well as the Bismarck, ND, Amarillo, TX, and Huntsville, AL NWS WFOs in the CONUS who were already familiar with NUCAPS soundings via participation in the JPSS NUCAPS User Working Group (NUWG). The time period of the assessment were the winter months of December, January, and February of 2020-2021.

Results

At the end of a series of shifts by the forecaster, they were asked to submit feedback via an online form (i.e. weekly summary feedback). They were asked to summarize their application and perceived value of Gridded NUCAPS in the operational setting. An abbreviated version of the feedback questions are provided in Table 1.

Overall, feedback indicated that the display of Gridded NUCAPS was applied much more than individual displays of NUCAPS soundings, but one user did respond that they "equally" use both forms of NUCAPS data display. Nearly all users categorized their frequency of use as "some," which we defined as about 25% of their shifts/workdays for the week. Only one user with prior operational experience and attendance at an HWT Experimental Warning Program Spring Experiment categorized their frequency of use as "Regularly" or 75% of their shifts/workdays for the week.

Forecasters were asked to list the Gridded NUCAPS products most readily used in their weekly period of feedback. Those products most frequently mentioned were TPW and Temperature at 850 mb. However, a wide range of products were cited 3-6 times each by users including Temperature at 700 mb, Relative Humidity within the 850-500 mb layer, and Lapse Rates within the 700-500 mb layer (Table 2). Mentions of surface-based products like 2m Temperature, Dew Point, and Relative Humidity were included in feedback 1-2 times each as well. New types of products like Tropopause Height and Ozone Anomaly were listed a couple times, but these were notably less frequent in the listing by users.

Applications and Primary Uses

The application of Gridded NUCAPS focused mostly on temperature and moisture analysis or model comparison as seen in Figure 1. Primarily, the analysis of moisture was most frequently chosen at 34% from the list of application types, and associated with the precipitation amount and rain/snow line forecast challenges. This was followed by both temperature analysis and model comparison at 24% to aid in forecasting mid-level instability, cold air outbreaks, and low-level temperatures advection related to freezing rain types of events or hazards. Due to this assessment period occurring in the winter months, the application of stability analysis was less frequent compared to other seasons such as spring and summer where prior testing activities (e.g., NOAA Hazardous Weather Testbed Spring Experiment) have included NUCAPS. Forecasters were asked to further specify a primary use where Gridded NUCAPS provided value. Many of the primary uses of Gridded NUCAPS revolved around the examination of data void areas where upstream features were likely to eventually impact precipitation events in the area of interest. For example, precipitating clouds were moving from the data void region of the Gulf of Alaska to over-land areas of south central AK as well as Kodiak Island (Figure 2). The Anchorage WFO examined the Lapse Rate within 850-700 mb for stability as well as the 850 mb Temperature to help assess precipitation type for an event on 1/12/21 in the north Gulf of Alaska (Figure 3). Small pockets of higher instability were seen within Gridded NUCAPS suggesting moderate showers were likely. Additionally, Kodiak Island was on the edge of rain/snow as 850 mb Temperatures were near -5 to -8 C, but surface temperatures were above 0 C due to the modifying Pacific SSTs. Similarly on 1/18/21 the Fairbanks WFO examined low-level Gridded NUCAPS data to determine the potential for freezing rain and moisture availability, and on 2/18/21 the Juneau WFO used the same methodology as Anchorage via the Lapse Rate and low-level Temperature data to monitor warm air return and a shift back to rain from snow. Other primary uses included the analysis of regions typically void of upper air observations such as over Canada as well as marine areas just offshore. Users looked at Gridded NUCAPS in the time between RAOBs to monitor cold air surges as well as moisture content (i.e. TPW) and instability just upstream from the area of interests in anticipation of precipitation amounts or as a comparison to earlier model forecasts.

Limitations

While Gridded NUCAPS provided value in many cases, there were limitations mentioned by users as part of the feedback for this new type of upper air resource in operations. Although NUCAPS is known to fail in regions of thick clouds and precipitation the boundary layer retrievals are known to be less accurate and one user commented that monitoring of features like fog or drizzle were limited. Another case using the 2-m Temperature and RH products noted pockets of seemingly erroneous values when trying to anticipate locations where heavier precipitation may later occur, particularly since the radar instrumentation was not functional at that time. These types of analyses reinforce the known limitations for the users and/or are opportunities to stretch the application of the observations to cases/applications that may be questionable regarding thick clouds and/or precipitation regimes. From an operational logistics perspective, the WPC user feedback indicated that the limitation of using the data had to do with the timing of its arrival. This is not to say that the data is latent, but rather the prescribed forecast process that results in an outgoing product from WPC requires upper air analysis to occur prior to the time at which the Gridded NUCAPS pass is available. WPC tends to issue their products at 1800 and 0600 UTC, which would mean that the JPSS overpass would need to be earlier to have NUCAPS available for the geographic region of interest several hours prior to the end of their forecast cycle and product deadlines. This type of limitation is something to consider in terms of recommended methodologies and/or uses in order to meet the logistical forecast needs, and more is discussed in the later 'Recommendations' section of this report.

Besides for the issues described above, these are some of the Gridded NUCAPS limitations listed within the user feedback:

- Comparison to model forecasts were problematic given the AWIPS/CAVE frame matching only occurred with one of the model output display times. The loading of multiple Gridded NUCAPS passes or segments for a large-scale comparison to the model was not easily performed.
- “Some of the layer product labels are not complete when viewing products in D2D.”

Some technical challenges related to the individual NUCAPS sounding displays themselves were brought forth in the feedback from users, and they are listed here as items to be solved via further training or ongoing software development (e.g., SHARPpy) as appropriate:

- “would love to see a way to visually look at the nucaps soundings in AWIPS better cause there are some glitches with loading in too many soundings. Also, if you try to click on too many and have the RAOB soundings on, then there is no easy way to move back and forth for comparison.”
- “NUCAPS soundings are not as accurate when there is cloud cover present and despite green dots of availability, there were some interesting soundings compared to models/obs.”
- “when clicking on soundings from the sounding availability, sometimes I have issues with the NSharpEditor not loading the sounding requested (potentially due to other soundings being loaded) and then if multiple soundings are loaded it is difficult to know which is for what location.”

Ratings

The NUCAPS data and associated ‘gridded’ display are both new to the forecasters in an already full system of AWIPS options and observations types. Typically, with the introduction of a new product, the assessment aims to understand the impact or value compared to existing resources. To this end several ‘rating’ requests were presented to the user. First, the feedback form asked for a rating of the Gridded NUCAPS utility (Figure 4). Nearly all of the feedback from users indicated “Small” to “Moderate” utility. A few responses indicated “Very Small” utility but this was essentially when the forecaster was unable to use the data at all due to either a lack of time during a busy event or the timeliness of the data itself, as mentioned in the prior Limitations section of this report. The forecasters participating in the assessment had a wide range of experience with NUCAPS. So the lack of “Large” impact could vary based on their comfort or understanding with NUCAPS data. Hence, the feedback form included a request for the user to do a self-rating of their own comfort level with NUCAPS (Figure 5). All the responses were either a “Moderate” or “High” comfort level with the NUCAPS data, and the most responses were the former. This suggests that the lower utility ratings are not due to a lack of understanding of the NUCAPS data, and that prior experiences (e.g. HWT Experimental Warning Program) and/or various training resources (as mentioned previously) have sufficiently met user’s needs. In addition, there was no relationship between ‘utility’ rating and the ‘comfort’ rating; for example, some of those “Small” utility responses also had “High” comfort levels. However, even a good understanding of the NUCAPS data does not imply that this new type of satellite retrieval of upper air data is as trusted as the existing resources such as RAOBs. Therefore, a third rating request asked the users to consider the quantitative values from

NUCAPS and their current level of ‘trust’ in the values (Figure 6). Except for one response, all of the user feedback indicated either a “Moderate” or “High” trust level in the quantitative values of NUCAPS. The one response with a “Very Low” trust level indication was due to technical issues with the display of the NUCAPS profiles in the AWIPS NSharpEditor where the chosen sounding was not properly displayed as expected. In summary, users felt reasonably comfortable and knowledgeable with NUCAPS and had sufficient trust in the values, but they generally experienced small to moderate impacts when using the data in operations.

Specific Case Examples

February 14, 2021: Dry Air Analysis Between RAOB Times (Amarillo, TX)

On February 14, 2021 a low pressure area and associated trough was diving into the Four Corners region of the Southwest CONUS. The Amarillo (AMA) RAOB sounding at 12Z showed strong winds from the southwest with high levels of RH through 600mb (Figure 7). Forecasts for the AMA area included snowfall with this impending system. There was a pass of S-NPP at 1850 UTC where a good quality sounding of MW+IR showed drying in the 700-600 mb layer while the lower levels warmed with the southwesterly flow (Figure 8). An hour later a pass from NOAA-20 allowed further NUCAPS profiles of the Albuquerque (ABQ) and El Paso (EPZ) areas which also show dry conditions in the 700 mb layer (Figure 9). These regions are upstream of the AMA location and hence, AMA experienced similar conditions as the dry air advected into the area. Examining Gridded NUCAPS RH at 700 mb showed a relatively dry condition in the ABQ and EPZ areas and decreasing TPW from the earlier RAOB. The 2-D plot of RH from NUCAPS data allowed improved spatial analysis of conditions vs having to examine many of the individual NUCAPS profile plots. Over the NM and TX/OK panhandle regions this dry air impacted the precipitation as the resulting amounts were notably less than anticipated from earlier NWP forecast output. The 00Z AMA RAOB for 2/15 (Figure 10) later confirmed the dry air filtering into the region. Analysis by the user suggested that Gridded NUCAPS ‘becomes useful to fill the gap’ between the 12 and 00Z RAOBs where the user gains a 2-D spatial awareness of changing RH conditions. While some of the individual soundings had questionable values in the boundary layer, enough good quality retrievals allowed for the Gridded NUCAPS display of moisture fields like RH and TPW. The combination of MW+IR data was possible due to breaks in the thick clouds to allow retrievals where traditional satellite IR imagery may have had limited use as it would tend to focus the user on only the cloud tops. Hence, the value of the Gridded NUCAPS data here is the earlier analysis of drying conditions and associated impact on precipitation amounts versus having to wait another 6 hours for this type of analysis of the 00Z RAOB.

February 17-18: Monitoring Upstream Airmass in Data Void (Juneau AK)

Prior to February 18, 2021 the Southeast AK region (i.e. Juneau, AK CWA) had cold air in place followed by a snow event after a cold air outbreak from Canada pushed south through the region. The relatively warm waters of the northeast Pacific ocean served as a large source of warming and increased moisture modification of the air, but the area was void of observations of the atmospheric profile, leaving only model guidance and interpreted satellite imagery. Using Gridded NUCAPS the forecaster was able to note the warming trend in the lower levels of the atmosphere which advected into the Southeast AK region given the flow around the low pressure area to the west (Figure 11). This resulted in the precipitation transitioning to rain as temperatures were sufficiently above freezing for a given depth. Station plots from the 16th depicted cold temperatures and snow showers along the coastal areas, but the precipitation type shifted to rain in these areas as warm air advected into the region on the 18th (Figure 12). Additionally, the forecaster examined the Gridded NUCAPS Lapse Rate products to analyze where areas of heavier precipitation were likely. The 2/18 plot at 2110 UTC (Figure 13) depicted the extreme southeast portion of the AJK CWA as having 850-500mb lapse rates near 7-8 C/km. The forecaster's feedback was:

"An overall idea of lapse rates over a large area helped determining where heavier precip was possibly occurring. We were also watching the warm up as we came out of the coldest air we have had this winter to once again being above freezing with rain."

The value of Gridded NUCAPS for this case pertains to the capability to monitor upper air conditions in upstream regions void of observations and to anticipate precipitation type changes. This is particularly important for coastal locations with incoming precipitation from data void regions that have large air mass modification potential. This value and associated methodology is independently the same as that from the earlier example by the Anchorage WFO for 12 January 2021, and thus reinforces the theme of application for precipitation events.

February 17: Rain/Snow Line Analysis (North MS/AL Region)

Just prior to 17 February 2021 cold temperatures had set records in TX region with many communities left without power and snow covered much of the state. A surge of cold was forecasted to move through the southeast CONUS with moisture being pulled northward from the Gulf of Mexico via a developing cyclone. A rain/snow event was anticipated to impact the northern portions of MS and AL. While many details regarding this case will not be covered here, the focus of this discussion is on the use of Gridded NUCAPS to provide a mid-day cross-section of the atmosphere to complement the use of other resources such as model forecasts of the same time. A lack of RAOB sites exist in the northern MS and AL area, and surrounding sites would include Birmingham, Nashville, and Jackson. In all of these sites the 00Z and 12Z soundings for 17 February 2021 had much colder temperatures at the surface compared to at 850 mb with Nashville below freezing at both levels and Birmingham and Jackson slightly above freezing at 850 mb (Figure 14). All of these sites had increasing precipitable water values, particularly at mid-levels and well upstream at Little Rock AR, a very moist and cold profile existed. With the forecasted precipitation the main concern was the position of the rain/snow line and possible accumulation of snow. Typically, cross-section plots are examined in the case of rain/snow events to estimate sufficient moisture in the dendritic growth zone and to analyze low-level temperature profiles to determine precipitation type and/or freezing rain. The NAM model run from 1200 UTC had a 7 hr forecast of relative humidity and web bulb temperature as shown in Figure 15. Note the high RH values from low to mid-levels on the left (i.e. west) side of line E and a narrow low RH band along 850 mb that spans the line. Also note that the wet bulb temperatures are essentially below freeze from the surface to low levels assuming that precipitation falls in this region and saturates the layer. A Gridded NUCAPS pass at 1856 UTC is used to create the same cross-section plot (Figure 16). Note the Quality Flags (not shown) along line E suggested good retrievals from the microwave sounder but not the IR sounder. Assuming that the general characteristics in the Gridded NUCAPS cross section are correct, one can see some obvious differences from the NAM forecast. Gridded NUCAPS has high values of RH confined to lower levels and no band of low RH appears at 850mb. In addition, the web bulb temperature stays above freezing for the east half of line E. This might suggest a rain/snow line somewhere in the east half of the cross-section plot verses the model plot which had below freezing temperatures for a saturating event in the near-term. Precipitation along line E did not occur for another 4-6 hours, but by 0000 UTC on 2/18 the northeast MS and northwest AL areas had light snow reported (Figure 17) with freezing drizzle and rain to the south and southeast. Accumulation of snow did not readily occur east and southeast of the Huntsville area, or about the right 1/4 of the cross-section plot. This tends to agree with the depiction provided by the Gridded NUCAPS plot. However, accumulations of several inches were reported from the west Huntsville area to Florence and into northeast MS. The value here is having an observation type for use in cross-section plots where model forecast output can be compared to help understand if the model seems reasonable for the event or if adjustments to earlier developed public/aviation forecast products may be warranted.

Conclusions and Recommendations

This assessment examined the operational utility of Gridded NUCAPS as an alternative form of display of NUCAPS profile retrievals. The time period of this activity was December 2020 through February 2021 and collaborators ranged from several parts of the CONUS to Alaska and they varied in their amount of prior experience with using NUCAPS data. Forecasters were asked to provide weekly summaries of their utility of Gridded NUCAPS as the main methodology to obtain their feedback. This reduced the strain and time commitment on participants during an already stressful and irregular work situation given the impacts of the COVID-19 pandemic. The overall user feedback indicated:

- The use of Gridded NUCAPS was occurring in about 25% of the operational shifts.
- The leading use of Gridded NUCAPS was moisture analysis in the context of precipitation amount and type
- Analysis of upper air thermal properties and comparison to model output via Gridded NUCAPS followed closely behind the aforementioned leading application related to precipitation
- Users self-described having a Moderate to High level of understanding of the NUCAPS data
- Users rated their confidence in NUCAPS quantitative values as Moderate to High

- The overall impact of Gridded NUCAPS in operations was rated as Moderate to Low regarding atmospheric spatial analysis, but several user-provided examples focused on precipitation, and in particular the application to anticipate precipitation types.

Based on the feedback, events analyzed during the assessment and examples submitted, an outcome of this assessment is a recommended approach to anticipating winter-time precipitation type or expected intensity. Gridded NUCAPS was utilized to analyze the temperature, moisture, and stability regimes ahead of clouds and precipitation. ***Recommended analysis fields include TPW, Temperature at 850 mb, Temperature at 700 mb, Relative Humidity within the 850-500 mb layer, and Lapse Rates within the 700-500 mb layer to assess the expected temperature, moisture, and stability regimes.*** In addition, it was determined that Gridded NUCAPS was valuable for gaining 2-D spatial awareness to fill in the observational gaps between conventional ROAB observations, enhancing awareness of changing temperature and moisture conditions. The value of Gridded NUCAPS as demonstrated in the example cases discussed above is as follows:

- **Earlier analysis of drying conditions** and associated impact on precipitation amounts versus having to wait another 6 hours for this type of analysis of the next RAOB.
- **The capability to monitor upper air conditions in upstream regions void of observations and to anticipate precipitation type changes.** This is particularly important for coastal locations with incoming precipitation from data void regions that have large air mass modification potential.
- **An observation type for use in cross-section plots** where model forecast output can be compared to help understand if the model seems reasonable for the event or if adjustments to earlier developed public/aviation forecast products may be warranted.

With any new product there will be some time required to infuse it into the existing operational practices. In addition, NUCAPS is a new type of observation and is sufficiently different in its derivation compared to traditional RAOBs that a forecaster will need both technical training on the product, and also some simulated cases to demonstrate on-the-job application methods. Given the availability of NUCAPS, feedback from WPC suggested a limitation to its application is simply the logistics of their own operations and the need for that type of data an earlier point in the forecast process. Potentially utility of Gridded NUCAPS for WPC forecasters could be increased through several development opportunities: a demonstration of products derived from instruments on the MetOp platforms with earlier local equator crossing times, use of NUCAPS-Forecast where the time dimension of observations is expanded, or developing strategies on how to use the data at a later time in the operational setting. Similarly, feedback from a more experienced user points to an overall solution to increase the utility of Gridded NUCAPS in terms of improved tools and/or methods for its application:

"An ongoing challenge is to create a way to easily compare Gridded NUCAPS data with model initialization. So far I have just created a side by side comparison using the tabs in CAVE but the nature of how each satellite pass loads makes it difficult to do much more than this unless I want

to load multiple passes via the Inventory mode each shift. It would be helpful to have something like a difference product, showing where NUCAPS and (for example) the RAP differ or align."

This comment from the user provides a solid recommendation for the development of a tool or method that would use the data in a way that results more in a decision or influential product, and perhaps would help to overcome the logistical challenges mentioned by the WPC user. Even in the general satellite community, the increasing amount of data to interpret is moving users toward decision products versus examination of raw data (i.e. temperature, humidity, etc.). In addition, a tool or method for the suggested differencing would potentially aid in a more daily use of NUCAPS data vs the current 25% usage seen in the feedback. For the winter-time events seen in this assessment period, the use of a differencing tool/method would have been particularly useful regarding the issue of precipitation type. Additional funding would provide the opportunity for the development of a robust simulated exercise for the rain/snow line case of 2/17/21 outlined above. As a recommended activity, a simulated exercise would provide training on the new winter-time analysis technique using Gridded NUCAPS and potentially demonstrate the use of an experimentally developed differencing tool/method.

References

Berndt, E.; Smith, N.; Burks, J.; White, K.; Esmaili, R.; Kuciauskas, A.; Duran, E.; Allen, R.; LaFontaine, F.; Szkodzinski, J. Gridded Satellite Sounding Retrievals in Operational Weather Forecasting: Product Description and Emerging Applications. Remote Sens. 2020, 12, 3311, https://doi.org/10.3390/rs12203311.

Esmaili, R. B., Smith, N., Berndt, E. B., Dostalek, J. F., Kahn, B. H., White, K., et al., 2020. Adapting Satellite Soundings for Operational Forecasting within the Hazardous Weather Testbed. Remote Sensing, 12, 886, https://doi.org/10.3390/rs12050886.

Weaver, G. M., N. Smith, E. B. Berndt, K. D. White, J. F. Dostalek, and B. T. Zadovsky, 2019: Addressing the cold air aloft aviation challenge with satellite sounding observations. J. Operational Meteor., 7 (10), 138-152, https://doi.org/10.15191/nwajom.2019.0710.

Tables and Figures

Table 1 Abbreviated versions of the questions, requested input, and ratings within the online feedback form used by forecasters at the end of a string of shifts or as part of weekly summary. The complete version of the form was linked during the assessment to the NWS VLab page for Gridded NUCAPS, authored by NASA/SPoRT.

Questions, Requests, Ratings	**Type of Response**
Was Gridded NUCAPS viewed more, equally, or less than the NUCAPS individual profiles?	Multiple Choice
How often was Gridded NUCAPS viewed this week?	Rating from 1-5
Which Gridded NUCAPS product was most readily used?	Open text response
What type of events was Gridded NUCAPS useful?	Choose all that apply
Describe primary need for profile info where Gridded NUCAPS provided value.	Open text response
Rate utility of Gridded NUCAPS.	Rating from 1-5
Rate your current level of comfort and understanding of Gridded NUCAPS.	Rating from 1-5
What is your current level of trust in the quantitative values?	Rating from 1-5
Provide comments or suggestions on the display of the data	Open text response

Table 2 Gridded NUCAPS products listed within user feedback as "most readily used" during their weekly operations

Product	Level	Layer	Times mentioned
Trop Hgt			(3) x,x,x
Temperature	850 mb		(6) x,x,x,x,x,x
Temperature	700 mb		(4) x,x,x,x
Temperature	500 mb		(2) x,x
Temp	2 m		(2) x,x
TPW and Lower PW		Low (to 850 mb)	(6) x,x,x,x,x,x
Lapse Rate		950-850 mb	(1) x
Lapse Rate		850-700 mb	(2) x,x
Lapse Rate		700-500 mb	(4) x,x,x,x
RH		850-500 mb	(3) x,x,x
RH		850-300 mb	(1) x
RH		700-500 mb	(1) x
RH	500 mb		(1) x
RH	2 m		(1) x
Dew Point	2 m		(1) x
Max CAPE			(1) x

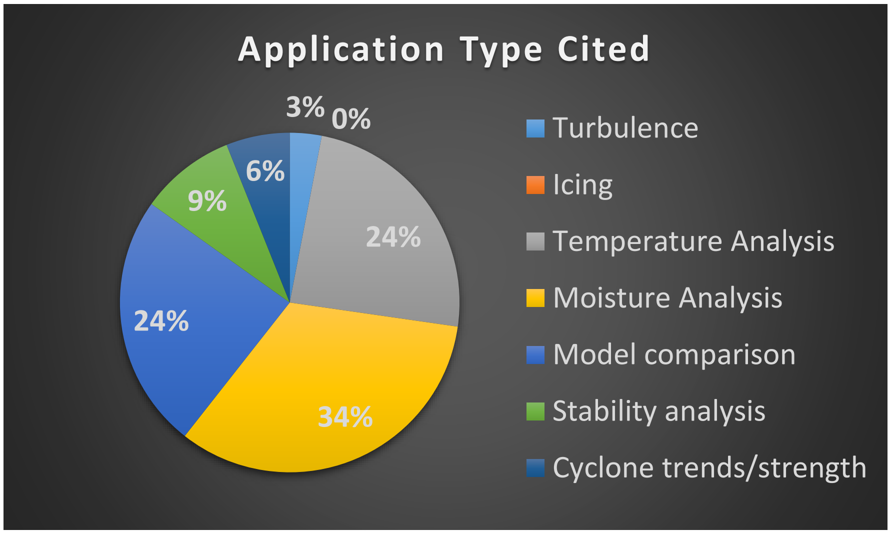

Figure 1 Distribution of forecaster's response when asked what applications of Gridded NUCAPS were used during the week representing the feedback. Note that users had the ability to choose all categories that apply. Also, the "Icing" category was not chosen due to lack of aviation-specific users.

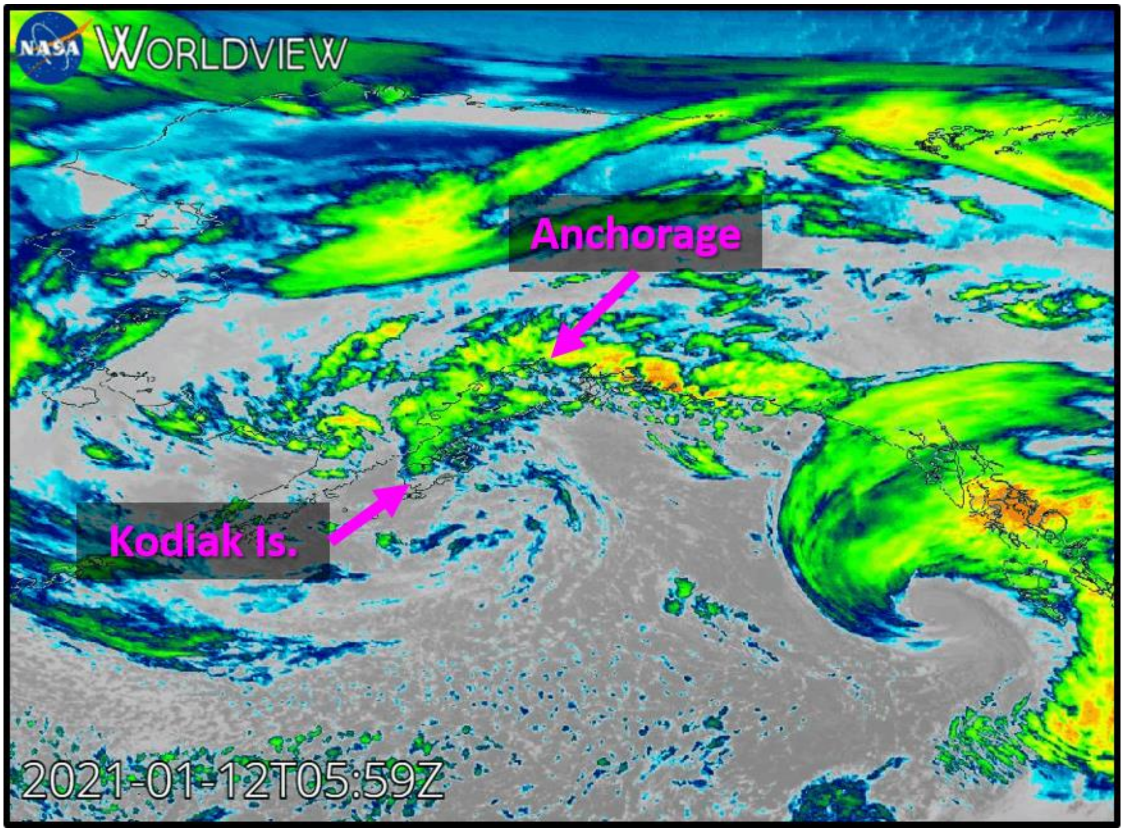

Figure 2 GOES-17 11 um (channel 13) imagery via NASA/WorldView for 0559 UTC on 12 January 2021 with color enhancement of grays (i.e. warm surfaces) to oranges/reds (i.e. cold cloud tops). Annotations of Anchorage, AK and Kodiak Island for reference in magenta.

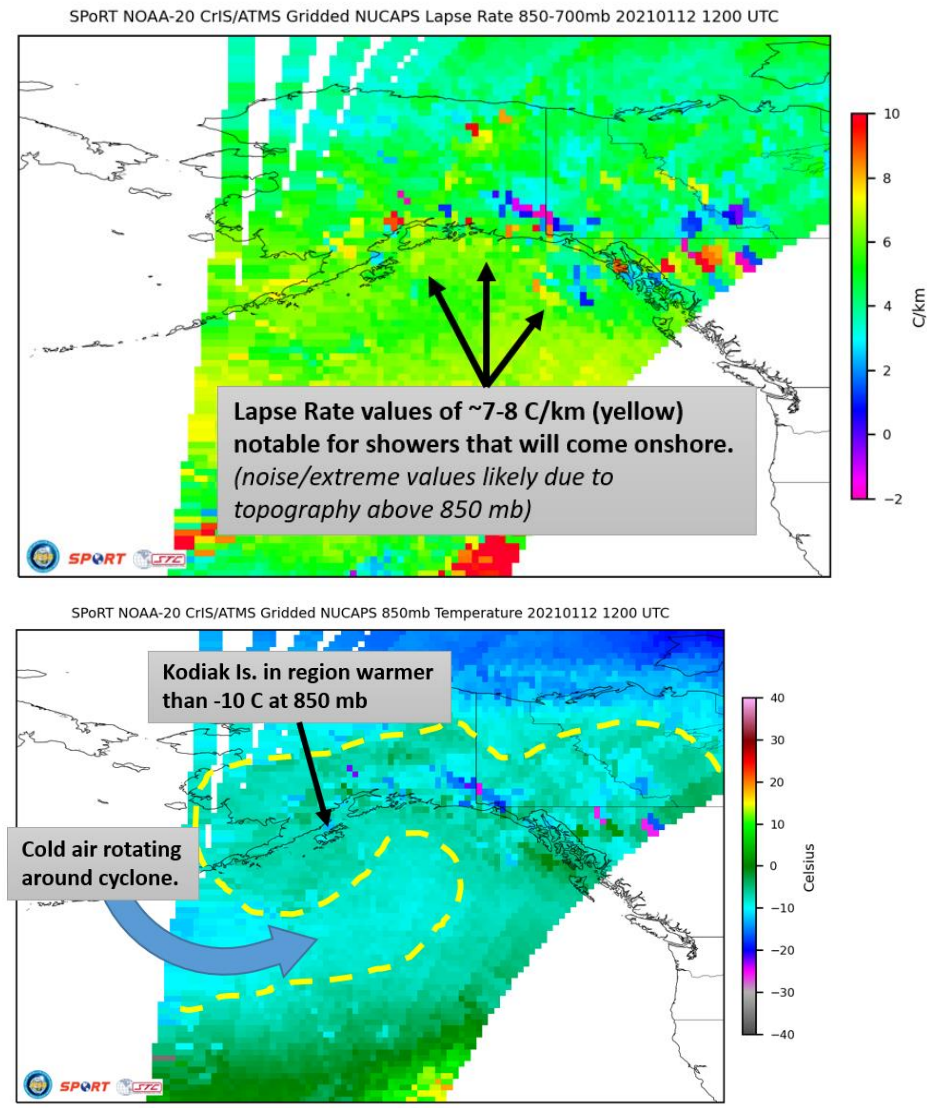

Figure 3 Gridded NUCAPS Lapse Rate (top) and Temperature at 850 mb (bottom) for 1200 UTC on 12 January 2021 over Alaska and North Pacific. Data examined by AFC WFO for onshore precipitation as well as precipitation type determination at Kodiak Is. (see annotations)

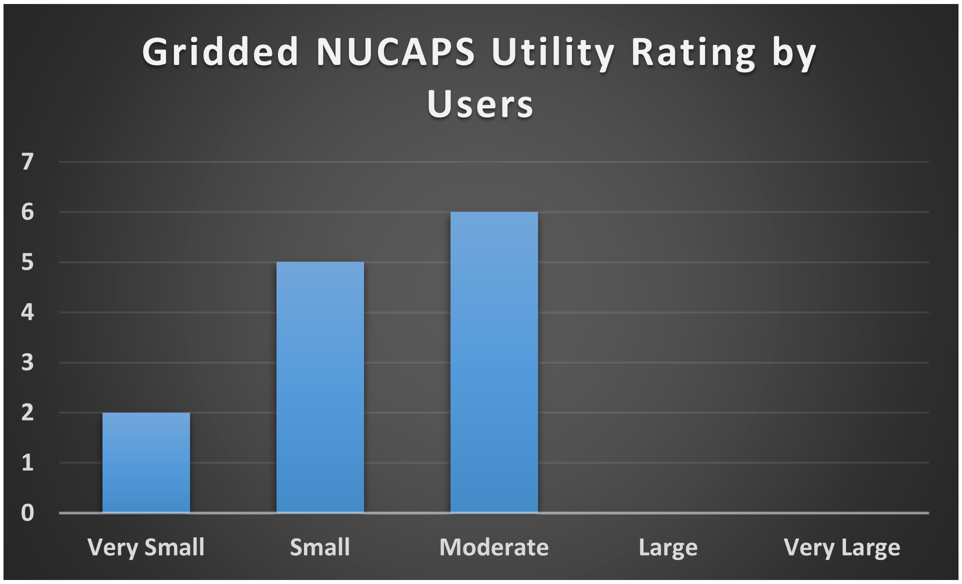

Figure 4 Rating of the Gridded NUCAPS utility for the week time period representing the user feedback. Note that the "Very Small" ratings occurred within feedback where the user noted that Gridded NUCAPS was not used either due to a lack of time in operations or the timeliness of the overpass itself.

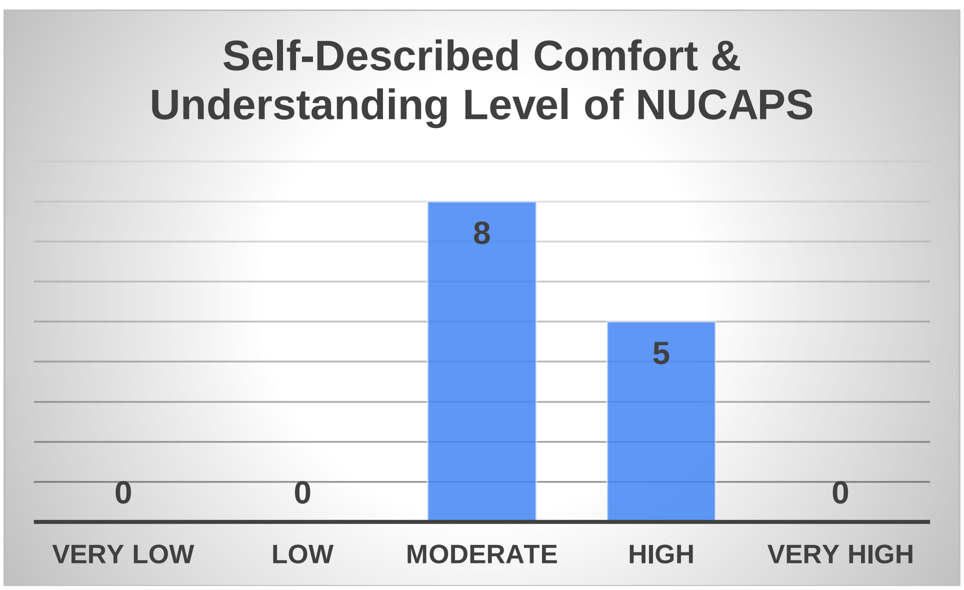

Figure 5 Rating of user's comfort level with applying the data as well as their understanding of the NUCAPS data itself. This is a subjective rating from the individual users, and the purpose is to gauge the impact of the information and training provided to date.

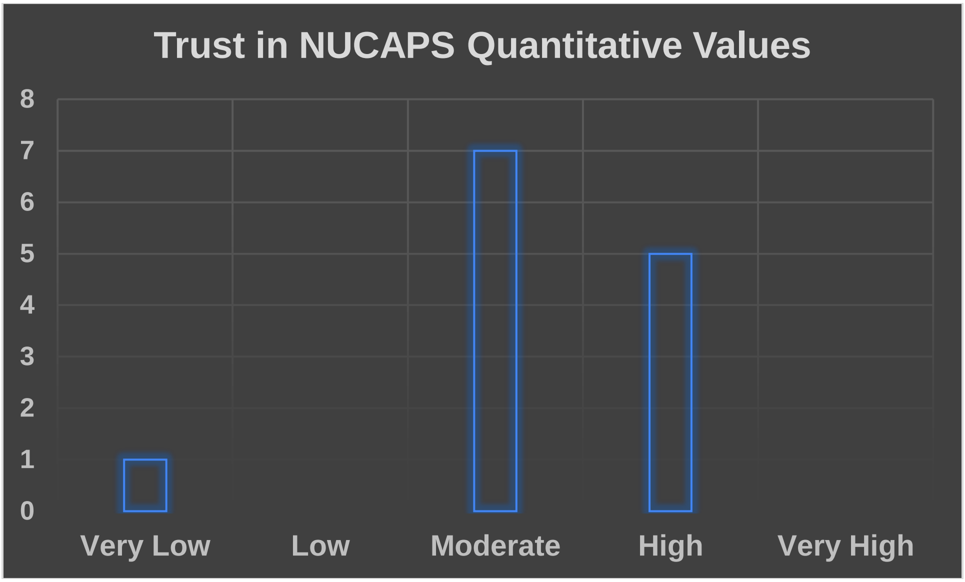

Figure 6 Rating of the user's trust (i.e. confidence) that the NUCAPS quantitative values displayed within the Gridded 2-D product are accurate. This complements prior survey questions related to utility and trust in order to provide insight to those responses.

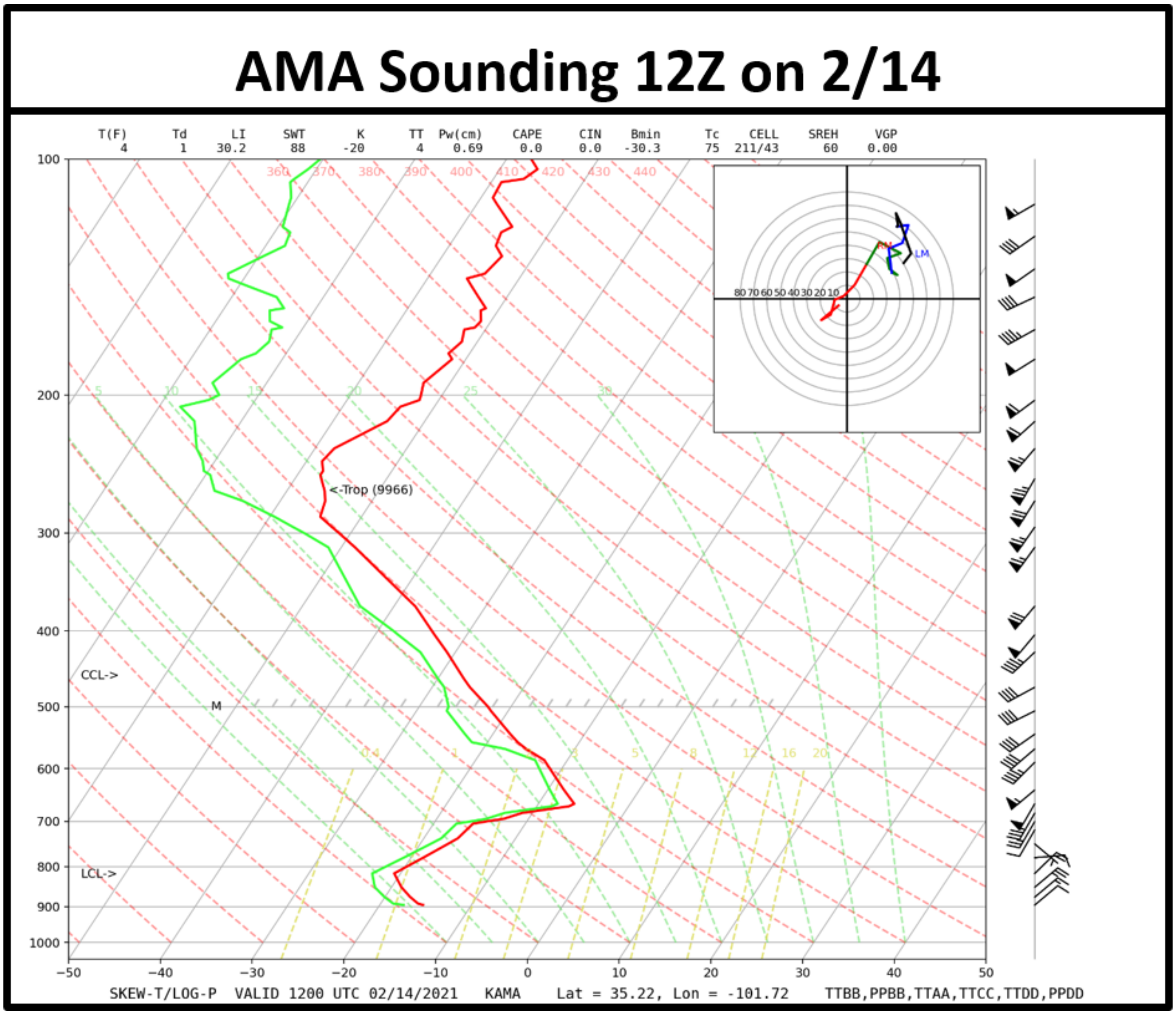

Figure 7 RAOB sounding at Amarillo, TX at 1200 UTC on 14 February 2021

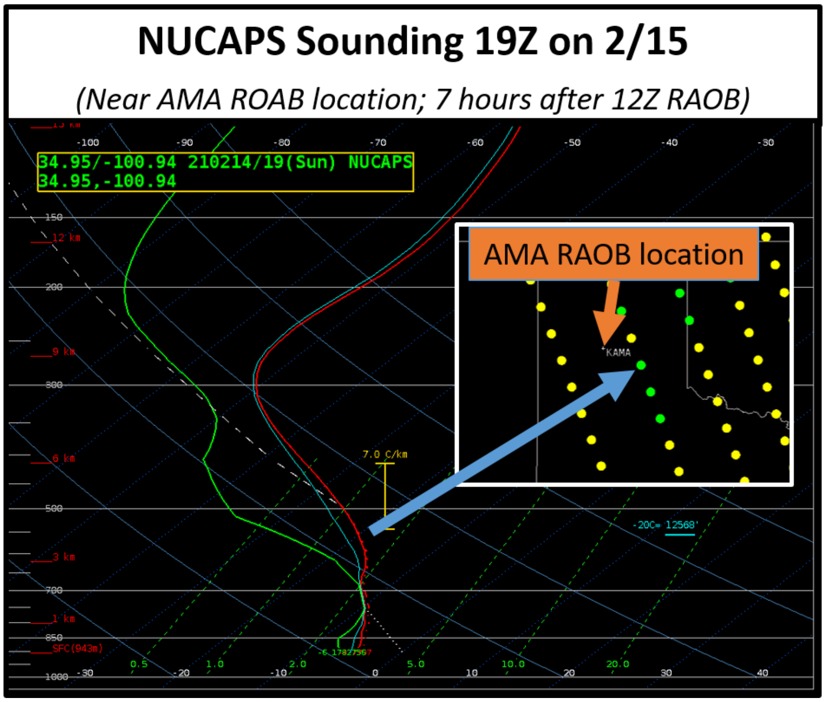

Figure 8 NUCAPS Sounding nearest to Amarillo, TX at 1900 UTC on 14 February 2021. Inset shows NUCAPS Data Availability and the point chosen. Note the green dot indicates 'good' retrievals from both infrared and microwave sounding instruments.

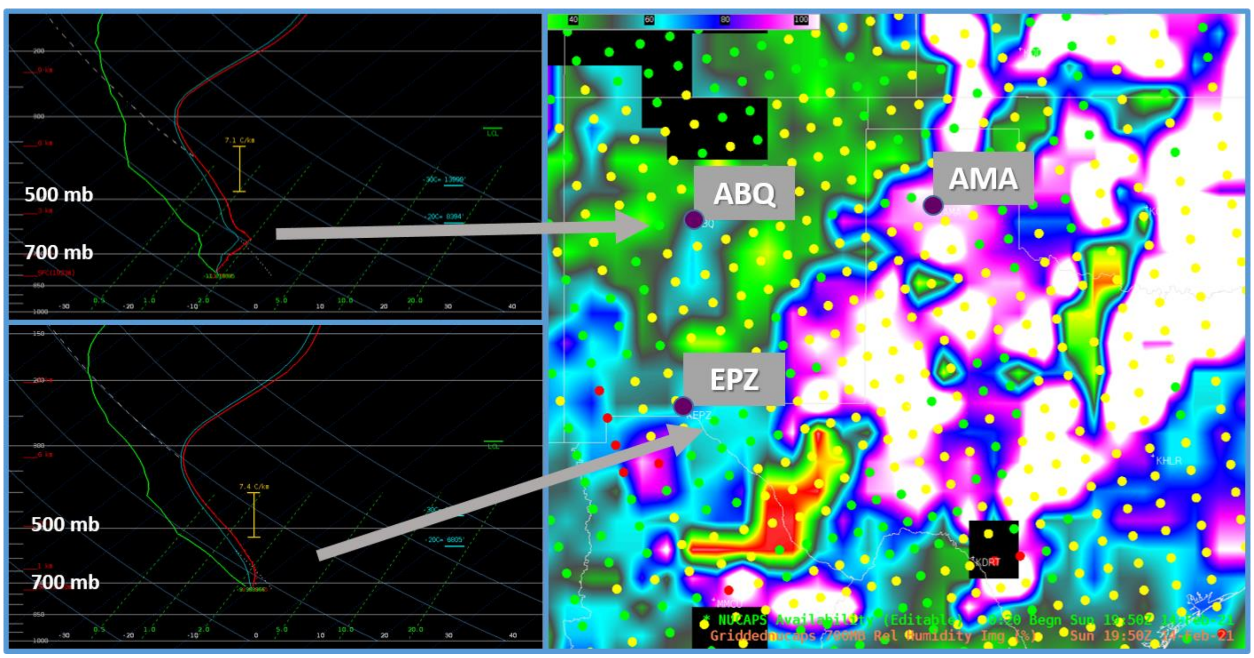

Figure 9 Gridded NUCAPS (right) of Relative Humidity at 700 mb at 1955 UTC on 14 February 2021 with the "Data Availability Quality Flags overlaid where green indicates a good retrieval from both infrared and microwave sounders, yellow indicates a good retrieval from only the microwave sounder, and red indicates a poor retrieval from both sounders. The NUCAPS Soundings are provided nearest to the Albuquerque, NM (ABQ) (upper left) and El Paso, TX (EPZ) (lower left) RAOB locations. The green quality points nearest to these locations were chosen.

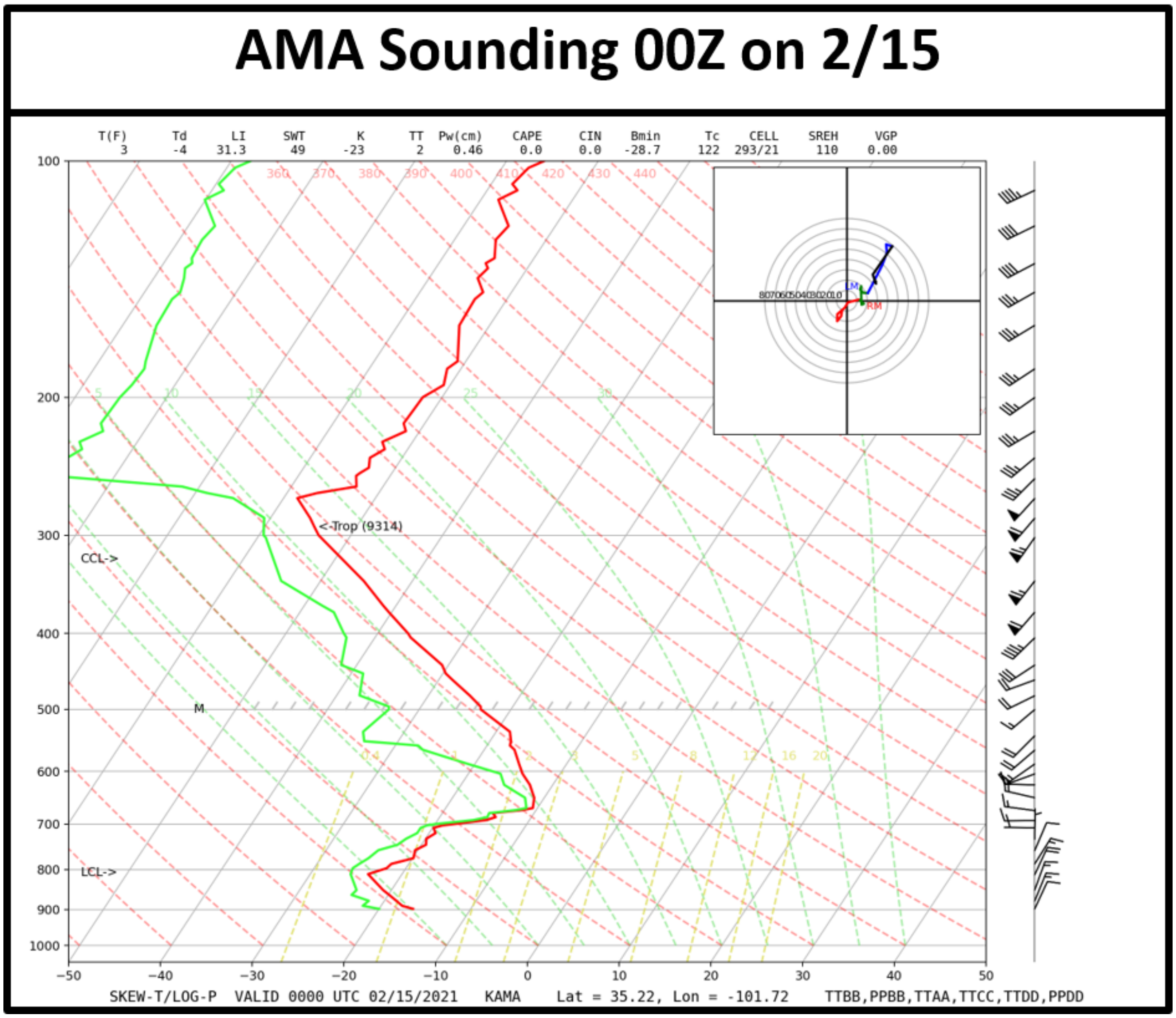

Figure 10 RAOB sounding at Amarillo, TX at 0000 UTC on 15 February 2021

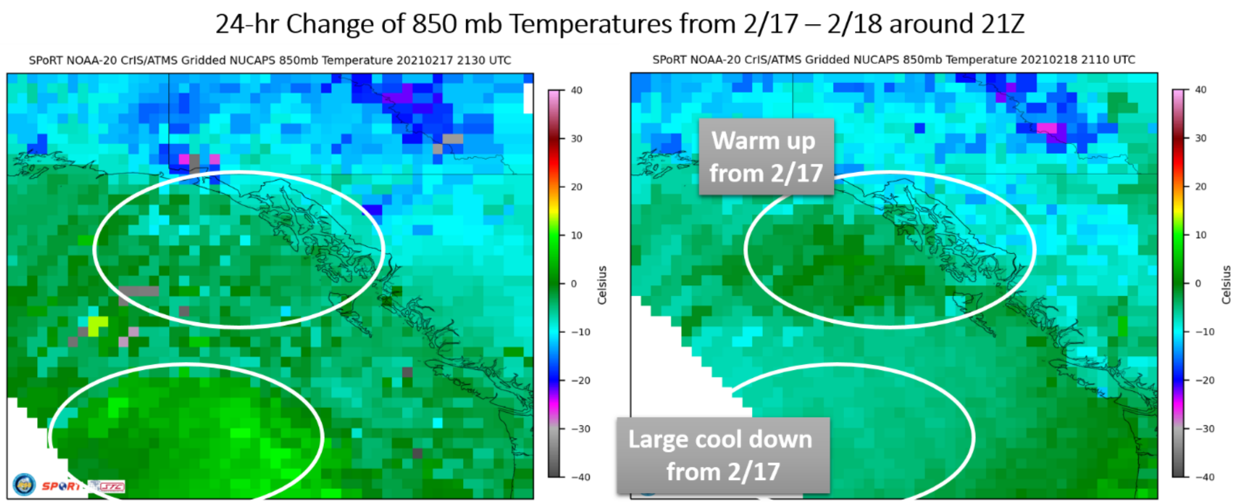

Figure 11 Gridded NUCAPS plots of Temperature at 850 mb for 17th (left) and 18th (right) February 2021 centered over Southeast AK. Ovals (white) note areas of change (see annotations) with a 24-hr change of warming in the upper oval and cooling in lower oval region.

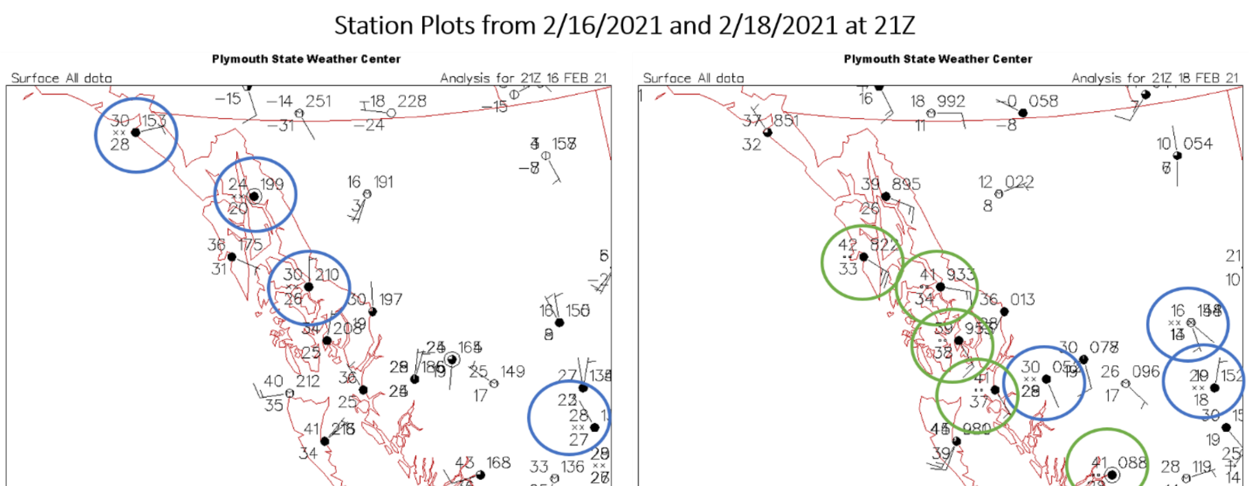

Figure 12 Station Plots of Southeast Alaska on 16th (left) and 18th (right) February 2021, via Plymouth State online archive. Station data in Fahrenheit. Annotation blue circles indicate where present weather is reported as snow while green circles represent rain reports.

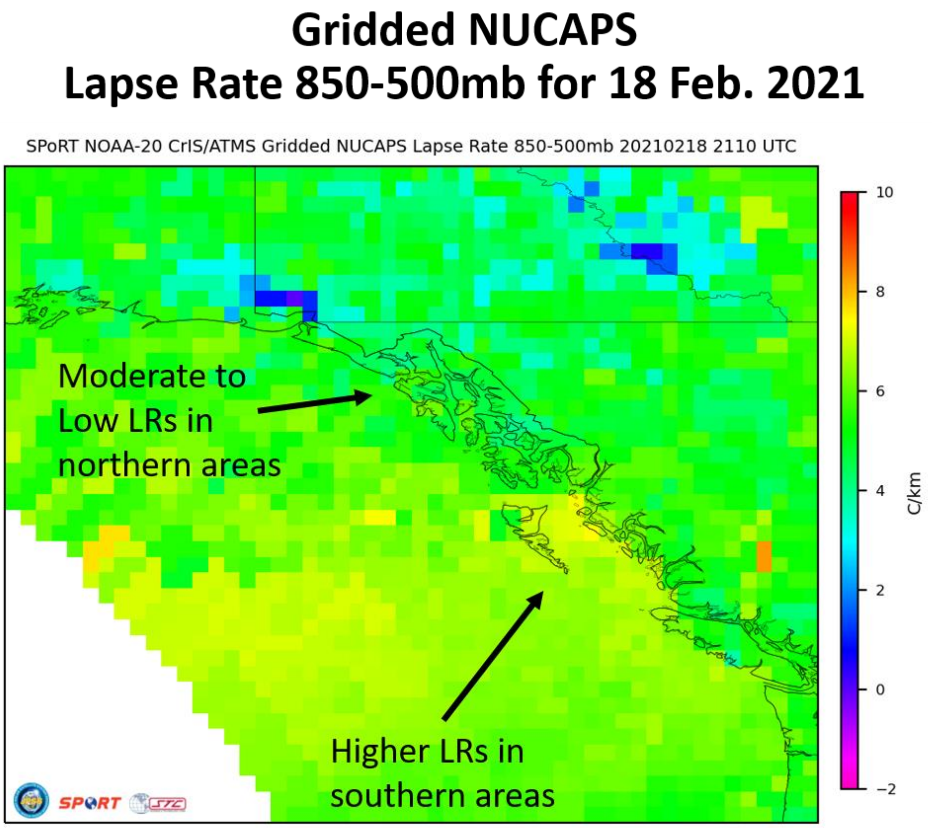

Figure 13 Gridded NUCAPS Lapse Rate at 850-500 mb over Southeast Alaska for 18 February 2021 via NOAA-20

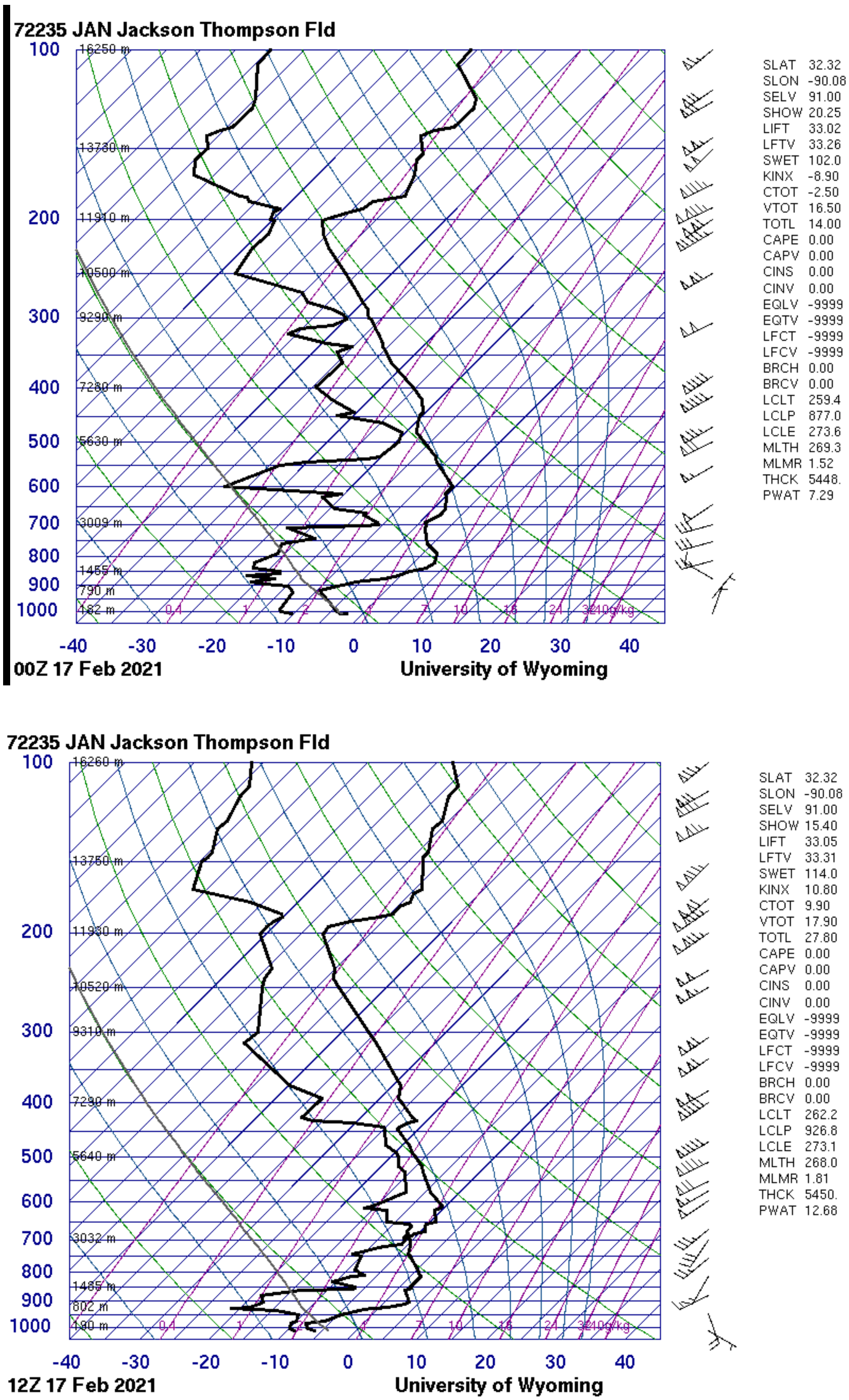

Figure 14 RAOB soundings at Jackson MS for 17 February 2021 at 00Z (top) and 12Z (bottom) obtained via Plymouth St. online archive.

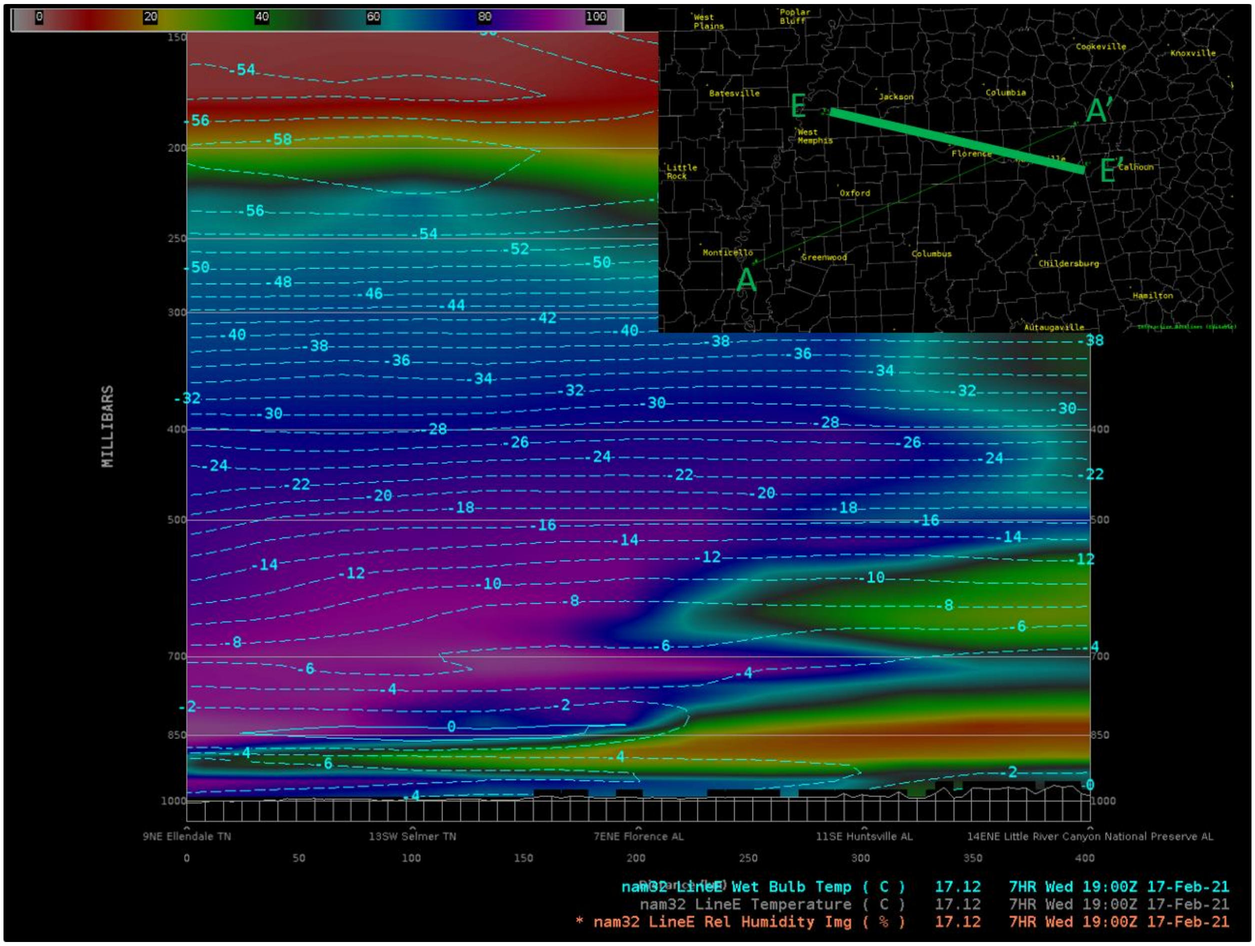

Figure 15 Cross section along line "E" of Relative Humidity (color scale) and Wet Bulb Temperature (cyan contours) from the NAM 32 km model forecast valid at 1900 UTC on 17 February 2021. Inset shows the position of line "E" (thick green line) with a left position in extreme southwest TN and a right position at the AL/GA border in the northern portions of the states.

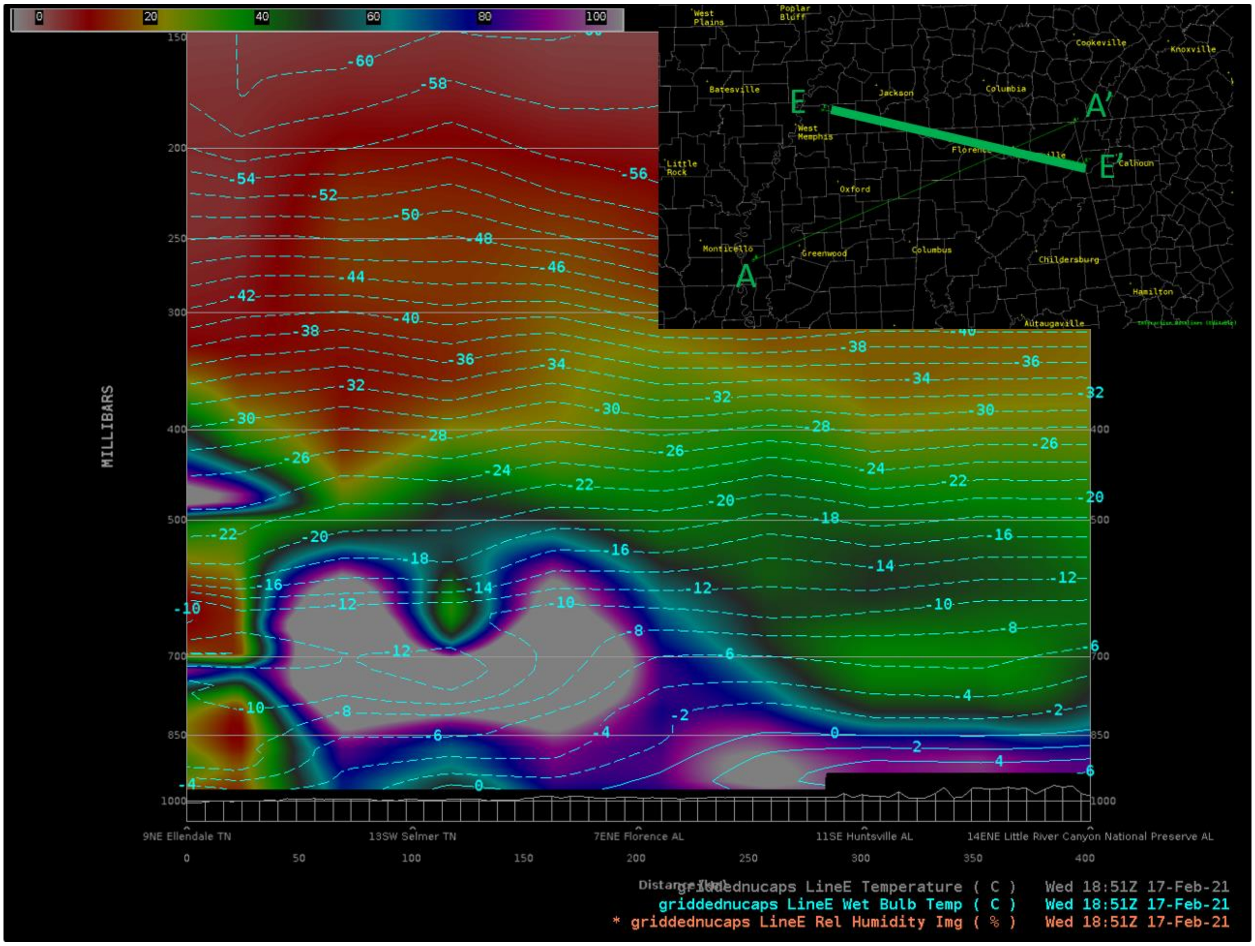

Figure 16 Same as Figure 15 except data from NUCAPS retrievals valid near the pass time of 1851 UTC on 17 February 2021.

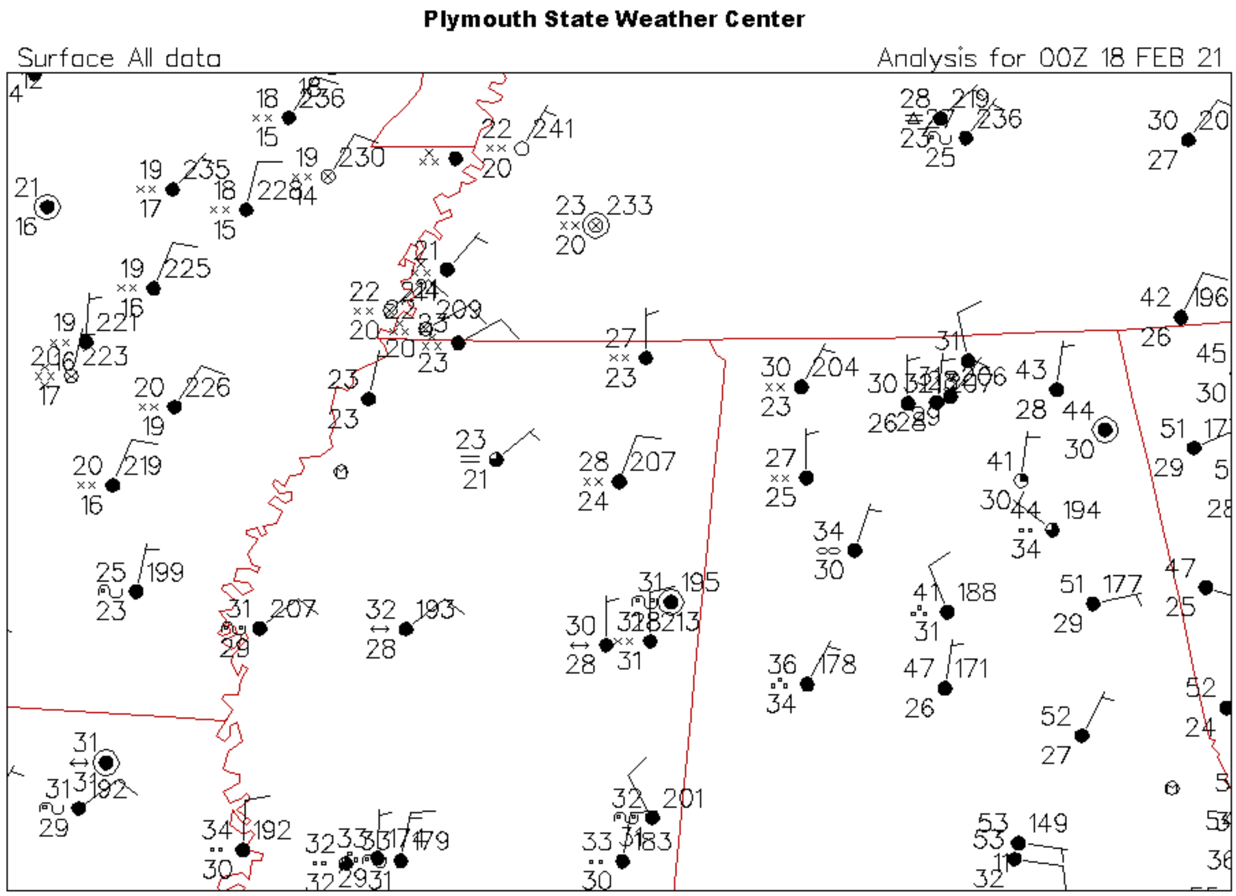

Figure 17 Station Plot (in Fahrenheit) at 0000 UTC on 18 February 2021 for the region centered on north MS and AL.