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A SOUNDING-BASED SEVERE WEATHER TOOL TO SUPPORT DAILY OPERATIONS AT KENNEDY SPACE CENTER AND CAPE CANAVERAL AIR FORCE STATION

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1. INTRODUCTION

The Applied Meteorology Unit (AMU) is a research to operations organization whose purpose is to improve weather support to America's space program at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Florida; Vandenberg Air Force Base, California; and Wallops Flight Facility, Virginia (Madura et al. 2011; Bauman et al. 2004). The AMU developed the original Severe Weather Forecast Decision Aid (Bauman et al. 2005) based on the 1000 UTC (0600 local time) CCAFS sounding (KXMR) as a first guess tool to help the forecasters determine the severe weather threat for the day at KSC, CCAFS and Patrick Air Force Base (PAFB), Florida. The original decision aid used a Hyper-Text Markup Language graphical user interface (GUI) and the period of record (POR) included the warm season months of May–September for the years 1989–2003. The decision aid was modified for use with a Meteorological Interactive Data Display System (MIDDS) GUI in 2009 (Wheeler 2009) and then data from the 2004–2009 warm seasons was added in 2010 (Wheeler 2010). In 2011, data from the 2010 warm season was added to the decision aid, verification statistics were calculated for the Total Threat Score (TTS) and logistic regression analysis was performed on the 22-year severe weather database (Watson 2011). The 2011 results indicated that the logistic regression equation did not show an increase in skill over the previously developed TTS. Therefore, the only change to the version of the decision aid developed in Wheeler (2010) was the inclusion of 2010 data in the database.

The new tool being reported in this article includes the warm season months in the 24 years 1989–2012 and was based on the 1500 UTC (1100 EDT) KXMR sounding instead of the 1000 UTC KXMR sounding and builds upon the previous work conducted in development of the 1000 UTC sounding-based tool. The 1500 UTC sounding was used to since it should provide better skill than the 1000 UTC sounding at the time 45th Weather Squadron (45 WS) usually decides to issue a severe weather watch for severe weather that could occur later that day. The benefits of the 1500 UTC sounding include showing how the boundary layer has modified in the three hours since sunrise, in addition to simply being closer in time to the potential severe weather. The AMU took advantage of using some of the existing climatological databases and methodologies described in the previously referenced reports to create this tool. Besides using the late morning soundings for this work, the AMU eliminated 83% of the subjective questions posed to the forecasters in the previous GUI, thereby streamlining the process of running the tool in MIDDS and creating a more objective assessment of the daily warm season severe weather threat. The AMU discovered the subjectivity in the previous GUI sometimes resulted in different severe weather threat assessments for the same day when used by different forecasters. Also, the AMU's statistical analysis determined that some of the parameters were not relevant when considering the severe weather threat. For example, on 95% of the days with reported severe weather, there was no severe weather reported on the previous day. Therefore the questions about persistence in the previous GUI were eliminated. This tool only indicates if the general conditions are conducive to severe weather. The actual location and timing of the severe weather will be strongly influenced by low-level boundary interactions such as sea breeze fronts from the Atlantic Ocean and/or Gulf of Mexico, Indian River and/or Banana River breeze fronts, thunderstorm outflows, and others. This tool, being primarily based on the KXMR sounding, does not take into account those crucial low-level boundary interactions.

2. DATA and METHODOLOGY

The AMU had compiled three existing data sets during previous work that were used in this task after they were updated with 2011 and 2012 data. They included upper-level (200 hPa) jet stream analyses, severe storm reports, and daily flow regimes. The two new data sets required for this task were the 1500 UTC XMR soundings and the stability parameters derived from those soundings.

2.1 Existing Data Sets

To update the existing data sets, the AMU generated and then downloaded the 200-mb wind and streamline maps (Figure 1) from the Plymouth State University (PSU) Weather Center (2013; vortex.plymouth.edu/u-make.html) for the 2011 and 2012 warm seasons. The maps were analyzed to determine the jet stream position and the results were entered into the existing 1989–2010 AMU jet stream analysis database.

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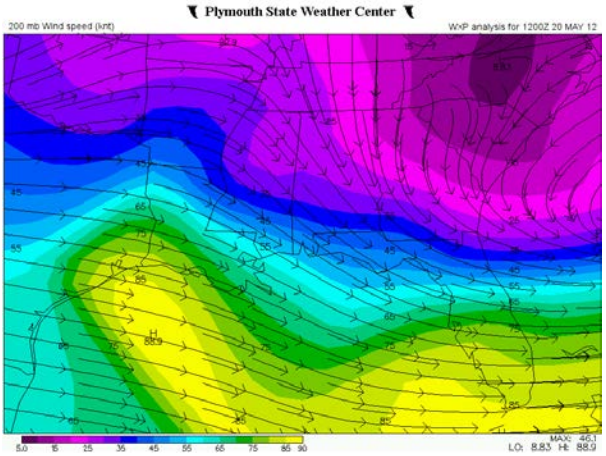


Figure 1. Example of a 200 hPa wind and streamline map generated from the PSU Weather Center used in this work to identify the jet stream position. Lines with arrows indicate the wind direction and the shaded regions show the wind speed in kt.

Next, the AMU downloaded the 2011 and 2012 warm season severe storm reports from the National Climatic Data Center Storm Events Database (NCDC 2013; ftp.ncdc.noaa.gov/pub/data/swdi) and then added the severe events for Brevard, Volusia, Indian River, Seminole, Osceola, and Orange counties in Florida (Figure 2) to the existing 1989–2010 AMU severe storm reports database. These are the counties that surround or are near Brevard County, which is where KSC/CCAFS/PAFB are located. Reports from the six counties were needed to make sure the database had enough events to derive meaningful statistical relationships since so few events occur in the immediate KSC/CCAFS/PAFB area. There are three coastal counties (Volusia, Brevard, Indian River) and three inland counties (Seminole, Orange, Osceola), all of which are typically in the same large-scale air mass as KSC/CCAFS/PAFB on most warm season days. Even though these severe reports may not have occurred at KSC/CCAFS/PAFB, they are still of interest since severe weather in relatively close proximity to the space center needs to be tracked for possible impacts to operations since the chance of severe weather is elevated at KSC/CCAFS/PAFB under those conditions. The main triggers of convection in the warm season are the location, movement, and strength of the local sea breeze front and collisions with other boundaries such as thunderstorm outflows. Severe weather events included tornadoes, waterspouts, convective surface winds ≥ 26 ms-1 (≥50 knots), and/or hail with a diameter ≥ 1.91 cm (≥ 0.75 inches) through 2009 and ≥ 2.54 cm (≥ 1.00 inch) after 2009. Finally, the AMU added the 2011 and 2012 daily lightning flow regimes (Lambert and Roeder 2008; Lericos et al. 2002) to the 1989–2010 AMU flow regime database. These flow regimes are based on the mean wind direction in the 1000–700 mb layer, which represents an optimum compromise between the lower altitude flow that governs the location and inland speed of the sea breeze front and the higher altitude that steers thunderstorms.

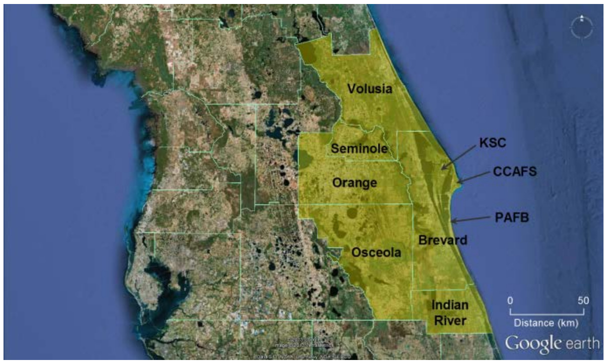


Figure 2. Map of central Florida showing the six counties (shaded in yellow) included in the severe weather events database. The location of KSC, CCAFS and PAFB are shown on the map; all three reside in Brevard County.

2.2 New Data Sets

The AMU received sounding observations in the form of ASCII text files from the contractor that operates the KXMR sounding site, Computer Sciences Raytheon. The AMU selected soundings with release times between 1430–1530 UTC and quality controlled each sounding. If more than one sounding on a single day was available between 1430–1530 UTC, the sounding closest in time to 1500 UTC or the one that was most complete was selected. Each sounding contained separate mandatory, significant, and 1,000-ft levels which the AMU merged together to create one complete file for each sounding.

Twenty four years of warm season soundings resulted in a total of 2,842 days with one sounding released between 1430–1530 UTC out of a possible 3,672. The AMU removed 14 soundings from the database on days when KSC/CCAFS/PAFB was under the influence of a tropical cyclone since these were not representative of the days where the convection is dominated by local effects desired for this tool. Another 30 soundings failed the QC checks due to missing data or physically impossible values and were excluded from the database. A total of 2,798 soundings were available for developing the severe weather tool. The following 24 severe weather indices and parameters were generated from the soundings:

- Lifted Index (LI)
- K-Index (KI)
- Thompson Index (TI)
- Showalter Stability Index (SSI)
- Total Totals (TT)
- Cross Totals (CT)
- Vertical Totals (VT)
- Severe Weather Threat Index (SWEAT)
- Convective Available Potential Energy (CAPE)

- CAPE based on the maximum equivalent potential temperature (CAPE Max θ_e)
- CAPE based on the forecast maximum temperature (CAPE FMaxT)
- Convective Inhibition (CIN)
- Precipitable Water (PW)
- Temperature at 850 hPa (T_{850})
- Temperature at 500 hPa (T_{500})
- Average relative humidity in the 1000–700 hPa layer (Avg70RH)
- Average relative humidity in the 850–500 hPa layer (Avg85RH)
- Average relative humidity in the 850–600 hPa layer (Avg86RH)
- Microburst Day Potential Index (MDPI) (Wheeler and Roeder 1996)
- Inversion height below 2400 m (~8 kft)
- Wind speed ≥ 13 ms^{-1} (~25 kt) and wind direction ≥ 109° and ≤ 270° at 850 hPa (850 Jet)
- Veering winds from surface to 3000 m (~10 kft) (WarmAdv)
- Helicity
- Storm Relative Motion Speed and Direction

3. ANALYSIS AND RESULTS

The analysis and results are described in three sections. The first section shows how the climatological stability indices and parameters were analyzed leading to the development of severe weather threat scores and a TTS for each day in the POR. The second section shows how the TTS values were assessed to develop a best-fit logistic regression curve based on the distribution of reported severe weather. The third and final section discusses the development of the GUI in the 45 WS MIDDS and transition of the GUI to operations.

3.1 Stability Thresholds and Threat Scores

After generating the stability indices and parameters, the AMU categorized days with reported severe weather and days without reported severe weather by threshold values for each index, and then developed charts showing the percent of time severe weather was reported based on specific thresholds. The thresholds were the same as those used in the Severe Weather Decision Aid (Bauman et al. 2005). An example using TT is shown in Figure 3. When the TT was in the low category (TT ≤ 45), severe weather was reported 11% of the time. When TT was in the medium category (46 ≤ TT ≤ 48), severe weather was reported 25% of the time. When TT was in the high category (TT > 48), severe weather was reported 45% of the time.

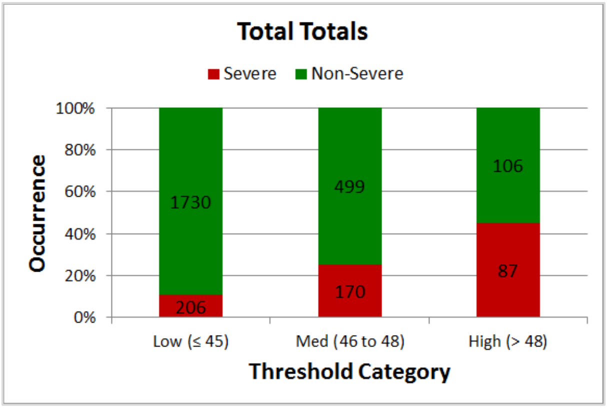


Figure 3. Stacked bar chart of TT for the low, medium and high threshold categories showing percent occurrence of the number of days with reported severe weather (red) and days with no reported severe weather (green).

The AMU used the categorized thresholds from each index to determine if they would be useful predictors of severe weather occurrence. They created a threat score for each index derived from the percent of time severe weather occurred in each threshold category. To scale the threat score between 0 and 10, they divided the percent value by 10. Based on this methodology, the TT threat scores for the Low, Medium, and High threshold categories were 1.1, 2.5, and 4.5. The AMU used these scaled threat score values as the basis to compute the TTS from multiple indices and parameters.

Figure 4 compares the threat score for each stability index in each category. Lines with steeper slopes show a correlation to reported severe weather by having low threat scores in the Low category increasing to higher threat scores in the High or Very High categories. Based on the slope of each line in Figure 4, the best stability index indicators of severe weather occurrence were SSI, TT, SWEAT, LI, and VT as they had the largest increase in severe weather threat score from lowest to highest threshold category. The CT, TI, and KI slopes were not as steep, representing a smaller threat score change across the threshold categories.

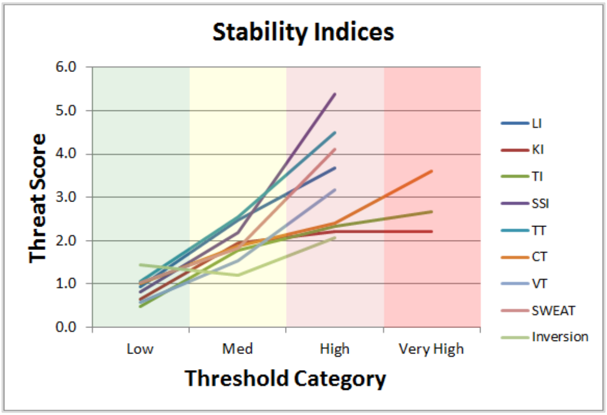


Figure 4. Line chart of stability indices showing the threat score for each index in each threshold category.

Therefore, they were not as good as the other indices in their forecastability of severe weather between categories. Similarly, the thresholds of energy indices derived from the soundings are shown in Figure 5. The CIN, CAPE Max θ_e, and CAPE FMaxT were the best energy index indicators with slopes similar to the CT, TI, and KI stability indices. Helicity, not shown in the charts, was not incorporated into the tool because its threat score decreased across the low, medium, and high categories.

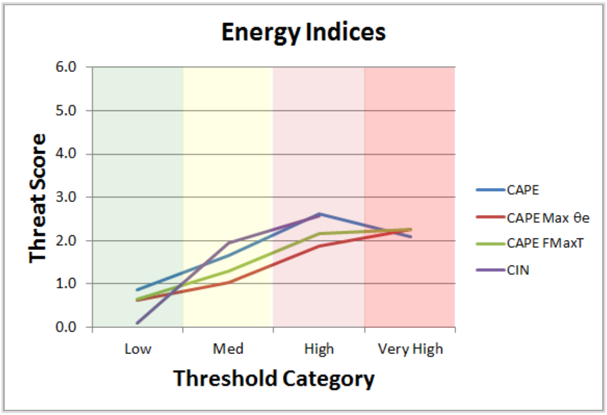


Figure 5. Line chart of energy indices showing the threat score for each index in each threshold category.

The AMU also considered moisture parameters derived from the soundings as severe weather indicators and the resulting chart is shown in Figure 6. The values of the Avg85RH and Avg86RH increase from the Low to Med threshold categories but then decrease at the High threshold category indicating they are poor predictors and were not used in the tool. The Avg70RH and PW both increased across the threshold categories and were used as predictors.

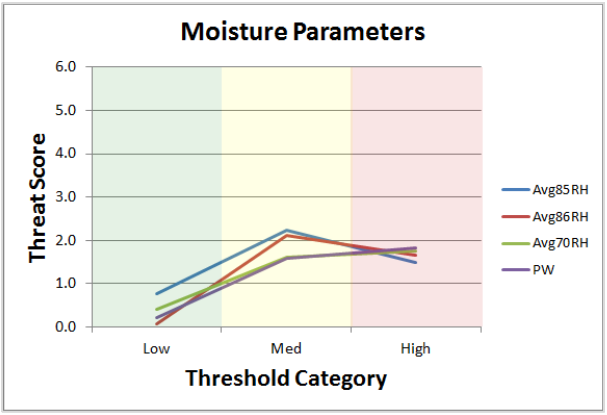


Figure 6. Line chart of moisture parameters showing the threat score for each parameter in each threshold category.

The other parameters considered as possible indicators of severe weather are shown in Figure 7. They include T850, MDPI, 850 Jet, WarmAdv, and T500. Of these parameters, only the 850 Jet showed a significant enough correlation to reported severe weather that it was incorporated into the tool.

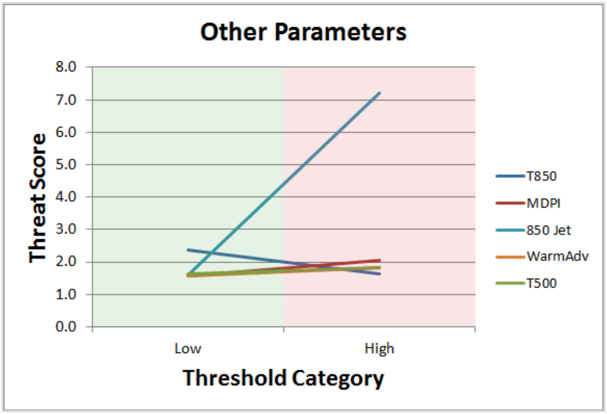


Figure 7. Line chart of other parameters showing the threat score for each parameter in two threshold categories. These parameters are binary, so only two categories are possible, unlike the 3-4 categories used for the other parameters, which are continuous.

Other parameters known to contribute to severe weather potential include the peninsular flow regime (Lericos et al. 2002) and the 200 mb jet position (Uccellini and Johnson 1979). Previous research indicated the flow regime had some influence on the frequency and intensity of convective winds (Ander et al. 2009). The threat scores for each of the flow regimes are shown in Figure 8. The two westerly regimes, northwest (NW) and southwest (SW), result in the highest threat scores because those regimes favor thunderstorm frequency in east Florida. In addition, these thunderstorms tend to be more intense since they have gained strength from ground heating throughout the day and from boundary interactions as they approach the sea breeze front from the Atlantic Ocean and other boundaries as they approach the eastern half of the Florida peninsula.

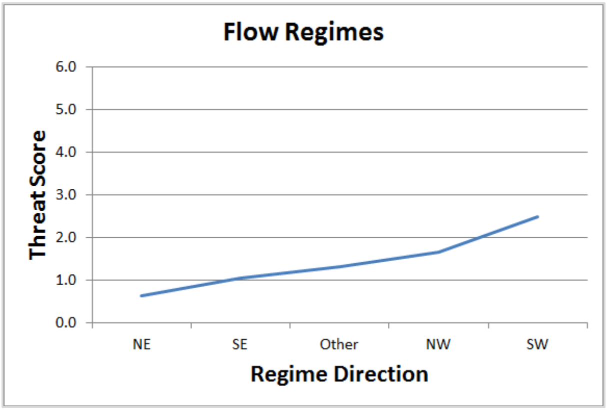


Figure 8. Line chart of flow regimes and corresponding threat scores.

The highest threat scores based on the 200 mb flow and jet position (Figure 9) relative to east-central Florida occur under the influence of left exit and right entrance regions (Uccellini and Johnson 1979), and in other regions of upper level divergence.

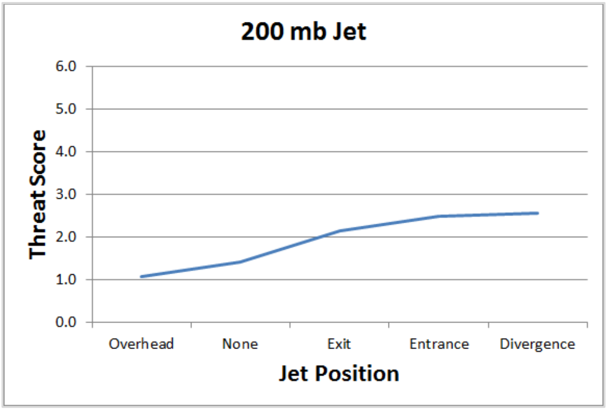
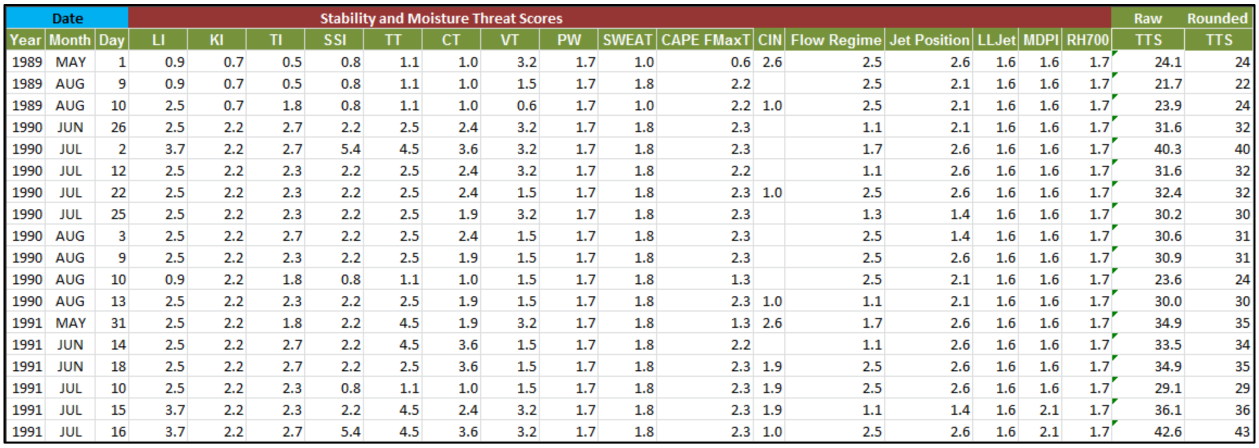


Figure 9. Line chart of 200 mb jet and corresponding threat scores.

The AMU compiled the results of all parameter's threat scores for each sounding, flow regime, and 200 mb jet position for the 24-year database in two Excel spreadsheets. One spreadsheet compiled the threat scores for each day with reported severe weather and the other for days with no reported severe weather. Figure 10 shows a sample of the spreadsheet with threat scores for days with reported severe weather. The daily TTS was determined by summing the individual threat scores from each parameter in each row. On days with reported severe weather, the TTS ranged from 15 to 50 with a median of 30. On days with no reported severe weather, the TTS ranged from 12 to 41 with a median of 22.



Date			Stability and Moisture Threat Scores																	Raw	Rounded
Year	Month	Day	LI	KI	TI	SSI	TT	CT	VT	PW	SWEAT	CAPE FMaxT	CIN	Flow Regime	Jet Position	LLJet	MDPI	RH700	TTS	TTS
1989	MAY	1	0.9	0.7	0.5	0.8	1.1	1.0	3.2	1.7	1.0	0.6	2.6	2.5	2.6	1.6	1.6	1.7	24.1	24
1989	AUG	9	0.9	0.7	0.5	0.8	1.1	1.0	1.5	1.7	1.8	2.2		2.5	2.1	1.6	1.6	1.7	21.7	22
1989	AUG	10	2.5	0.7	1.8	0.8	1.1	1.0	0.6	1.7	1.0	2.2	1.0	2.5	2.1	1.6	1.6	1.7	23.9	24
1990	JUN	26	2.5	2.2	2.7	2.2	2.5	2.4	3.2	1.7	1.8	2.3		1.1	2.1	1.6	1.6	1.7	31.6	32
1990	JUL	2	3.7	2.2	2.7	5.4	4.5	3.6	3.2	1.7	1.8	2.3		1.7	2.6	1.6	1.6	1.7	40.3	40
1990	JUL	12	2.5	2.2	2.3	2.2	2.5	2.4	3.2	1.7	1.8	2.2		1.1	2.6	1.6	1.6	1.7	31.6	32
1990	JUL	22	2.5	2.2	2.3	2.2	2.5	2.4	1.5	1.7	1.8	2.3	1.0	2.5	2.6	1.6	1.6	1.7	32.4	32
1990	JUL	25	2.5	2.2	2.3	2.2	2.5	1.9	3.2	1.7	1.8	2.3		1.3	1.4	1.6	1.6	1.7	30.2	30
1990	AUG	3	2.5	2.2	2.7	2.2	2.5	2.4	1.5	1.7	1.8	2.3		2.5	1.4	1.6	1.6	1.7	30.6	31
1990	AUG	9	2.5	2.2	2.3	2.2	2.5	1.9	1.5	1.7	1.8	2.3		2.5	2.6	1.6	1.6	1.7	30.9	31
1990	AUG	10	0.9	2.2	1.8	0.8	1.1	1.0	1.5	1.7	1.8	1.3		2.5	2.1	1.6	1.6	1.7	23.6	24
1990	AUG	13	2.5	2.2	2.3	2.2	2.5	1.9	1.5	1.7	1.8	2.3	1.0	1.1	2.1	1.6	1.6	1.7	30.0	30
1991	MAY	31	2.5	2.2	1.8	2.2	4.5	1.9	3.2	1.7	1.8	1.3	2.6	1.7	2.6	1.6	1.6	1.7	34.9	35
1991	JUN	14	2.5	2.2	2.7	2.2	4.5	3.6	1.5	1.7	1.8	2.2		1.1	2.6	1.6	1.6	1.7	33.5	34
1991	JUN	18	2.5	2.2	2.7	2.2	2.5	3.6	1.5	1.7	1.8	2.3	1.9	2.5	2.6	1.6	1.6	1.7	34.9	35
1991	JUL	10	2.5	2.2	2.3	0.8	1.1	1.0	1.5	1.7	1.8	2.3	1.9	2.5	2.6	1.6	1.6	1.7	29.1	29
1991	JUL	15	3.7	2.2	2.3	2.2	4.5	2.4	3.2	1.7	1.8	2.3	1.9	1.1	1.4	1.6	2.1	1.7	36.1	36
1991	JUL	16	3.7	2.2	2.7	5.4	4.5	3.6	3.2	1.7	1.8	2.3	1.0	2.5	2.6	1.6	2.1	1.7	42.6	43

Figure 10. A portion of the Excel spreadsheet used to calculate the TTS for each day based on the sounding parameters, flow regime and 200 mb jet position.

Initially, similar to the previous AMU Severe Tool, the AMU categorized the TTS as shown in Table 1. The top row of bold-face numbers shows the TTS categories for days with reported severe weather. The second row shows the number of days in each TTS category. The third row shows the frequency of occurrence of days in each TTS category. The bottom row shows the frequency of occurrence of days with reported severe weather in each TTS category.

Table 1. Number of days with reported severe weather in each of seven TTS categories, the frequency of the number of days with reported severe weather in each TTS category and the frequency of the occurrence of reported severe weather in each TTS category.

	TTS Categories							
	≤ 14	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**≥ 40**	**Total**
Number of severe days	0	9	60	159	173	51	11	463
Frequency of severe days	0%	2%	13%	34%	37%	11%	2%	100%
Severe report occurrence	0%	1%	6%	21%	57%	72%	92%	

The TTS distribution for days with reported severe weather and for days with no reported severe weather should demonstrate the ability of the TTS to indicate the severe weather potential. Figure 11 shows the distributions of days with and without reported severe weather. While there is some overlap, the maxima of the distributions are distinct, indicating the TTS distribution provides insight into the severe weather potential. On days when severe weather was reported, the TTS was ≥ 30 during 50% of those days. On days with no reported severe weather the TTS was ≥ 30 during 6% of those days. Conversely, when the TTS was ≤ 24, 69% of the days had no reported severe weather while 15% of days had reported severe weather.

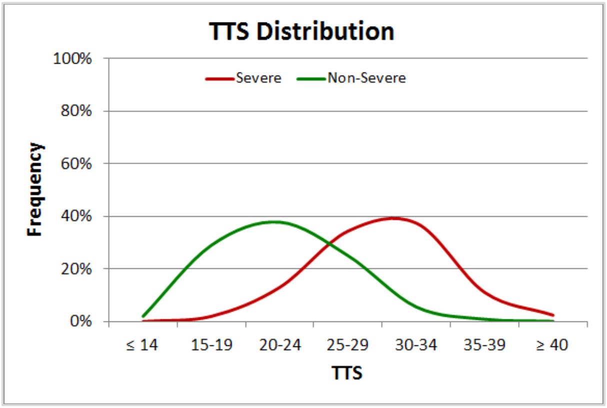


Figure 11. The TTS distribution on days with reported severe weather (red line) and days with no reported severe weather (green line) for the 1500 UTC based sounding at CCAFS.

Another consideration for forecasters would be the occurrence of reported severe weather based on TTS category. For example, as Figure 12 illustrates, when the TTS was ≥ 40, severe weather was reported 92% of the time. While that is significant, looking at Table 2, only 2% of days with reported severe weather were in this TTS range. So, while this TTS category does not occur often, when it does occur, severe weather is very likely. This is as expected since severe weather is rare, a good predictor indicating severe weather should likewise occur infrequently.

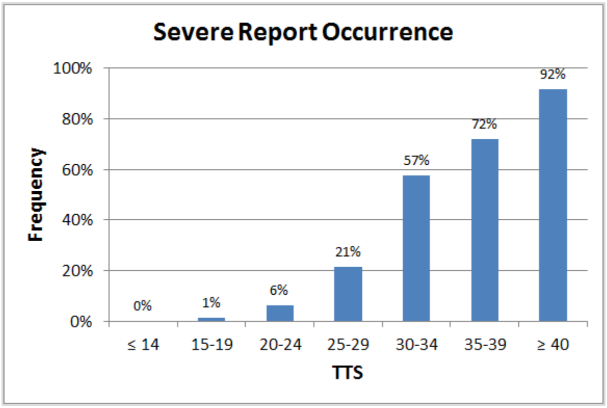


Figure 12. The distribution of reported severe weather frequency based on seven TTS categories.

After discussing the TTS categories with the 45 WS forecasters, the AMU decided the seven numerical categories may be too broad to provide quality guidance to the forecasters and considered using single TTS values instead of categories to provide higher fidelity output of the frequency of occurrence of reported severe weather. Figure 13 shows a line chart of each TTS value. The sudden drop of probability for TTS 44–49 are likely due to very small sample size and large rural area where severe weather would not be reported if it occurred. While this methodology provides higher fidelity, it also has more noise than the categorical data—especially at higher TTS values with a smaller sample size.

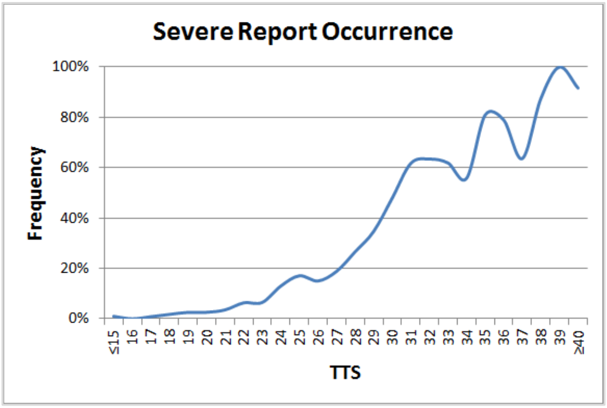


Figure 13. The distribution of reported severe weather frequency based on individual TTS values.

3.2 Best-fit Logistic Regression Curve

To help minimize the noisy data and create a more useful tool for the forecasters, the AMU fit several types of curves to the data including logarithmic and polynomial. A second order polynomial is shown in Figure 14. However, the polynomial curve reached a maximum of 59% at a TTS of 37 and fell below 0% at a TTS of 18. Further examination of the distribution in Figure 12 and Figure 13 suggest a logistic curve response. Being a continuous function, the best-fit logistic curve also avoids the possible problems of categories: overly large bins to get sufficient sample size per bin or noisy inconsistent results from insufficient sample size per bin. Other possible problems from a categorical approach include inconsistent behavior of adjacent categories such as a decreasing/increasing likelihood of severe weather with increasing/decreasing TTS, or a slight/large change in TTS resulting in a large/small change in likelihood of severe weather by crossing into a new category/staying within a category. Finally, the best-fit logistic curve provides extrapolation of the probability of severe weather that is consistent with the other data to slightly higher or slightly lower TTS not observed during the development POR.

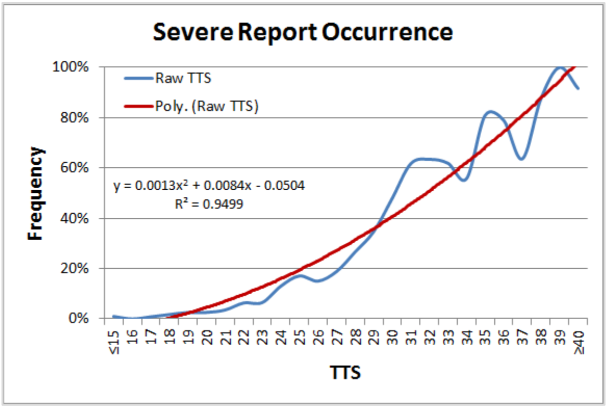


Figure 14. As in Figure 13 with a second order polynomial curve (red line) fit to the TTS values (blue line).

The 45 WS offered to assist the AMU by developing a best-fit logistic curve since the logistic curve is constrained to be within 0% to 100% and is often used in probabilistic regression. Fitting a logistic curve cannot be solved analytically and must be done iteratively, in this case manually due to lack of statistical software. Each of the three coefficients was step-wise iterated until the RMSE of the differences between the logistic curve and the observed values was minimized. The iteration was cycled until the coefficients changed by less than 0.0005 (optimized to three decimal places). The 45 WS also tested other best-fit curves (quadratic, exponential, and power law) for completeness in case they performed better. These three curves exceeded 100% at the higher TTS values, similar to the second order polynomial curve. The best-fit logistic regression curve is specified by equation (1) and is shown in Figure 15.

$$y = 100 * \left(\frac{1}{1 + exp\left(-(0.764 + 0.270 * (x - 34.013)) \right)} \right) \quad (1)$$

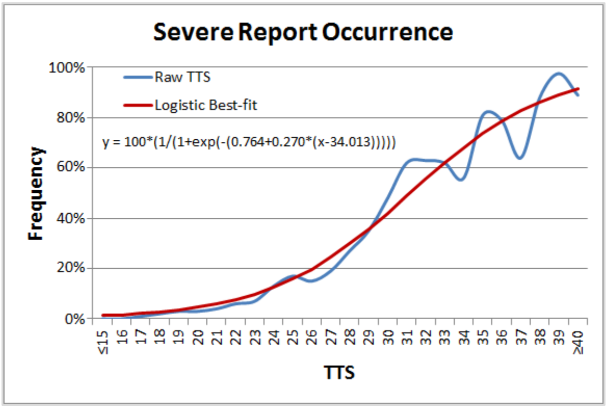


Figure 15. As in Figure 13 with a best-fit logistic regression curve (red line) fit to the TTS values (blue line). A correlation coefficient (R2) is not available because best-fit logistic curves must be done iteratively and manually. Bin-to-bin variations are smoothed over and gaps with anomalous results (TTS 44-49) are bridged.

The logistic curve is a better fit to the data than the other methods and offers the additional desired behavior of not being able to exceed 100% at large TTS values or falling below 0% at low TTS values. The mean difference between the actual data and the logistic curve is -0.66 indicating the logistic curve has a slight tendency to over forecast, which is acceptable since this provides increased safety. The best-fit logistic curve offers an improvement of just over 19% over the original categorical approach and that improvement is a higher probability of severe weather, which is conservatively safer. In addition, the logistic curve bridges gaps of TTS in the POR used in developing this tool and extends the technique to higher and lower values of TTS not covered by the categorical approach, covering 52% more TTS than the categorical approach.

Table 2 shows the final TTS values and corresponding occurrences of reported severe weather based on the logistic regression curve shown in Figure 15 that were implemented in the MIDDS GUI.

3.3 Development for MIDDS

The AMU developed the 1500 UTC Severe Weather Tool in MIDDS using the Tool Command Language and its associated Tool Kit (Tcl/Tk). The user starts the tool from the main weather menu on MIDDS. The program executes the Tcl/Tk code to compute and retrieve sounding parameters and then presents the user with the GUI for manual input. Then the code computes a threat score for each parameter and the TTS for the sounding. The tool displays the output in two graphic windows for the user to view and saves two files in MIDDS for archive.

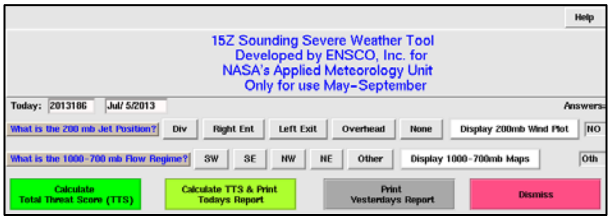
3.3.1 The GUI

When the user executes the program in MIDDS, a message window is displayed notifying the user that the program is acquiring the sounding data and calculating the parameters. Once the sounding parameters are ready, the GUI is displayed for the user to enter information about the 200 mb jet position and flow regime as shown in Figure 16. There is a Help button in the upper right of the GUI window that describes how to use the GUI and a description of the tool itself. The date is displayed in two formats just above the questions on the left: year and Julian day, and calendar day in month/day/year. The two gray buttons below the dates associated with each of the two questions provide a definition of each parameter via a pop-up window when the mouse is positioned over them. The user can also click one of the two white buttons at the right end of the row associated with each question to display maps in the MIDDS graphics window of the phenomena being assessed in order to answer the questions. Once the user clicks one of the gray buttons, the choice is displayed in the box at the far right of the window. After both choices are made, the user clicks the green box in

Table 2. The final TTS values (green shading) and corresponding occurrences of reported severe weather (red shading) based on the logistic regression curve fit.

TTS	**≤14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Severe Freq (%)	1	1	2	2	3	4	5	6	8	10	13	16	20	24	30	36	42	49
TTS	**32**	**33**	**34**	**35**	**36**	**37**	**28**	**39**	**40**	**41**	**42**	**44**	**45**	**46**	**47**	**48**	**29**	**≥50**
Severe Freq (%)	56	62	68	74	79	83	86	89	92	93	95	97	98	98	99	99	99	99

in the lower left to calculate the TTS. The GUI then closes and two other windows open with the results.


15Z Sounding Severe Weather Tool
Developed by ENSCO, Inc. for
NASA's Applied Meteorology Unit
Only for use May–September

Today: 2013186 Jul/ 5/2013

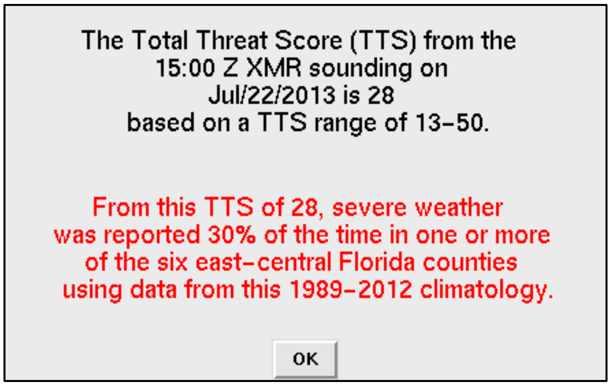
What is the 200 mb Jet Position?

What is the 1000-700 mb Flow Regime?

Figure 16. The 1500 UTC sounding-based Severe Weather Tool GUI.

3.3.2 Output Windows

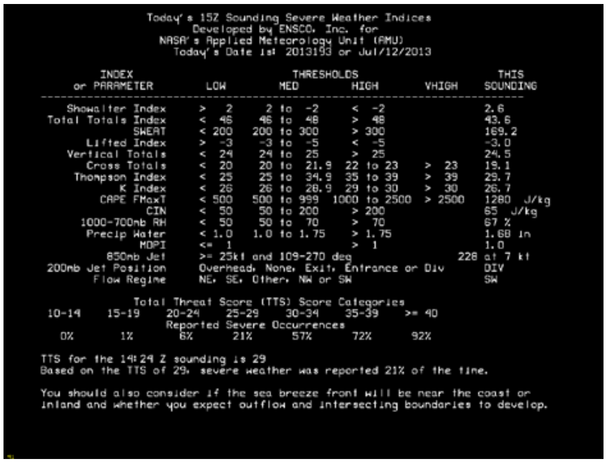
The TTS, reported severe weather occurrence and associated information are shown in two windows in MIDDS. The first, shown in Figure 17, provides the user with a summary of the output from the tool. The first group of text (black font) displays the current sounding's time and date, the TTS, and the data set's range of the TTS values. The second group of text (red font) restates the TTS from the current sounding, displays the frequency of occurrence of reported severe weather based on the TTS and reminds the user that the data set is based on reported severe weather in six east-central Florida counties and the period of record was 1989–2012. The summary window was designed to give the user a quick look at the information output by the tool.


The Total Threat Score (TTS) from the
15:00 Z XMR sounding on
Jul/22/2013 is 28
based on a TTS range of 13-50.

From this TTS of 28, severe weather
was reported 30% of the time in one or more
of the six east-central Florida counties
using data from this 1989-2012 climatology.

Figure 17. TTS summary window displayed in MIDDS provides a quick overview of the tool's output to the user.

The second window displayed, Fig. 18, shows all of the sounding parameters and their values used to derive the TTS. The heading shows the month, day, and year plus Julian date of the sounding. Below the heading is a table showing the index or parameter in the first (left) column. The next four columns show the low, medium, high, and very high severe thresholds for each index or parameter to serve as a reference for the user. The last (right) column shows the value of the index or parameter from the sounding being evaluated. The next section of text below the table displays the time of the sounding, the TTS, and the reported occurrence of severe weather based on the TTS. Finally, the paragraph at the bottom of the window serves as a brief reminder to the forecaster that this tool should be used as a guide when determining the severe weather potential at KSC/CCAFS/PAFB for the day since the TTS value is based on a climatological study of severe weather occurrence in six east-central Florida counties. The forecaster must also consider the development and position of the sea breeze front and any outflow boundaries that could serve as triggers for convection and possibly lead to severe weather.


```
                     Today's 15Z Sounding Severe Weather Indices
                          Developed by ENSCO, Inc. for
                      NASA's Applied Meteorology Unit (AMU)
                        Today's Date is: 2013193 or Jul/12/2013

          INDEX                        THRESHOLDS                         THIS
       or PARAMETER        LOW        MED          HIGH        VHIGH     SOUNDING
   ----------------------------------------------------------------------------
     Showalter Index      >   2      2 to  -2     <  -2                  2.6
   Total Totals Index     <  46     46 to  48     >  48                  43.6
                SWEAT     < 200    200 to 300     > 300                  169.2
         Lifted Index     >  -3     -3 to  -5     <  -5                  -3.0
      Vertical Totals     <  24     24 to  25     >  25                  24.5
         Cross Totals     <  20     20 to  21.9   22 to 23    >  23      19.1
      Thompson Index      <  25     25 to  34.9   35 to 39    >  39      29.7
              K Index     <  26     26 to  28.9   29 to 30    >  30      26.7
           CAPE FMaxT     < 500    500 to 999   1000 to 2500  > 2500     1280  J/kg
                  CIN     <  50     50 to 200     > 200                  65  J/kg
        1000-700mb RH     <  50     50 to  70     >  70                  67 %
         Precip Water     < 1.0    1.0 to 1.75    > 1.75                 1.68 in
                 MDPI     <=  1                   >  1                   1.0
           850mb Jet      >= 25kt and 109-270 deg                    228 at 7 kt
   200mb Jet Position     Overhead, None, Exit, Entrance or Div          DIV
          Flow Regime     NE, SE, Other, NW or SW                        SW

                   Total Threat Score (TTS) Score Categories
   10-14     15-19     20-24     25-29     30-34     35-39     >= 40
                       Reported Severe Occurrences
     0%        1%        6%       21%       57%       72%       92%

   TTS for the 14:24 Z sounding is 29
   Based on the TTS of 29, severe weather was reported 21% of the time.

   You should also consider if the sea breeze front will be near the coast or
   inland and whether you expect outflow and intersecting boundaries to develop.
```

Figure 18. Detailed TTS window displayed in MIDDS provides the user with index and parameter severe thresholds and the specific values derived from the current sounding used to generate the TTS.

In addition to the two output windows, the AMU code saves two files to MIDDS for archive purposes. One is a comma separated value (CSV) formatted file that displays the Julian date, time, month, day, and year of the sounding plus the indices and parameters with their associated values from the sounding. The second file is saved in MIDDS as a text file that replicates the detailed TTS output window in Figure 18 and can be displayed in any text viewer software.

3.3.3 Testing and Training

The AMU tested the tool by running it each day a sounding was available to ensure MIDDS was calculating the correct values. Each parameter's threat score and resulting TTS was manually calculated to make sure they were identical to the corresponding threat scores calculated by the code in MIDDS for each sounding. To automate this process, the AMU wrote code in Microsoft Excel VBA that imported the MIDDS CSV files and calculated each parameter's threat score and the TTS to compare to the manually calculated values. The code was tested on 14 soundings to make sure it worked before discontinuing manual calculation of the threat scores and TTS. The AMU tested 40 soundings by comparing values from the MIDDS CSV files to the Excel-calculated values and ensuring consistent values before installing the software on the operational MIDDS.

In order to allow the forecasters to start using the tool during the current warm season, the AMU provided training to the 45 WS during two of their daily weather discussions in mid-July 2013. Presenting the training on two different days ensured all shift workers were present for the training. The AMU presented a very short overview of the work and then demonstrated how to use the tool in MIDDS. The tool has been used in daily operations since mid-July 2013.

4. POSSIBLE IMPROVEMENTS

There are several opportunities to improve this tool. Updating the tool to incorporate additional warm seasons would be useful since only 24 years of observations were available in developing this tool. This is especially important for severe weather which has an inherently low frequency of occurrence. Other statistical techniques may allow better selection of the predictor variables and better selection of their thresholds. Accounting for lack of independence between predictands is especially important. Possible statistical techniques include discriminant analysis and/or canonical variance. Alternative methods to predict the likelihood of severe weather should also be considered. Although logistic regression was not useful when developing the severe weather tool based on the 1000 UTC sounding (Watson 2011), it should be reconsidered since 83% of the subjective predictands have been eliminated. Those subjective predictands may have introduced too much noise and precluded the logistic regression from working as well as it might. In addition, other approaches such as Categorization And Regression Trees may be applicable. Finally, the gain in skill in predicting severe weather from the 1000 UTC sounding to the 1500 UTC sounding and identifying the days when the 1500 UTC sounding will or will not be useful in improving the severe weather forecast could provide a cost-savings by not releasing the 1500 UTC sounding when not needed.

5. CONCLUSIONS

Because people and property at KSC and CCAFS are at risk when severe weather occurs, the 45 WS tasked the AMU to develop a warm season severe weather tool for use in MIDDS based on the late morning, 1500 UTC, XMR sounding. The 45 WS daily and weekly severe weather forecasts are used by managers to determine if they need to limit an activity such as working on gantries, or protect property such as a vehicle on a pad. The 45 WS requested this severe weather tool be based on the 1500 UTC sounding since they frequently make decisions to issue a severe weather watch and other severe weather warning support products in the late morning because this sounding is more representative of the atmospheric instability than the early morning sounding.

The AMU built upon work in their previous tasks developing severe weather decision aids by using three existing data sets that were compiled during those tasks and updating them with 2011 and 2012 data. Those data sets included upper-level (200 mb) jet stream analyses, severe storm reports and daily lightning flow regimes. The AMU developed two new data sets for this task that included the 1500 UTC XMR soundings and the stability parameters derived from those soundings. The POR included the warm season months in the 24 years from 1989–2012.

The AMU determined a threat score based on individual sounding stability indices and parameter thresholds and, from those, calculated a TTS for every 1500 UTC sounding in the 24-year database and compared the TTS to reported severe weather occurrences on each day with a sounding. They determined a frequency of reported severe weather for each TTS, the 45 WS developed a best-fit logistic regression curve and then the AMU incorporated the values in a GUI for an operational tool.

The tool automatically retrieves and calculates the required indices and parameters from the sounding and then presents the user with a GUI to choose the 200 mb jet position and 1000–700 mb flow regime. This GUI eliminated 83% of the subjective questions posed to the forecasters in the previous GUI, thereby streamlining the process of running the tool and creating a more objective assessment of the daily warm season severe weather threat. The AMU delivered the severe weather tool to the 45 WS and it is being used to support daily and launch operations.

The final report for this work is available on the AMU website at http://science.ksc.nasa.gov/amu.

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