4B.3 **The Sounding Analog Retrieval System (SARS)**

Ryan Jewell[1]
Storm Prediction Center, Norman, OK

1. INTRODUCTION

The Sounding Analog Retrieval System (SARS) is a forecasting algorithm that uses sounding derived parameters to find historical severe weather events using a database of proximity soundings associated with a particular type of severe weather. From these matches, SARS arrives at probabilistic forecasts of the severe phenomenon. SARS finds analog matches based on a short list of thermodynamic and kinematic parameters using specific parameter ranges that are determined from a calibration process.

For severe hail, SARS has been designed to forecast the probability of significant hail (diameter ≥ 2.00", SIG) along with the most likely maximum hail size, ranging from 0.75" to ≥ 4.00". These size forecasts are conditional on the occurrence of hail ≥ 0.75". Although most of the work on SARS has been in association with severe hail, this method can be modified to predict other types of severe weather phenomenon as long as a sufficiently large proximity sounding database exists. For example, a supercell tornado version of SARS is currently being developed.

First, the historical sounding database that was used in the development of SARS is described. Next are sections explaining how the analog sounding matching parameters were chosen, along with the calibration process which determines the search ranges for each parameter. Finally, the relationship between the SARS forecast and the observed maximum hail size is discussed and skill scores are presented.

2. PROXIMITY SOUNDING DATABASE

The severe hail proximity sounding database consists of 1148 soundings, spanning 18 years from 1989-2006. It should be noted that sizes as small as 0.75" are included since that was the threshold for severe hail nationwide until it was increased to 1.0" in 2010. While most of the soundings are concentrated in the plains states, consistent with severe hail climatology (Doswell et al. 2005), all areas of the contiguous U.S. (CONUS) are represented (Fig. 1).

In order for a proximity sounding to be accepted into the database, it had to be launched within 100 nm of the severe hail report, and the report must have occurred between 2100-0200 UTC, similar to the time and space criteria used by Craven and Brooks (2004). The sounding must have been launched in the inflow air mass feeding the storm, and convectively contaminated soundings were discarded. Further, archived surface observations were used to determine if the most representative surface temperature and dewpoint were captured by the sounding. If not, those two variables were modified. Modification of surface parcel properties was deemed necessary because hail formation is very sensitive to liquid water content, among other parameters (Knight and Knight 2002). Aside from surface conditions, no other aspects of the soundings were modified. As a result, mixed layer parameters such as MLCAPE could not be used. Instead, MUCAPE was used as a measure of instability (Craven et al. 2002, Doswell and Markowski 2004). More information on the proximity criteria as well as quality control methods for this database can be found in Jewell and Brimelow (2009). Indeed, the SARS database is simply an expanded version of the same database.

3. SARS MATCHING PARAMETERS

It is hypothesized that the key to finding meaningful analog soundings with SARS is to match aspects of the environment that are relevant to hail formation, both directly and indirectly. Final hail size depends not only on factors such as updraft strength and liquid water content, but also on updraft duration which can be a function of storm mode and shear profiles. Ambient sounding parameters tested included various measures of instability such as MUCAPE, temperature and lapse rate profiles at various levels, freezing and wet bulb zero levels, several measurements of bulk shear and storm relative winds, and station elevation. In the end, only a few parameters showed discrimination value across the spectrum of hail reports (Edwards and Thompson 1998). These are:

1) Most Unstable CAPE.
2) Mixing ratio of the most unstable parcel.
3) 500 mb temperature (C).
4) 700-500 mb lapse rate.
5) 0-6 km bulk shear.

Together, these parameters appear to discriminate hail environments in terms of maximum expected size well enough to be used as a forecast tool. One

[1] *Corresponding author address:* Ryan Jewell, Storm Prediction Center, National Weather Center, 120 Boren Blvd #2300, Norman, OK 73072; E-mail: ryan.jewell@noaa.gov

limitation to this approach is that it is derived from observed vertical point profiles and does not account for environment changes in time nor space. How parameters are changing in time as well as other aspects of the weather pattern may hold additional clues that could be incorporated into SARS.

4. CALIBRATION OF SARS

Once the matching parameters were chosen, it was necessary to determine how wide the range of parameter values should be to be considered "a match" resulting in the identification of an analog sounding. Larger ranges would result in more matches but perhaps result in less useful results, whereas narrower ranges might result in very few or no matches. Optimally, the methodology would result in a sufficient number of quality matches such that the information contained within those matches could be used to produce an accurate hail forecast.

Each of the 1148 soundings in the database was tested against the remaining 1147 to assure independence in the verification testing. Since each sounding had a maximum reported hail size associated with it, these data were compared to the average report size associated with the matching soundings. Several hundred thousand parameter range combinations were tested, using the aforementioned parameters with several possible ranges for each. Using the 500 mb temperature as an example, the search ranges tested could be +/- 1 , 3, 5, 7, 9 C. Limiting this range to 1 C would result in significantly fewer matches as opposed to a range of 7 C. Assuming eight parameters are to be tested, with five ranges each, this would result in 5^8 (390,625) unique parameter range combinations. The goal was to find the combination that maximized skill scores for the largest number of cases. For example, very narrow parameter ranges might result in an analog system that produced a very high Critical Success Index (CSI) but was only able to find matches for a small percentage of the cases. Therefore, as a starting point, the minimum threshold for the required percentage of cases with at least one matching sounding was set to 90%.

Two separate calibrations were performed. The first had the goal of maximizing CSI and True Skill Statistic (TSS) scores (Doswell et al. 1990) for SIG hail forecasts. Using 50% as the arbitrary threshold, if over 50% of matches were associated with SIG hail, then it was considered to be a forecast for SIG hail. As of this writing, the SARS SIG output has not been calibrated to correspond to the actual probability of occurrence, although a relationship will be derived shortly.

The second method was developed to produce the highest linear correlation between forecast and observed hail size across the entire size spectrum (≥ 0.75"). These two methods were named "SARS-SIG" and "SARS-SIZE", respectively.

5. SKILL SCORES AND DISCUSSION

For SARS-SIG, the parameter ranges that resulted in the best skill scores are shown in Table 1. This combination resulted in a CSI of 0.729, a TSS of 0.683, a Probability of Detection (POD) of SIG hail of 0.853, and a False Alarm Ratio (FAR) of 0.166. For the parameter ranges show in Table 1, matches were found for 1143 (99.6%) of cases. Filtering was then done to remove noise near the SIG threshold of 2.00" and to further confirm the system's ability to discriminate clearly between SIG and NON-SIG hail. By removing all reports >1.5" and < 2.5" (mainly 1.75" (Golf Ball) and 2.00"), skill scores increased substantially, with a CSI of 0.843 and a TSS of 0.784. In addition, the POD for SIG hail increased to 0.945 and the FAR decreased to 0.113.

For the SARS-SIZE calibration, the intent was to maximize the correlation between forecast and observed hail size across the entire size spectrum. Once the best parameter ranges were determined to optimize performance, eight hail size bins were created, with the ultimate goal of forecasting the most likely hail size bin *report*. This was done by relating an average SARS size to each report bin rather than applying a bias correction to the raw SARS output. The bins are (in inches): < 1.00, 1.00 to 1.50, 1.75, 2.00, 2.50, 2.75, 3.00 to 4.00, > 4.00. These bins correspond to the most commonly reported hail sizes, while less common sizes are placed in the closest common size bin (there was only one case in which the size fell directly in between two size bins, a 2.25" report that was placed in the 2.50" bin). Figure 2 illustrates the average SARS output binned by report size. An increase in average SARS hail size can be seen with increasing report size, with the most dramatic rise in output between the 1.00"-1.50" and 2.50" bins. This indicates that SARS-SIZE has increased discrimination ability between non-SIG and SIG hail.

The standard deviation across all bins was 0.43". The bins with the largest standard deviations were 1.75" and 2.00", near the middle of the size spectrum, while the lowest were associated with the lower and upper ends of the spectrum. This standard deviation compares quite favorably with that of the HAILCAST hail model (Jewell and Brimelow 2009) which exhibited a value over 0.70".

6. SARS INTEGRATION INTO OPERATIONS

SARS is currently run experimentally at the SPC in both sounding and model gridded data formats. The sounding analyses can be performed on observed RAOBS or model forecast soundings. For the sounding analyses using the SPC version of N-SHARP (National center Skew-T/Hodograph Analysis and Research Program (Hart et al. 2003), forecasters can view SARS results in tandem with the HAILCAST hail model (Fig. 3). This is most useful when inspecting small geographic areas over a few hours time period. Using model gridded data, forecasters can view SARS summary products over the CONUS, with SARS output available for the NAM, RUC, and EtaKF control member from the SREF. Examples of SARS-SIG and SARS-SIZE forecasts are shown in Figs. 4 and 5, respectively.

7. FUTURE PLANS

There are several ways in which the SARS hail forecasting algorithm can be improved. The first is to collect more proximity soundings to the database and perform additional calibrations, as well as to test other matching parameters. Second, a real-time verification database using SPC hourly Mesoscale Analysis (SFCOA) grids (Bothwell et al. 2002) can be compiled. SARS can be run on SFCOA grid point vertical profiles and the results can be verified using gridded severe weather reports. This would help build a more complete statistical sample which would include a substantial number of null cases as opposed to the conditional database that is currently used.

In addition, a supercell tornado SARS system is expected to be developed over the coming year, and will focus on delineating between tornadic and non-tornadic supercells, as well as weak (EF0-1) and significant (EF2+) tornadoes. This scheme will initially be based on a sample of RUC proximity soundings collected by Thompson et al. (2007), but may also be expanded using additional grid soundings that will be collected by rerunning the SARS grids on a historical set of SFCOA grids back to 2003. A SARS system could also be developed for damaging winds, producing a probability of severe wind as well as SIG (≥ 65 kt) wind. This may be attempted after supercell/tornado SARS, and may prove to be the most challenging given the known weaknesses in the severe wind report database (e.g., Doswell et al. 2005).

ACKNOWLEDGMENTS

I would like to thank David Bright, Andy Dean, John Hart and Richard Thompson for their programming contributions that enabled successful integration of SARS into SPC operations.

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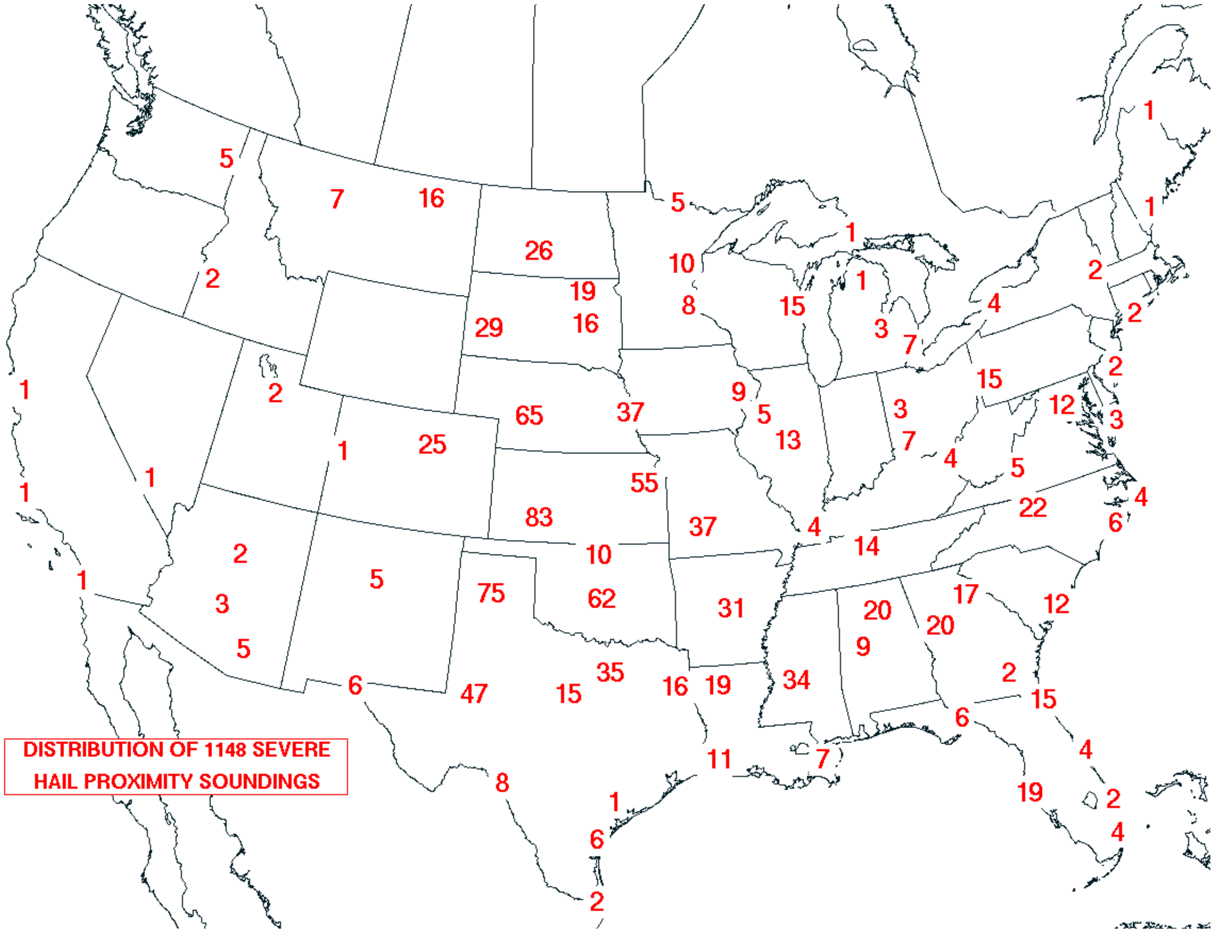

Figure 1: Locations and number of hail proximity soundings used for both SIG and NON-SIG events. Database includes soundings from every month. Note: Includes soundings associated with 0.75” hail corresponding to the severe hail criterion prior to 2010.

PARAMETER	RANGE (+/-)
MUCAPE	40% j/kg
Mixing Ratio of MU Parcel	2.0 g/kg
700-500 mb Lapse Rate	1.5 C/km
500 mb Temperature	7 C
0-6 km Bulk Shear	8 m/s

Table 1: Parameters used in the SARS-SIG matching routine along with ranges.

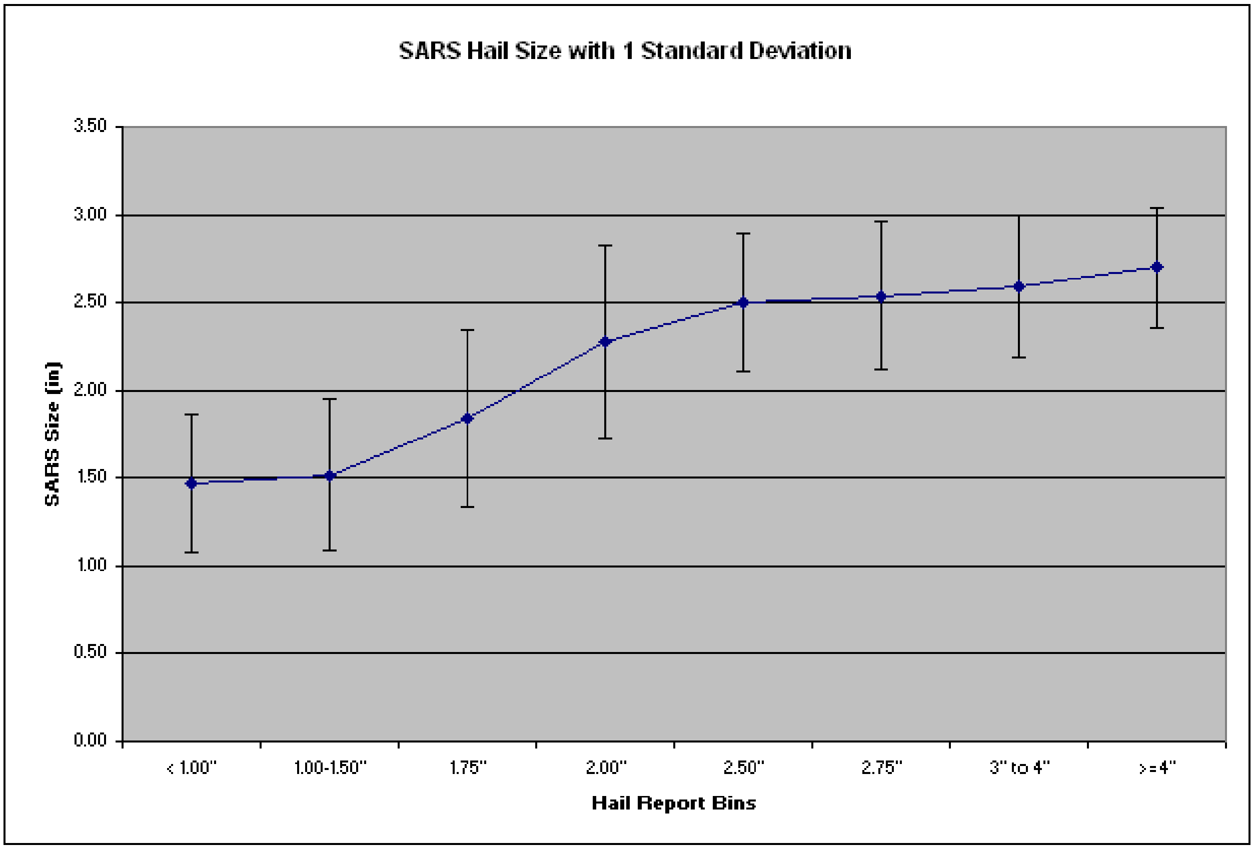

Figure 2: Mean SARS-SIZE output (blue line) and one standard deviation (bars) of soundings binned by size category. For example, the average SARS-SIZE output for the 2.50" cases was about 2.50".

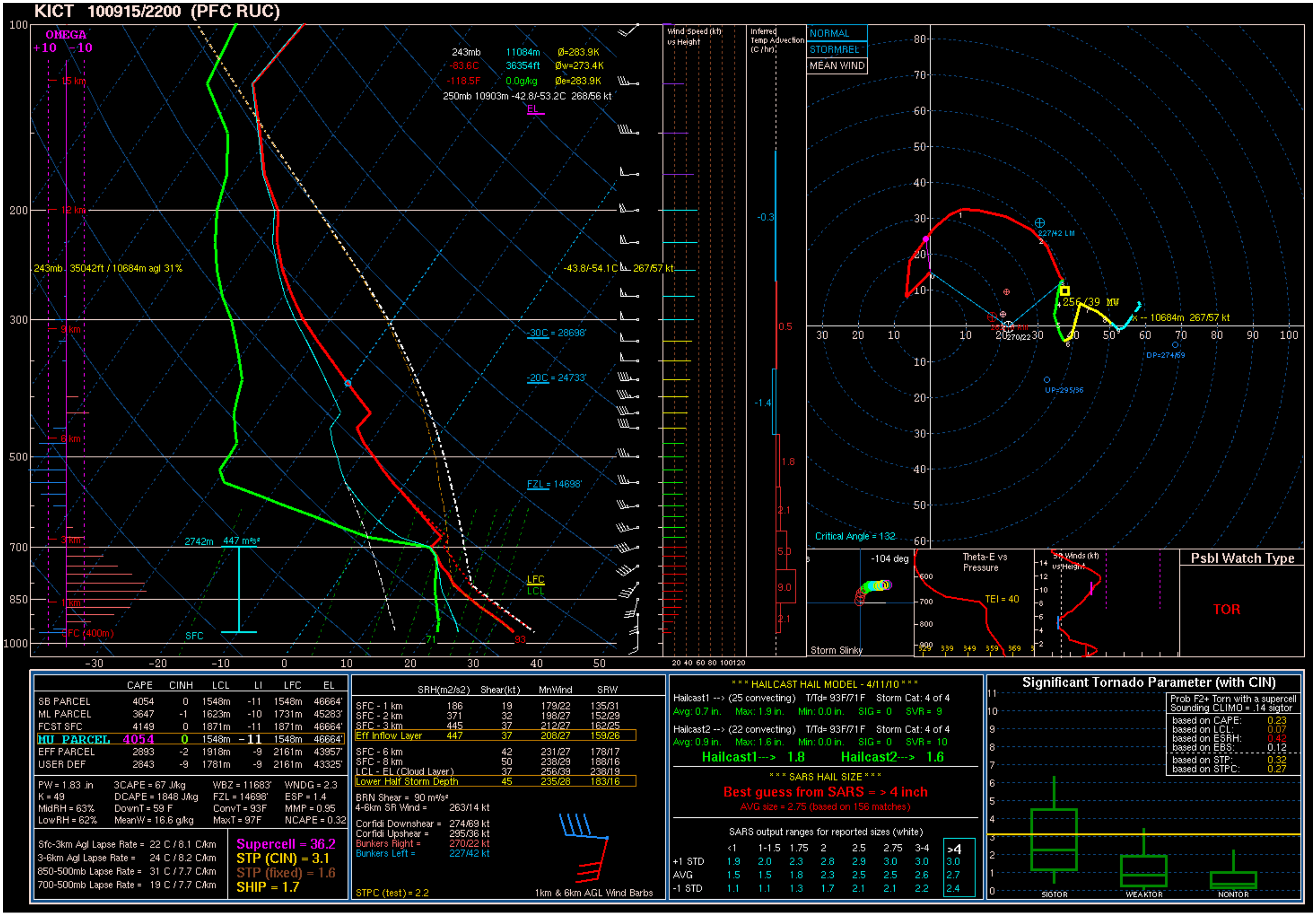

Figure 3: NSHARP screenshot with SARS output (bottom row, second from right). In this example, SARS is forecasting >4" hail based on 156 matches.

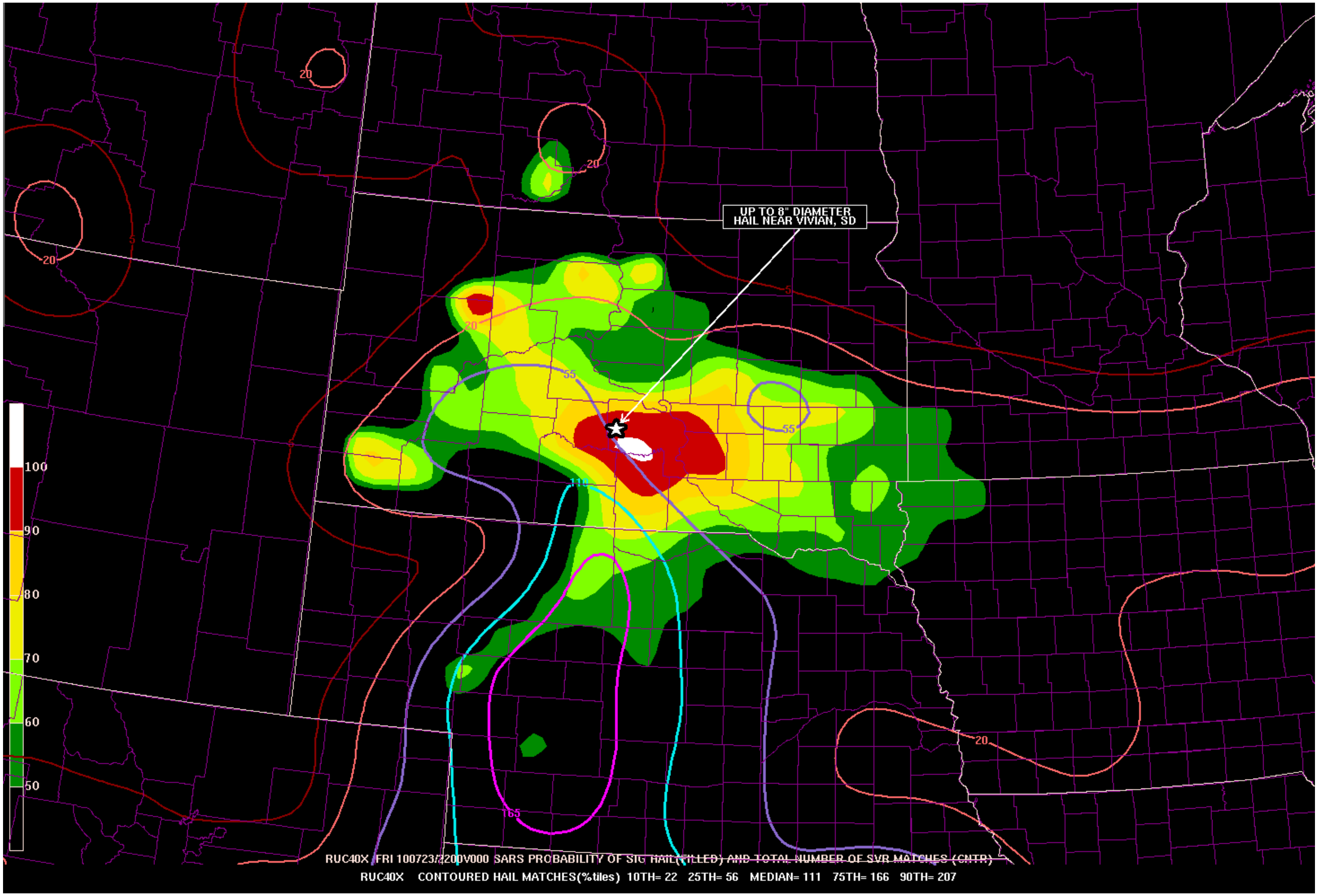

Figure 4: SARS-SIG output based on 00-hr RUC model gridded profiles from the record Vivian, SD hail day on 23 July 2010. Contours are the number of sounding matches, and color fill is the percent of matches that were associated with SIG hail. White star indicates location of the hail report.

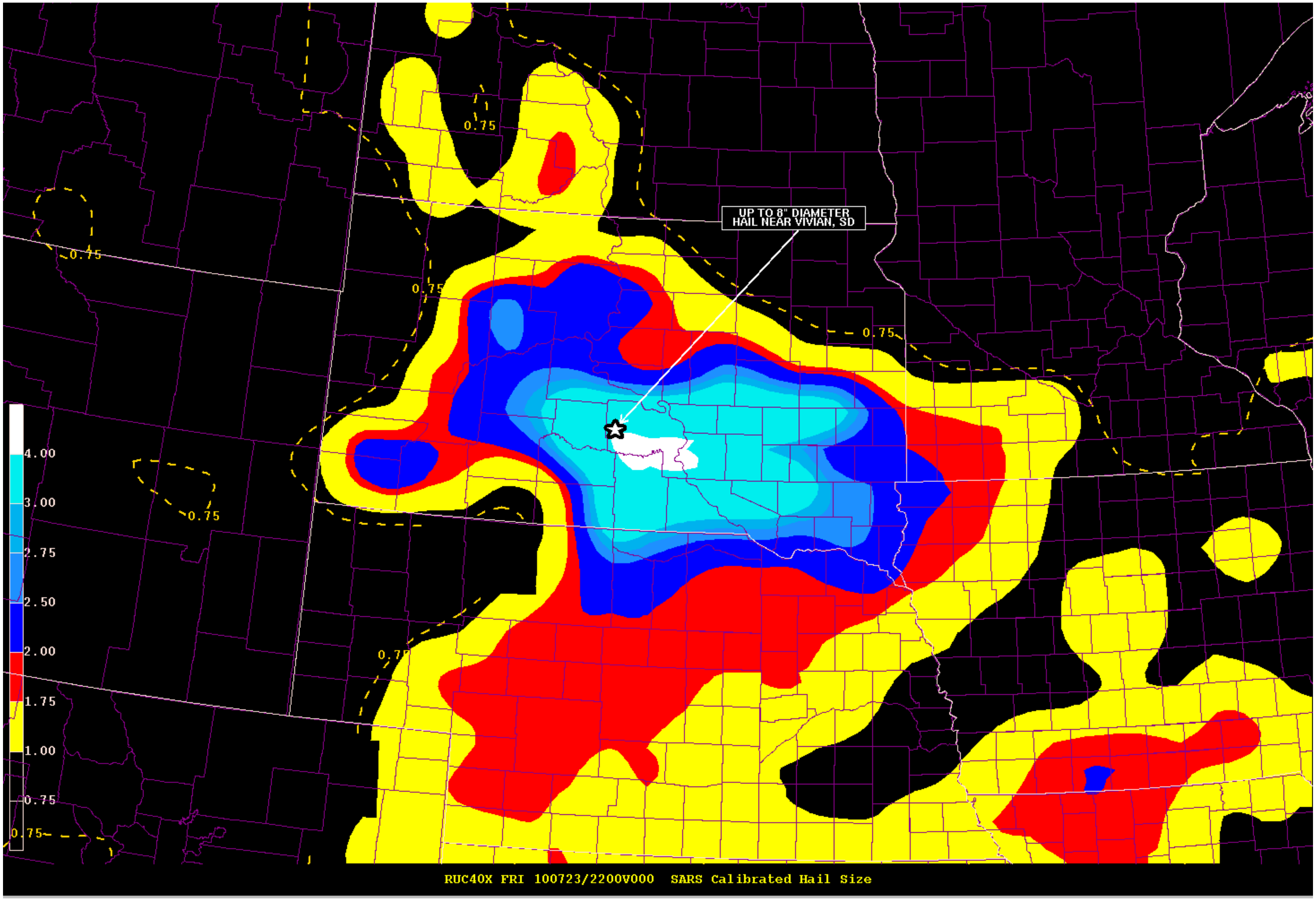

Figure 5: As in fig. 3 but with SARS-SIZE output in inches.