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IMPROVED METHODOLOGY FOR CORRELATING MESOCYCLONE DETECTIONS WITH TORNADOES

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1. INTRODUCTION

The introduction of the WSR-88D Doppler radar into nationwide use has greatly enhanced our ability to study storm-scale vortices such as mesocyclones and tornado vortex signatures. During the past decade several algorithms have been developed by the NOAA National Severe Storms Laboratory (NSSL) to diagnose these vortices and determine their characteristics using WSR-88D data. One such algorithm is the Mesocyclone Detection Algorithm (MDA) (Stumpf et al. 1998). Using the MDA, many mesocyclone attributes have become available for study. One important avenue of research is determining the correlation of mesocyclone attributes with the occurrence (or non-occurrence) of severe weather phenomena such as tornadoes, strong winds, and hail; however, work in determining this correlation has been rather limited. Past works attempting to determine such this correlation include: Desrochers and Donaldson 1992 and Marzban et al. 1999. Most of these works have looked at rather limited sample sizes due to the manual mesocyclone-tornado correlation technique used and the necessity of using high-resolution (level II) radar data from tape archives. Other works (including Mitchell et al. 2000) attempting to find a correlation using large data sets only look at the presence or lack thereof of a mesocyclone detection in association with a tornado track.

The initial focus of the work reported here is on resolving the correlation between tornado reports (or lack thereof) and mesocyclone detections with their associated attributes using several statistical procedures. This correlation is being determined using a climatological perspective rather than a small-scale, case-by-case perspective used previously. The eventual goal is to demonstrate the practicality and usefulness of a mesocyclone climatology based on the MDA.

2. METHODOLOGY

Level II data were collected from six radars in the Southern Plains: KAMA, KFWS, KINX, KLBB, KSRX, and KTLX (for locations, see map in Fig. 1), which are the initial radars associated with the CRAFT project. Since full- time recording of data for this project began in 2001, the 2000 data set is incomplete and event specific. For this work, approximately 360 hours of level II data during 2000 was processed from *each* radar. While this by no means represents a complete convective climatology for 2000 for this region, it can serve the purpose of a test-bed for verification techniques to be employed in future analyses.

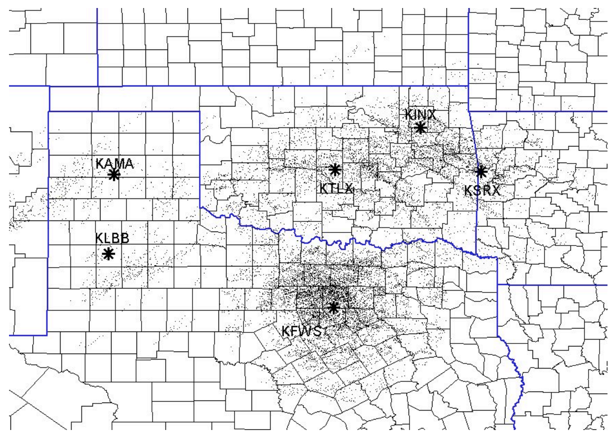

Figure 1. Map showing the locations of the six radars used in this research and the 15,379 mesocyclone detections remaining after filtering of the 2000 level II data. Note the bulls-eye of detections around KFWS, an example of a radar-specific artifact.

The methodology of this work differs from the previously mentioned studies and overcomes some significant difficulties. First, there are several known problems with the MDA and its ability to detect storm scale vortices. Many of these are a result of radar beam geometry (Stumpf et al. 1998, Mitchell et al. 2000). Other problems involve velocity errors especially apparent at certain ranges given specific combinations of Volume Coverage Patterns (VCPs) and Pulse Repetition Frequencies (PRFs) that may lead to a significant number of anomalous detections. Dealiasing can also lead to the false indication of mesocyclones in ground clutter. Mesocyclones that are detected due to dealiasing problems are often ranked as strong. To address these problems, a filtering technique has been developed that eliminates many of these false detections while only slightly impacting the quality of "true" detections. This filter attempts to correlate mesocyclone detections with storm cell detections produced by the Storm Cell Identification and Tracking (SCIT) algorithm using a predefined search radius (12 km in this case) (Johnson et al. 1998). Mesocyclone detections that cannot be associated with a storm cell were removed from the mesocyclone data set. For more

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details on this filtering, see the companion paper **5.4** by McGrath et al.

For this research, each mesocyclone detection is defined as a singular, independent event in time and space with unique attributes. The algorithm's ability to track a mesocyclone from one volume scan to the next is rather limited, so no attempt was made to combine individual mesocyclone detections into mesocyclone tracks. In addition no attempt was made to combine detections of the same mesocyclone from multiple radars.

The filtered data set was ingested into a GIS environment to produce a display of mesocyclone detections. These were then compared with ground-truth tornado tracks for the corresponding event acquired from the Storm Prediction Center (SPC) database. For simplicity, any curvature in a tornado path was ignored. The problems with the SPC database are well known and will not be discussed here, but quality control of these data has been of great importance for this work (Witt et al. 1998). To account for temporal and spatial errors in the location given for a specific tornado, all mesocyclones within the spatial and temporal window surrounding a tornadic event were tagged as being associated with that tornadic event (Witt et al. 1998). This "windowing" technique also takes into account small location errors inherent in MDA's detection coordinates. This procedure is used in place of earlier techniques that attempted to correlate a single mesocyclone detection with a tornado when in fact more than one may be significant (Stumpf et al. 1998). Also, earlier works analyzed the radar data manually to determine tornado-mesocyclone relationships. This is not practical for the large-scale, climatological analyses that will be attempted in the future. The techniques proposed by this work also have the advantage of being much more objective than previous techniques by minimizing the human element in the verification process.

The spatial window used was a search radius of 10 km from the tornado track to search for mesocyclone detections. The temporal window chosen for this analysis was -20 min before to +6 min after a tornado report to search for mesocyclone detections that pass the spatial test (Witt et al. 1998).

A unique aspect of this method is that it allows for the combination of the MDA output from multiple radars into a spatial environment before a verification analysis is undertaken. Previous works focused verification on output from a single radar. In the interest of producing radar climatologies, one must discard the paradigm of only analyzing output from a single radar since mesocyclone occurrence is not tied to a specific radar or radar geometry. Ingesting the MDA output from multiple radars into a GIS environment allows the spatial analysis to be undertaken using a Cartesian coordinate system rather than the spherical, radar-specific, system.

3. STATISTICS

Several different statistical analysis procedures were used in determining the correlation between mesocyclone detection attributes and tornadoes. These statistics were used to verify the usefulness of this mesocyclone climatology. Initially, various skill scores were calculated using several of the raw MDA attributes. The skill-scores being analyzed include Critical Success Index (CSI), Heidki Skill Score (HSS), Probability of Detection (POD), and False Alarm Rate (FAR) (Wilks 1995). In calculating these statistics, tornadoes that cannot be associated with any mesocyclone detections will be ignored since the skill of a mesocyclone detection attribute cannot be determined if there is no detection with which to begin. The skill scores were calculated for each attribute using multiple thresholds to determine which threshold would have the greater forecasting potential.

As many of the attributes are highly correlated it was decided to apply Principal Component Analysis (PCA) to the attribute data set. Attributes that had little predictive value, such as mesocyclone azimuth, were removed prior to this analysis to eliminate as much noise as possible. Using PCA it is possible to combine multiple attributes into a single variable, which could prove to have greater skill in forecasting tornadoes as it combines information from multiple useful variables. To better quantify the physical meaning of the new variables, the loadings were rotated using the varimax scheme in order to maximize (or minimize) attribute correlation. Finally, skill scores were calculated again using the "new" variables and compared with those of the raw attributes.

4. RESULTS

After filtering of the initial mesocyclone data set, 15,379 mesocyclone detections over the six radars were included in the preliminary 2000 mesocyclone climatology (Fig. 1). During the dates and times for which radar data were available, 31 tornadoes were reported to have occurred. At least one mesocyclone was detected for every tornado report. Also, it should be noted that no tornadoes occurred within range of the KAMA radar; however, detections from KAMA were kept in the data set due to the climatological nature of this work. Using the procedures described above to determine tornadic mesocyclone detections, only 264 detections could be defined as tornadic. This represents a disturbingly small number of the total number of detections within the data set. Still, an objective analysis of the tornadic detections seemed to indicate that often these detections were classified as strong by the MDA while most of the non-tornadic mesocyclones were classified as being weaker, as expected.

To quantify the objective analysis, the skill scores of several MDA-derived mesocyclone attributes were calculated. The attributes chosen were Mesocyclone Strength Index (MSI), Neural Network probability of a Tornado (NNT), mesocyclone Depth, and Low Level mesocyclone Diameter (LLDia). Of these attributes, MSI proved to have by far the greatest skill at distinguishing between tornadic and non-tornadic mesocyclones (Fig. 2). However, even the skill of MSI is very limited with a maximum HSS of only 0.17 associated with an alarmingly high FAR of nearly 0.85 and low POD of 0.3. The next best attribute, NNT, has a HSS that only marginally exceeds 0.1 again with high FAR and low POD. The other attributes, Depth and LLDia, show virtually no skill at all (Fig. 2). Since these results are far below published results of MDA attributes (Stumpf et al. 1998), it was decided to test these procedures using a single tornadic event. (The hypothesis that the higher skill scores in Stumpf et al. 1998 were a result of only focusing the verification on specific tornadic cases). Thus, four tornadic days from the 2000 data set were chosen during which 20 tornadoes were detected. Using this limited data set, the HSS for MSI improved to a maximum of 0.27 with improved values for POD and FAR (Fig. 3). Still, this is not great, but is more in line with the results reported by Stumpf et al. (1998) and verifies that the procedures used in this work are indeed valid.

To improve the skill of the MDA attributes in the climatological data set, it was decided to attempt PCA on the MDA attributes in order to generate a reduced number of independent variables with which to work. This analysis resulted in one variable in particular that included information from most of the velocity derived attributes while remaining independent of attributes such as mesocyclone Depth and Range. Determining the skill of this new variable revealed that combining the velocity information into a single variable improved the skill of using MDA information as a predictor for tornadoes. However, this improvement over MSI was only slight increasing HSS by 0.03 (Figs. 2 and 3). Still, this improvement was seen using several different rotation methods and thresholds during the process of PCA. Thus, it appears that this improvement in skill, though small, is real and worthy of future exploration.

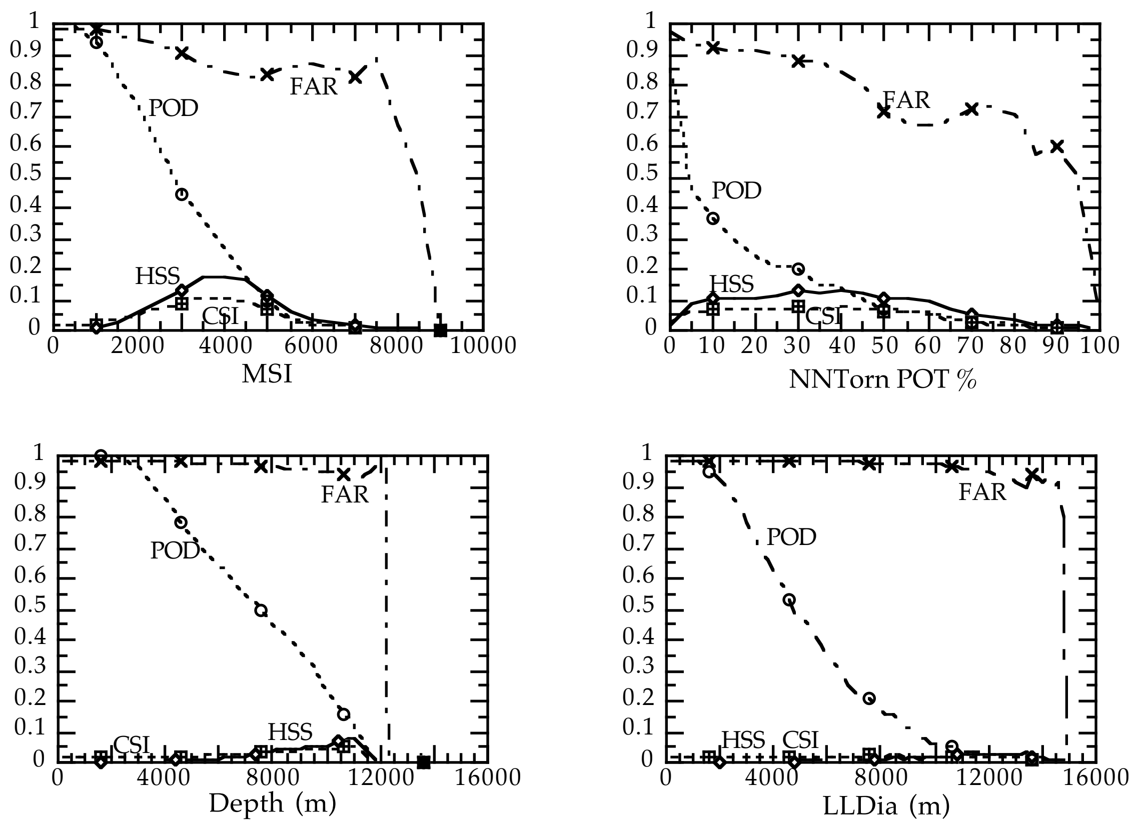

Figure 2. Skill scores for selected mesocyclone detection attributes. Note the very high FAR values associated with all the attributes at most threshold levels. Using HSS as a guide, it is apparent that MSI is the attribute with the best skill and NNTorn second. Mesocyclone Depth and LLDia show virtually no skill at predicting tornadoes. The result for LLDia is somewhat surprising given that many believe that a tightening of the low-level circulation is associated with a tornado.

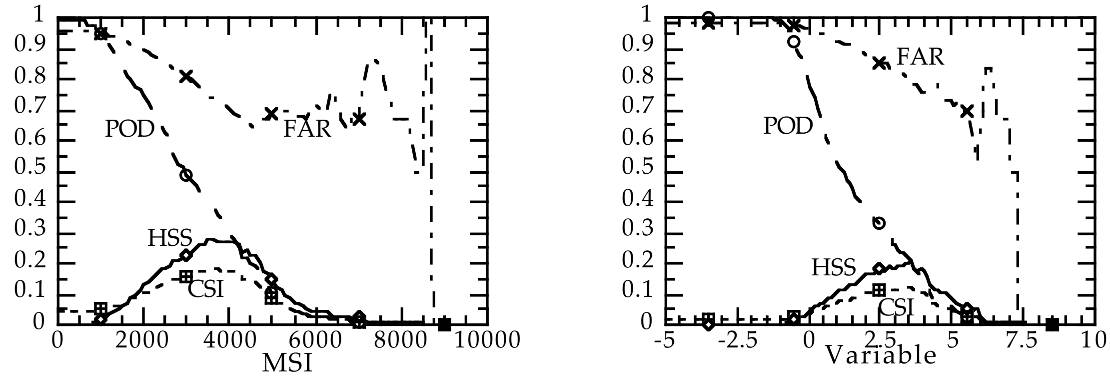

Figure 3. Left is a plot of the skill scores for MSI during the March test case. Note that CSI and HSS are significantly higher and FAR lower than in the climatological case. Right are the skill scores associated with the new variable produced during the PCA of the climatological data set. Compare with MSI in Figure 2 and note that HSS and POD are improved somewhat.

5. CONCLUSIONS AND FUTURE RESEARCH

An analysis that parallels that reported here is underway using the 2001 level II data from the same six radars. The 2001 data set represents a much more complete collection of all the convective events for the year, so it is hoped that analysis of it will provide more definitive results than those given here. In addition, it is hoped to break up the 2001 data by seasons to determine if the tornado predictive skill of the mesocyclone attribute varies with each season. Finally, the large 2001 data set will be used as a basis for creating non-linear models relating tornado occurrence to several attributes while using the 2000 data set as an independent test set.

Still, the process of creating a representative mesocyclone climatology has proven quite challenging. Many of the difficulties appear due to shortcomings in the current realization of the MDA. An example is the numerous false detections found around 147 km. Post-processing of the algorithm output with filtering and PCA significantly increases the correlation between tornado occurrence and mesocyclone attributes; however, the increases do not approach the level necessary to utilize the mesocyclone climatology for additional research of the type presented here. It is hoped that the next realization of the MDA will address many of these shortcomings. Once this is done, it may be possible to achieve significantly better results using techniques such as those described above.

Finally, it is hoped to continue this process using different WSR-88D algorithms and different verification techniques. One such future possibility is an algorithm currently in development that can combine velocity information from multiple WSR-88D radars to produce a mesocyclone detection. This multi-radar approach would remove many of the radar-specific issues associated with the current method of assembling a mesocyclone climatology and could significantly improve its usefulness.

6. ACKNOWLEDGMENTS

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