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THE WDSS-II SUPERCELL IDENTIFICATION AND ASSESSMENT ALGORITHM

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1. INTRODUCTION

Supercell thunderstorms account for a small percentage of convective activity, and yet they are responsible for a disproportionate amount of severe weather damage. Long track, violent tornadoes, giant hail, and extreme surface wind gusts are more likely to accompany supercell thunderstorms than most other types of organized convection (Browning 1977; Burgess and Lemon 1991; Moller, et al. 1994). Because of this propensity to harm life and property, supercell thunderstorms draw increased attention from National Weather Service warning forecasters. Faced with a severe weather situation, a warning forecaster must rely on his/her data interpretation skills, situation awareness, and the ability to integrate numerous sources of data, using human expertise to make effective and timely warning decisions. However, interrogating a potentially severe thunderstorm requires a large allocation of the forecaster's temporal and cognitive resources. The presence of several potentially dangerous storms within the County Warning Area further strains the forecaster's ability to investigate the severity of each storm, decreasing his/her interrogation efficiency (Bunting 1998; Durso and Gronlund 1999). The addition of automation through signature detection algorithms has shown to improve the interrogation efficiency a forecaster can exhibit in a severe weather situation (Lemon, et al. 1992), but such tools can promote algorithm dependency.

Previous methods of automated thunderstorm interrogation have focused on the independent detection of single features (or single set of features) commonly associated with severe thunderstorms, leaving the classification process as an exercise solely for the human user. Research has shown that supercell thunderstorms simultaneously possess many of these features. Thus, a feature-based object recognition scheme can be used to identify such storms. Since supercell thunderstorms frequently produce severe weather, the recognition that a storm is adopting supercell-like characteristics is beneficial to the warning forecaster.

Within the Warning Decision Support System - Integrated Information (WDSS-II), the Supercell Identification and Assessment Algorithm (SIAA) has been developed to integrate the results of multiple signature detection algorithms, creating a more holistic approach to storm type classification. By simultaneously searching for several features known to be related to severe potential in thunderstorms, and common to supercell thunderstorms, the amount of cognitive processing required by the human is reduced, and the likelihood of the user applying a relevant conceptual model is increased. In an effort to promote this heightened level of situation awareness, SIAA is designed to mimic the feature-based interrogation process that a human meteorologist would follow in determining storm type, and assessing the priority level at which the storm should receive increased attention.

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2. ALGORITHM DESCRIPTION

Because of its intuitive use of membership, fuzzy set theory is used as a proxy for the human process of classification in determining the degree to which a thunderstorm is supercellular. There are several advantages gained by using fuzzy sets and fuzzy logic for this application. Many of the following observations fit well with the fuzzy set description laid forth in (Zadeh 1965). First, within the field of meteorology, there is no universally accepted quantitative definition of a supercell thunderstorm. The boundaries between storm type classes are not crisp. Also, uncertainty often exists about the presence, or significance of a feature, which implies a degree of membership of an object to some class, or classes. Fuzzy set theory is well equipped to deal with a spectrum of membership of an object to multiple classes.

Second, fuzzy set theory facilitates a feature-based approach towards the intuitive classification of an object, provided that the class features can be well defined, as with supercells. Fuzzy sets allow the measurement of feature memberships to idealized classes, and combination of these memberships to arrive at easily understood classification decisions.

Finally, fuzzy logic supports the implementation of a rule base and the ability to describe the situation in linguistic terms. These rules may be constructed to model the relative importance of features in the classification decision, and can provide both supporting and refuting evidence to place an object in a certain class. In addition, the use of fuzzy set operators yields fuzzy rules and classifiers that are very flexible and easy to change, or tune (union, intersection, complement, and aggregation; Yager 1988; Klir and Folger 1988; Zadeh 1965).

2.1 *Storm type classification*

The concept of a long-lived, quasi-steady, intense, rotating thunderstorm has been a topic of vigorous investigation for several decades, even predating the term "supercell" (Browning 1962). The advent of more sophisticated data processing techniques and radar technology, especially Doppler radar, has improved the understanding of supercell structure and evolution. Through the past fifty years, research has shown that despite assuming a wide variety of configurations and orientations, supercells can possess common identifiable features. Although there is no widely accepted quantitative definition of a supercell, several of these features are mentioned in most, if not all supercell definitions. Such features include:

1) deep, persistent shear (the mesocyclone; Davies-Jones

1984; Brooks, et al. 1993)
2) possession of a bounded weak echo region (Chisholm 1973; Lemon 1980),
3) deviant motion, with respect to the mean wind (Browning 1963; Lemon and Doswell 1979; Klemp and Weisman 1983; Moller, et al. 1994).

SIAA functions as a mesocyclone-based algorithm, processing information only for those storms that are associated with some sort of four dimensional azimuthal shear in the Doppler radar radial velocity data. SIAA depends on the NSSL Mesocyclone Detection Algorithm (MDA; Stumpf, et al. 1998) to identify these shear regions.

Following a fuzzy logic scheme similar to that used in (Lakshmanan and Witt 1997), classification of a storm as a Supercell (**fz_max**), Marginal Supercell (**fz_marg**), or Non Supercell (**fz_min**) is done using both actual and hedged values of two fuzzy membership values, **fz_yes** and **fz_no**, in the following fuzzy classifiers:

fz_max = (**fz_yes** AND "not" **fz_no**)
OR
("very much" **fz_yes** AND "very much" "not" **fz_no**)

fz_marg = (**fz_yes** AND **fz_no**)
OR
("very much" **fz_yes** AND "very much" **fz_no**)

fz_min = ("not" **fz_yes** AND **fz_no**)
OR
("not" "very much" **fz_yes** AND "very much" **fz_no**)

where "not" represents the fuzzy complement of the argument (1 - **fz_val**), "very much" represents an overestimating hedge of the argument (1 - e^(-1.5***fz_val**))/(1 - e^(-1.5)), and OR/AND represent the logical or/and operators, that return the max/min value of the expression.

The base fuzzy membership values of **fz_yes** and **fz_no** are determined by the following calculations:

fz_yes = (**fz_sp_previous** AND **fz_sp**)
OR
("somewhat" **fz_sp_previous** AND "very much" **fz_sp**)
OR
("somewhat" **fz_sp**)

fz_no = "not" **fz_meso**

where "somewhat" represents an underestimating hedge of the argument (1 - e^(1.5***fz_val**))/(1 - e^(1.5)), and **fz_sp_previous** is the Supercell fuzzy membership value of the current shear signature from the previous volume scan. The **fz_sp** value represents the intermediate feature-based supercell fuzzy membership value for the current shear signature. This value is computed by applying a weighted average aggregation to several other fuzzy membership values (Yager 1988):

fz_sp = .4***fz_meso** + .3***fz_meso_life** + .2***fz_bwer** + .1***fz_deviant_motion**

with the following brief discussion about each term:

fz_meso - represents the mesocyclone strength fuzzy membership value; computed linearly using the 3-D meso strength rank parameter for the current shear signature from MDA (Stumpf, et al. 1998), with a membership range of 0 to 4; assigned the largest weight because the mesocyclone is the most common feature mentioned across supercell definitions/discussions (Browning 1963; Lemon and Doswell 1979; Klemp and Weisman 1983; Moller, et al. 1994)

fz_meso_life - represents the mesocyclone longevity fuzzy membership value; computed linearly using the number of minutes since the first detection of the current shear signature, with a membership range of 0 to 25 minutes; assigned the next largest weight because the persistence of the 3-D shear signature is a distinctive attribute of supercells (Browning 1977; Moller, et al. 1994)

fz_bwer - represents the significance of any bounded weak echo region associated with the current shear signature; retrieved from the NSSL Bounded Weak Echo Region detection algorithm (Lakshmanan and Witt 1997); assigned a relatively small weight because of detection difficulty (Chisholm 1973; Lemon 1980)

fz_deviant_motion - represents the mesocyclone deviant motion fuzzy membership value; computed linearly using the angular difference between the current shear signature's motion vector and the 0-6 km shear vector, with a membership range of 0 to 25 degrees (Maddox 1976; Weisman and Klemp 1984); assigned the smallest weight because of MDA dependency

Note that the **fz_no** value in the fuzzy classifiers is computed using the fuzzy complement of **fz_meso**; this formula is used because a storm is not a supercell if it is not associated with a reasonably strong 3-D shear signature.

The structure of these rules highlights the feature-based approach of this recognition scheme. The presence of any one feature in temporal or spatial isolation, no matter how strong, is not sufficient to classify the storm as a supercell.

2.2 *Attention worthiness classification*

The ultimate goal of SIAA is to draw attention to thunderstorms that pose a significant danger to the public. To this end, a second classification process is employed to alert the user to storms that exhibit varying degrees of danger, and thus different priorities for increased base data scrutiny. This classification process is also feature-based, but focuses on those features that research has shown to be related to severe weather production in supercells. These features include:

1) a strong mesocyclone (Burgess, et al. 1979; Burgess and Lemon 1991)
2) a hook echo (Forbes 1981; Markowski 2002)
3) an inflow notch (Browning 1964)
4) a bounded weak echo region (Chisholm 1973; Lemon 1982)
5) strong, or rapidly increasing low-level rotational velocity

The fuzzy classifiers used in this process have the same structure as those previously described for storm type classification (**fz_max**, **fz_marg**, **fz_min**). However, different fuzzy membership values are used in the fuzzy rule base.

fz_yes = (**fz_immediate_previous** AND **fz_immediate**)
OR
("somewhat" **fz_immediate_previous** AND "very much" **fz_immediate**)
OR
("somewhat" **fz_immediate**)

fz_immediate = .35***fz_meso** + .2***fz_hook_echo** + .15***fz_inflow_notch** + .15***fz_bwer** + .15***fz_llrotv**

The fuzzy membership values of **fz_meso** and **fz_bwer** are the same as those used in the storm type classification process. The new terms are described as follows:

fz_hook_echo - represents the hook echo fuzzy membership value; the inner border of the storm is extracted, using 35 dBZ as a border threshold; a uniform nonrational approximating b-spline is fit to this border; a dynamically sized, near-mesocyclone search region is investigated for points of large positive curvature along the border, such that the maximum curvature value closest to the mesocyclone is accepted as the dominant signature; assigned a fairly large weight because hook echoes have been associated with tornadogenesis (Forbes 1981; Markowski 2002), and this procedure has proven effective in detecting hook echoes

fz_inflow_notch - represents the inflow notch fuzzy membership value; inflow notches are detected in the same manner as hook echoes, except they are characterized by points of large negative curvature; assigned a smaller weight because of high frequency of notches in radar data

fz_llrotv - represents the low-level rotational velocity significance fuzzy membership value; computed using the maximum of two other fuzzy membership values: the current maximum low-level rotational velocity (membership range from 0 to 20 ms^{-1}), and the increase in low-level rotational velocity since the last volume scan (membership range from 0 to 10 ms^{-1}); assigned a smaller weight because of MDA dependency

The results of SIAA are reported in the form of a table and set of icons. The table summarizes the fuzzy membership values of the classes and features associated with each MDA identified shear signature. The icon is labeled with the storm type class ("Sp" for Supercell, or "Mrg" for Marginal Supercell), followed by the attention worthiness class ("X" for Maximally Deserving, "R" for Marginally Deserving, or "N" for Minimally Deserving of immediate attention). The icon is also color coded based on the attention worthiness classification.

3. PERFORMANCE RESULTS

The algorithm was tested on two large data sets: 31 May, 1996, KABR, and 3 May, 1999, KTLX. Both of these cases contained several supercells, marginal supercells, and non supercells in a variety of configurations, orientations, and ranges. Table 1 summarizes the testing results.

	H	M	FA	POD	FAR	CSI	HSS
Strm	893	199	144	0.82	0.14	0.72	0.66
Attn	962	130	144	0.88	0.13	0.78	0.72

Table 1. Summary of testing results for KABR-053196 and KTLX-050399. **Strm** and **Attn** are the storm type and attention worthiness classification results, respectively. **H** is hits, **M** is misses, **FA** is false alarms, **POD** is probability of detection, **FAR** is false alarm rate, **CSI** is critical success index, and **HSS** is Heidke skill score (Wilks 1995).

Overall, these performance metrics suggest that the algorithm performed very well in discriminating between supercells and non supercells, and between storms that deserve immediate attention and those that deserve attention at a lower priority. The low FAR values and high CSI values show that SIAA has exhibited a high degree of classification accuracy, while showing restraint in the classification of weaker storms. The relatively high HSS values show that SIAA possesses a high degree of skill, as compared to random classification.

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