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"Progress of Research to Identify Rotating Thunderstorms Using Satellite Imagery"

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Final Report

Contract NAS8-36547

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FINAL REPORT
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The objective of this contract was to determine the possibility of detecting potentially tornadic thunderstorm cells from geosynchronous satellite imagery. During the life of the contract, we examined eight tornado outbreak cases which had a total of 123 individual thunderstorm cells, 37 of which were tornadic. These 37 cells produced a total of 119 tornadoes. The outflow characteristics of all the cells were measured. Through the use of two-dimensional flow field model, we were able to simulate the downstream development of an anvil cloud plume which was emitted by the storm updraft at or near the tropopause. We used two parameters to characterize the anvil plume behavior: its speed of downstream propagation (U max) and the clockwise deviation of the centerline of the anvil plume from the storm relative ambient wind at the anvil plume outflow level (MDA). UMAX was the maximum U-component of the anvil wind parameter required to successfully maintain an envelope of translating particles at the tip of the expanding anvil cloud. MDA was the measured deviation angle, acquired from McIDAS, between the storm relative ambient wind direction and the storm relative anvil plume outflow direction; the latter being manipulated by controlling a tangential wind component to force the envelope of particles to maintain their position of surrounding the expanding outflow cloud.

The eight tornadic outbreak cases studied were:

TABLE 1

Case	Date (Julian)	Number of Cells Examined	Number of Tornadic Cells Reported	Number of Tornadoes
Wisconsin-Illinois	84118	16	5	7
Iowa	84159	12	6	34
Ohio-Pennsylvania	85151	22	8	28
Texas-Louisiana	87319	16	4	17
Kansas	86261	16	4	5
Nebraska	85130	13	4	8
Oklahoma	84117	16	3	7
South Dakota	86209	12	3	13
Total		123	37	119

The measured values of UMAX and MDA, as described, were used as bivariates in a polynominal regression scheme to predict the tornadic intensity of a given cell. The estimated intensity was obtained from storm damage reports by NOAA observers on the scene. If a cell produced two or more tornadoes, a weighted mean value, based on the Fujita tornado rating scale, was used to define the cell's tornadic intensity. The two predictors were UMAX and MDA, and the observed tornadic intensity, $\hat{Y}$, was the response variable. The relationship among the predictor variables and the response variable for a given outbreak case (a case where five or more tornadoes were reported) was examined using a polynomial equation:

$$\hat{Y} = \beta_0 + (\beta_1 x_1 + \beta_2 x_2) + (\beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2) + \ldots.$$

First, second, third and fourth degree polynomial variance analyses were carried out on each of the eight cases. In instances where the number of events did not warrant fourth degree examination, the analysis was limited to third degree. The results of these analyses are given in Table 2. The table is limited to third degree polynomial results since we did not feel that our sample sizes were large enough to warrant fourth degree treatment.

TABLE 2

Regression Results for Eight Case Studies
Coefficient of Determination R^2
Degree of Polynomial

Case	(First)	(Second)	(Third)
Wi-ILL day 84 118	0.8031	0.9813	0.9939
Iowa day 84159	0.6289	0.8765	0.9293
OH-PA day 85151	0.7267	0.8975	0.9602
TX 87319	0.7490	0.8958	0.9447
KN 86261	0.5531	0.7541	0.9195
NE 85130	0.8247	0.9822	0.9990
OK 84117	0.3680	0.6855	0.9547
SD 86209	0.7268	0.9121	0.9904
raw combined data	0.5569	0.6375	0.6916
non-dimensional combined	0.6226	0.7324	0.8245

Table 2 indicates a strong relationship between the two predictor variables and the response variable, especially so when the second and third degree polynomial fits were used. Since we were interested in using observed values of UMAX and MDA to predict the response variable (the tornadic intensity of a given cell), we examined the eight cases individually and collectively to determine the feasibility of this approach. If we limit our attention to the quadratic results for a given outbreak, in most instances better than 80% of the variance was being accounted for.

However, if our goal is to devise a system to reliably forecast the tornadic potential of a particular cell before the full history of the outbreak unfolds, we are forced to use some statistics that are representative of the entire population of cells for all eight cases. We combined the data for all cells and note from Table 2 that the coefficient of determination, R^2, decreased to an unacceptable value for all three degrees of the polynomial. We concluded that each of the eight cases presented a different distribution of R^2 vs UMAX and MDA such that when combined, the scatter was greatly increased. In order to get a feel for this aspect, we created first order plots for each of the eight cases. These resulted in plane surfaces whose intercepts on the axis varied and whose tilt in 3-D space also varied. We sought to partially correct this by using a common origin for all eight cases, arrived at by taking the inflection point for the $Y = 1$ curve and normalizing the data points for each case by dividing those points by the inflection point values of UMAX and MDA. This procedure reduced all eight curves to the same origin but did not alter the orientation of the data planes in 3-D space. These non-dimensionalized values for UMAX and MDA were combined and regressed against the response variable, $\hat{Y}$. The results are seen in Table 2. Here we see that the cubic form accounts for over 80% of the variance which is good but may not be good enough to employ this technique to a real forecast situation. Although both the quadratic and cubic regressions for the non-dimensionalized data set provide correlation coefficients of 0.8 or better, the problem we face in extending these results to an operational forecast are apparent. In order to use a previously determined regression result between observed UMAX, MDA and $\hat{Y}$ in order to forecast for newly observed UMAX and MDA in a particular cell, some way would have to be found to reduce these new values to their non-dimensional forms. This would require obtaining the breakpoint values for the impending outbreak in advance of the tornado outbreak itself.

We approached this problem in two ways. We sought to forecast the breakpoint values of UMAX and MDA from the prevailing meteorological situation. For example, we used various combinations of the shear in the horizontal wind with height versus the breakpoint value for MDA. These results were encouraging but not conclusive. Perhaps by using more stratification of the data, we may be able to improve these regression results to the point where they would be reliable predictors. In a like manner, we would wish to examine the relationship between the convective buoyancy as indicated by the RAOB and the ensuing UMAX in a similar approach to predicting the breakpoint value for UMAX. This work was not undertaken under the contract before it terminated.

In summary, research under the contract accomplished the following:

1. We devised a way to measure the tornadic intensity of an individual thunderstorm cell in a group (5 or more cells) outbreak. We used officially determined intensity ratings by NOAA on-the-site inspections.

2. We developed the necessary mathematical and fluid flow models needed to simulate the anvil plumes which emanated from the top of individual thunderstorm cells in a two dimensional framework. We developed a tracking technique, which was programmed for McIDAS, to allow us to measure the rate of anvil expansion and the deviation of the anvil center line from the storm relative ambient wind at the anvil level.

3. We showed that a high degree of correlation existed between the tornadic intensity of a given cell and its measured descriptive parameters. Correlation coefficients of 0.9 and better were found between cells in a given outbreak and the cell's behavior. We found that on average, we could account for 0.8 or better of the variance in the response variable for an individual outbreak.

4. We believe that a generalized forecasting methodology can be developed if we incorporate standard upper air data which describes the stability of the environment in which the outbreak develops. Previous studies have shown that shear in the horizontal wind in the levels 0-4 km and the potential buoyant energy of the sounding show reasonable relationships to the intensity of the thunderstorms which form in these environments. Unfortunately, the contract terminated before we could examine this hypothesis. For any further research on this problem, we strongly urge that the merits of this approach be investigated.

Publications

Anderson, Charles E. and Kevin J. Schrab. "The Use of Satellite Imagery to Identify Tornadic Thunderstorms." 1988 In: Preprint 15th Conference on severe local storms. February 1988, Baltimore, MD, AMS, Boston, MA.

Schrab, Kevin J. "A Study on the Use of Satellite Imagery to Identify Tornadic Intensity of Thunderstorms." 1988. M.S. Thesis, University of Wisconsin-Madison.

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