1.3 ANALYSIS OF TORNADO DAMAGE ON MAY 3RD, 1999 USING REMOTE SENSING AND GIS METHODS ON HIGH-RESOLUTION SATELLITE IMAGERY

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1. INTRODUCTION

Although widespread damage occurred with the 3 May 1999 tornado outbreak, the damage track associated with the Oklahoma City tornado was unique from a satellite perspective. High-resolution satellite data from the Indian Remote Sensing (IRS) satellite was able to detect a significant portion of the Oklahoma City tornado's damage path through rural and urban areas (**Fig. 1**). While a few other tornado damage paths are detected to lesser degrees with this data, many of the other tornado tracks do not have obvious signatures in the satellite data.

In order to investigate the characteristics of tornado damage detected by high-resolution satellites, the OU Geography Department, Space Imaging, Inc., and the NASA Space Grant program acquired 5-m panchromatic and 25-m LISS multi-spectral imagery taken by the IRS satellite before (5-18-97) and after (5-8-99) 3 May 1999. Remote sensing techniques and GIS methods are used to analyze characteristics of the tornado tracks, and they are compared with detailed damage surveys conducted by members of the OU Weather Center (see Stumpf *et al*, 2000).

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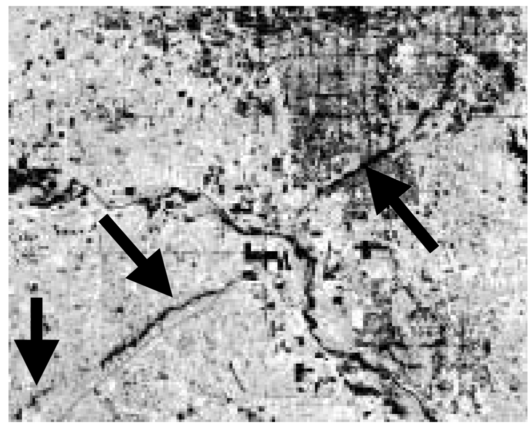

Fig. 1. Second principle component of the 25-m multi-spectral imagery with arrows pointing to the tornado damage signature of the Oklahoma City tornado.

This study represents a first step in evaluating the utility of using high-resolution satellite imagery to supplement severe weather damage surveys.

2. PRINCIPLE COMPONENT ANALYSIS

The 25-m multi-spectral data is the primary data source used in this study because it reveals more of the damage tracks than the 5-m resolution panchromatic single-wavelength data. The multi-spectral data is composed of green (0.52-0.59 μm), red (0.62-0.68 μm), and near-infrared (0.77-0.86 μm) bands that can be combined in multiple ways to classify ground conditions. A principle component analysis (Singh and Harrison, 1985) is used to determine the best linear combinations of the three bands to show the variance inherent in the data.

The results of the principle component analysis (PC) are shown in **Table 1**. Visual analysis of the three PC layers (not included here) clearly shows that the Oklahoma City tornado damage is best detected using the second principle component (PC2). It is evident in **Figure 1** that high values (black) in PC2 outside the damage track represent non-vegetated areas such as lakes, bare soil, and roads. The high values in PC2 over rural vegetation areas suggest that a significant areal change in vegetation cover is partly related to the damage signature. In order to fully understand what is causing the damage signature in the satellite data, a comparison with ground observations is essential.

Table 1: Principal component layers derived from the IRS 25-m multi-spectral imagery.

PC Layer	1	2	3
Eigen value	1646	433	26
Green	0.51	0.37	0.78
Red	0.45	0.66	-0.60
Near Infrared	0.74	-0.66	-0.17

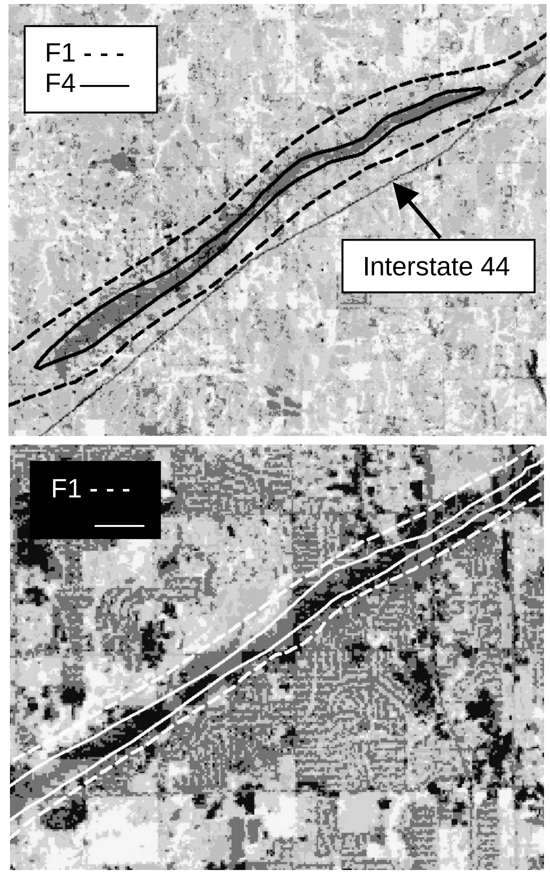

Fig 2. F-scale contours on PC2 in rural (top) and urban (bottom) areas.

3. OKLAHOMA CITY TORNADO DAMAGE CORRELATION WITH PC2

Members of the Norman Weather Center have created a detailed F-scale analysis for the Oklahoma City tornado and some of the other tornadoes on this day. The spatial patterns of the Oklahoma City tornado damage track in PC2 roughly correlate with F4 tornado damage in rural areas (**Fig. 2**). In urban areas the strongest signature is many times within areas of F3 damage (**Fig. 2**) though there is less of an overall correlation in urban areas than in rural areas. Some portions of the damage track are not detected in PC2 despite observations of F1-F3 damage at these locations. Thus, the damage signature in PC2 is most strongly correlated with strong to violent tornado damage (F3 or greater) in areas of significant areal change in landcover.

4. NDVI ANALYSIS WITH COMPARISON TO SURFACE CHARACTERISTICS

Another approach to investigate tornado damage with multi-spectral satellite data is to evaluate the health and biomass of vegetation by computing the Normalized Difference Vegetation Index (NDVI) using the red and near-infrared band values (Groten, 1993). Using satellite data before and after tornado damage allows the change in vegetation to be evaluated. The NDVI

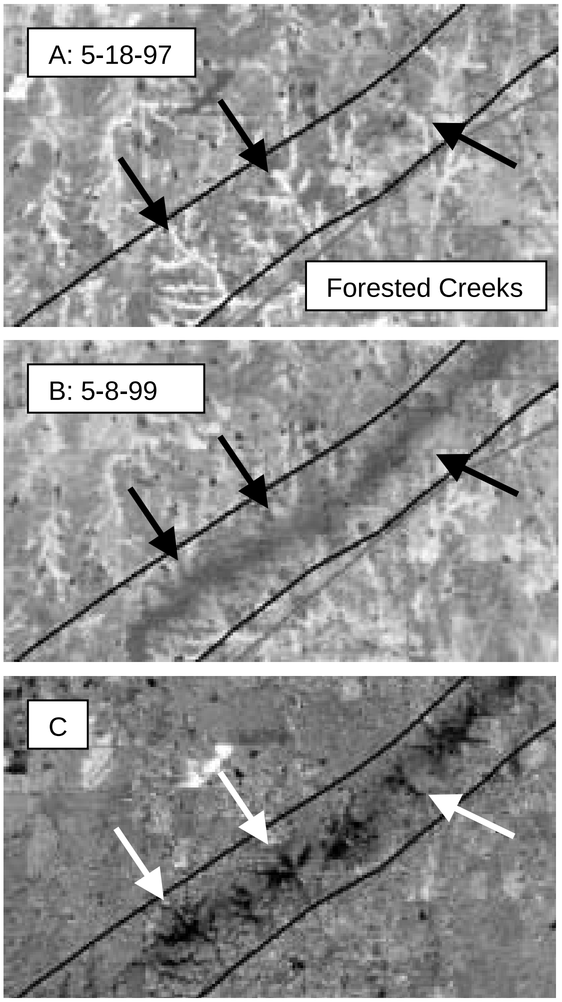

Fig. 3. NDVI images before (A) and after (B) damage and change in NDVI (C).

and change in NDVI portrays the Oklahoma City tornado's damage path similarly to PC2 in both rural and urban areas, but it shows more of the damage path (yet not all) in rural areas.

Heavily forested creek areas with significant damage are detected well using NDVI, particularly over the first half of the damage track (**Fig. 3**). Ground surveys indicate widespread vegetation destruction (trees stripped clean of vegetation, large areas of scoured and mud covered ground) throughout the rural areas containing strong signatures in NDVI. Areas of F3 damage near the beginning of the track with no signal in PC2 or NDVI suggest that variations in landcover can

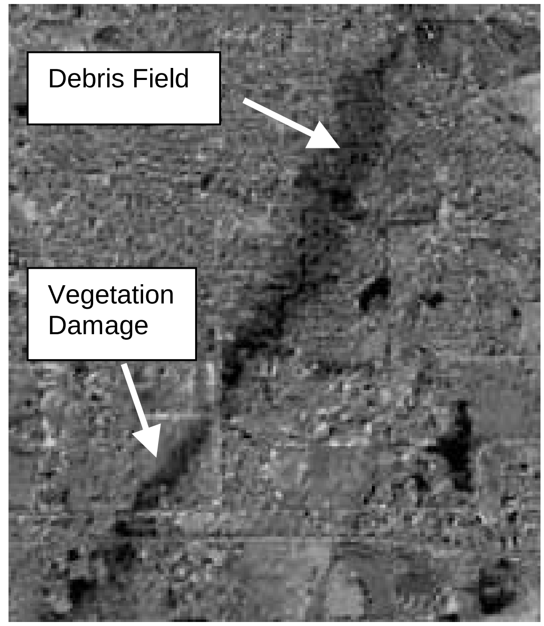

Fig. 4 NDVI change over Del City.

significantly affect the signature in the satellite data.

Ground-based observations in urban areas yield more insight into damage signatures using NDVI. **Figure 4** shows the vegetation damage in a large field and a debris field in a residential area in Del City. The ground survey documents that the field containing ankle-high damaged grass was devoid of significant debris, whereas in the residential area debris covered the ground.

5. SATELLITE SIGNATURES FOR OTHER TORNADOES

Of the 37 tornado damage paths contained within the satellite analysis region (some of which contained significant path lengths), only four other paths were well defined in the satellite data: one near Choctaw, two near Mulhall, and one near Perry. This number could be raised higher upon a more detailed evaluation of the high-resolution tornado damage track data for other tornado tracks which was not available at the time this document was created.

The Choctaw tornado damage is particularly interesting because the tornado was more narrow (220 m) and weak (primarily F1 damage with small areas of F2). NDVI shows a weak signature along much of its path, while PC2 does not show the damage track at all. The other three damage tracks were associated with stronger long-track tornadoes. The NDVI signature is stronger than the PC2 signature for these damage paths as well.

6. SUMMARY/CONCLUSIONS

A significant portion of the Oklahoma City tornado damage path was clearly detected in 25-m high-resolution multi-spectral satellite imagery. The damage tracks in the satellite data represent significant areal changes in landcover resulting from damaged vegetation and large debris fields. Further analysis is needed to determine why the large amount of other tornado damage on this day does not show up as clearly as the Oklahoma City tornado damage.

Four other tornado damage areas were detected in the multi-spectral satellite imagery. Though three of the damage tracks were associated with some of the more significant tornadoes of the outbreak, one narrow damage track primarily contained F1 with some F2 damage. Thus, landcover characteristics may be just as important as tornado damage intensity in determining whether a particular damage track can be detected using high-resolution satellite imagery.

This study has demonstrated the utility of using high-resolution multi-spectral satellite data to observe the significant areal changes in landcover associated with tornado damage tracks. A principle component analysis and an NDVI analysis were found to be useful in diagnosing damage areas. Even higher resolution satellite data is now commercially available (5-m spectral and 1-m panchromatic) with the IKONOS satellite. Follow-on projects are planned to continue investigating severe weather damage with this high-resolution data. If satellite signatures of surface damage can be shown to be common among certain landcover types (e.g. heavily forested areas), there may be areas of the world that could benefit from using remote sensing to supplement severe weather ground surveys.

7. ACKNOWLEDGEMENTS

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