233

USING DUAL POLARIMETRIC RADAR TO ASSESS PRESCRIBED AND WILDLAND FIRE INTENSITY IN FLORIDA

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1. Introduction

Plumes associated with fires have been frequently observed using Doppler radar. Most studies have involved using horizontally polarized radar data. Banta et al (1992) observed a forest fire in Colorado using an X-band radar. Though primarily focused on horizontally polarized reflectivity, circular depolarization was used to infer the shape of the scatterers. Hufford et al (1998) used radar as part of a multiplatform observation of an Alaskan wildfire. Tsai et al (2009) used a W-band radar and lidar to investigate a prescribed burn. Jones and Christopher (2010a and 2010b) used NEXRAD radar along with satellite data to describe 2009 grassfires in Oklahoma and Texas. Though not a wildfire, Rogers and Brown (1997) used radar to observe an industrial fire plume. While not exhaustive, this list provides an overview of the scope of the literature.

Papers involving polarimetric radar observation of smoke plumes, and wildfires in particular, are much more limited. Jones et al (2009) observed an apartment fire using a C-band polarimetric radar. Melnikov et al (2008, 2009) used the S-band KOUN radar to investigate a grass fire in Central Oklahoma, and attempted to model the scatterers involved. With its NEXRAD Dual Polarization upgrades now complete, Florida is ideal for radar observation of wildfires. The state sees a median of over 4,600 wildfires and typically authorizes over 120,000 prescribed burns annually with a diverse set of fuels. Smoke plumes are regularly visible on radar, and can be easily matched to known wildfires and authorized prescribed burns with records kept by the Florida Forest Service (FFS).

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Polarimetric radar data can now be investigated further to determine fire character, and perhaps future behavior. It is important to note that radars within the NEXRAD network are not sensitive enough to detect the smoke in a fire plume. Rather, they are detecting scattering from pieces of debris, either burned or unburned, lofted within the smoke. However, for the sake of simplicity, we continue to refer to what appears on radar as a smoke plume.

2. Dataset

The primary challenge in constructing a dataset for this study was selecting a subset of the available data which contained a full range of wildfires and prescribed burns of various techniques and fuel types from multiple radar installations. Radar data from Jacksonville (KJAX), Tampa Bay Area (KTBW), Melbourne (KMLB), and Miami (KAMX) were used.

To maximize the potential of seeing plumes on radar, a number of candidates were selected from the Florida Forest Service's Fire Management Information System (FMIS) to match both size and distance criteria. Candidates were generally defined as having occurred within 50 miles of a radar, and of sufficient size (100 acres for wildfires, 300 acres for prescribed burns). An exception was made for KAMX, where the distance filter was extended to 100 miles, and the prescribed burn threshold reduced to 100 acres. This was done in order to include burns associated with the harvesting of sugarcane. These burns occur in a region beyond 50 miles of any radar, and are typically around 100 acres or less in size. However, because of the technique used, the fires are very intense, and are usually visible on KAMX.

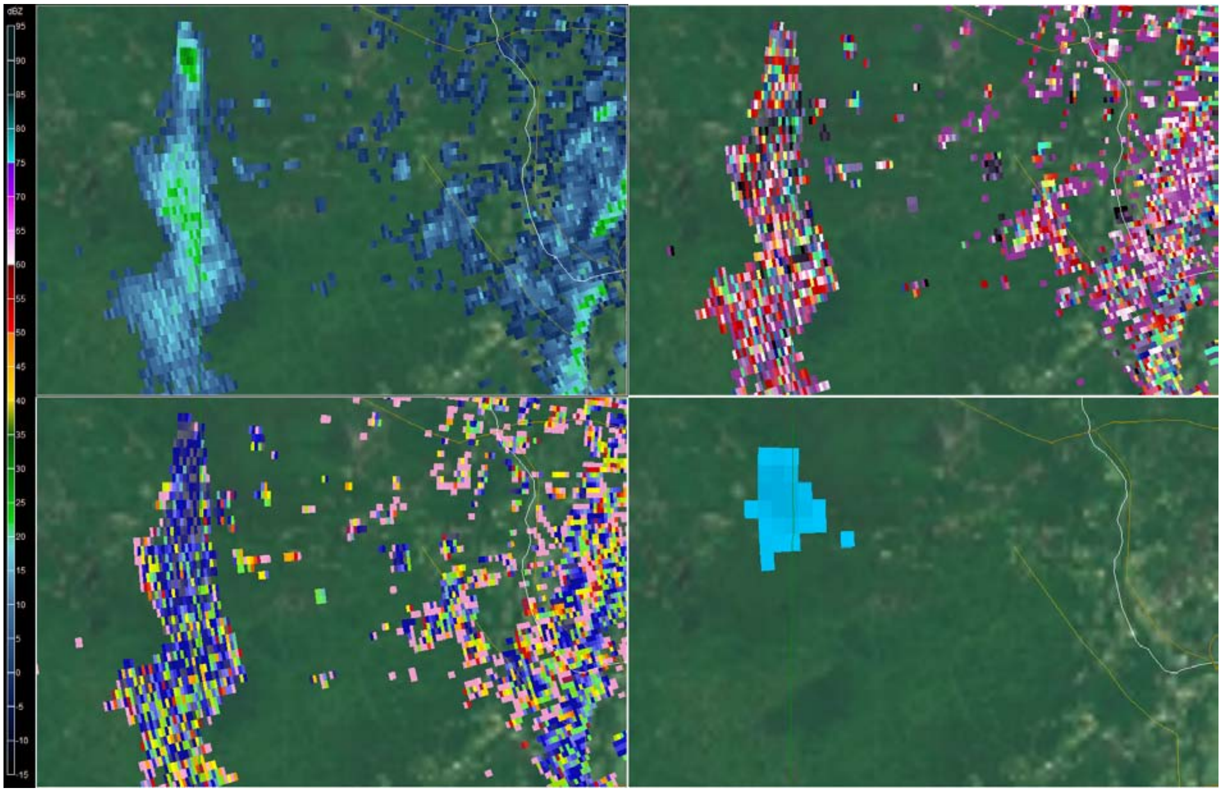

Figure 1. KJAX at 1946 UTC on April 6, 2012. Panels are, clockwise from upper left: reflectivity, differential reflectivity, echo tops, correlation coefficient.

The results of the candidate selection resulted in an overly large dataset. From this pool, 91 days were selected to investigate the polarimetric character of fires. All days with qualifying wildfires were chosen, as well as a number of days with the greatest number of qualifying prescribed burn authorizations. This maximized the probability of having visible plumes, as well as having a greater diversity of burn techniques. Level II radar data was obtained from the National Climatic Data Center for the selected dates, and viewed with GR2Analyst software from Gibson Ridge.

3. Observations of Prescribed Burns and Wildfires

3.1 County Line Fire

The County Line fire was a lightning-ignited fire that started on April 5, 2012. A large, multiple-day fire, it ultimately burned nearly 35,000 acres in Northeast Florida. A radar image from this fire on April 6 is shown in Figure 1. About three hours before the moment in Figure 1, the size of the fire was estimated at 312 acres, and by the next day, it had grown to over 4,500 acres.

At this time, the fire was growing, but was still relatively small and only had a maximum reflectivity of 31 dBZ. It did, however, have an established updraft column, with echo tops at nearly 16,000 feet. The plume demonstrated typically positive differential reflectivity (Z_{DR}) and low correlation coefficient (CC), in keeping with observations in the existing literature. This reaffirms the radar's observation of horizontally oriented, non-meteorological echoes.

However, there appear to be more subtle patterns within the plume. Near the fire's source and updraft column, there was an area of generally near-zero, or even negative Z_{DR}. Downstream, Z_{DR} was considerably larger. This "hole" of lower Z_{DR} was common in observed plumes while actively burning.

Correlation Coefficient (CC) was quite low, as expected for a non-meteorological return. Near the fire column, CC was very low – as low as 0.2 – and increased downstream. The area near the updraft may have had tumbling debris, and like hail, this may have created the anomalous area of differential reflectivity. In addition, the stronger updraft may loft larger pieces of debris that are not supported downstream, and fall out of the resolution volume in those parts of the plume. This creates a more heterogeneous population near the updraft, depressing CC even more.

While the downstream growth of differential reflectivity and correlation coefficient was essentially universal, the area near the updraft with coherent areas of lower Z_{DR} and CC did not appear to be as frequent over the dataset. However, it was a common feature in larger and/or more intense fires. It is possible that these features also could exist in smaller, less intense fires, but be difficult or impossible to discern. Less intense fires may not be able to generate enough net differences over a large enough volume to overcome the noise inherent in the polarimetric observations.

3.2 Merritt Island Prescribed Burn

On January 31, FFS authorized a 2,100 acre prescribed fire on Merritt Island. Because of its size and relative proximity to KMLB, the plume became a major feature. The burn was an aerial ignition, which is typically an intense initiation for prescribed fire. Smoke was quite heavy, and even forced the closing of the nearby Kennedy Space Center for a time.

Figure 2 shows a scan from the afternoon of the burn. This plume is very intense, with a maximum reflectivity of 53 dBZ. However, the plume does not rise to a very high height. This is likely due to a strong inversion present near 850 mb, capping the rise of the plume. Though not pictured, the plume drops off rapidly in higher elevation scans, with no echoes present much above 10,000 feet. This would serve to concentrate more smoke in the lower atmosphere, increasing the reflectivity in lower elevation scans and increasing the probability of smoke concerns.

Like the County Line fire, this burn also demonstrates lower Z_{DR} near the fire column, though not quite to the same extent seen in the County Line plume. The value of Z_{DR} also shows a trend of increasing downstream, though there is no contiguous area of negative Z_{DR}. CC is also very low near the fire column, and becomes somewhat greater downstream. There seem to be two explanations for this pattern, though it is unclear whether one mechanism or the other is responsible, or if there may be a mixture of the two. One thought is that downstream from vertical motions related to the fire plume, a preferred species of light, needle or plate-shaped debris settled in a horizontal orientation to the wind. Other scatterers appear to have dropped out of the plume, thus the characteristics of this particular piece of debris dominate the sample volume. Another possible explanation is that downstream, there may be potential nucleation effects by condensation or glaciation. This would also result in an increase in both Z_{DR} and CC. Without in-situ measurements of the plume, it is difficult to say which of these explanations is occurring, or if both are acting in tandem. In cases of

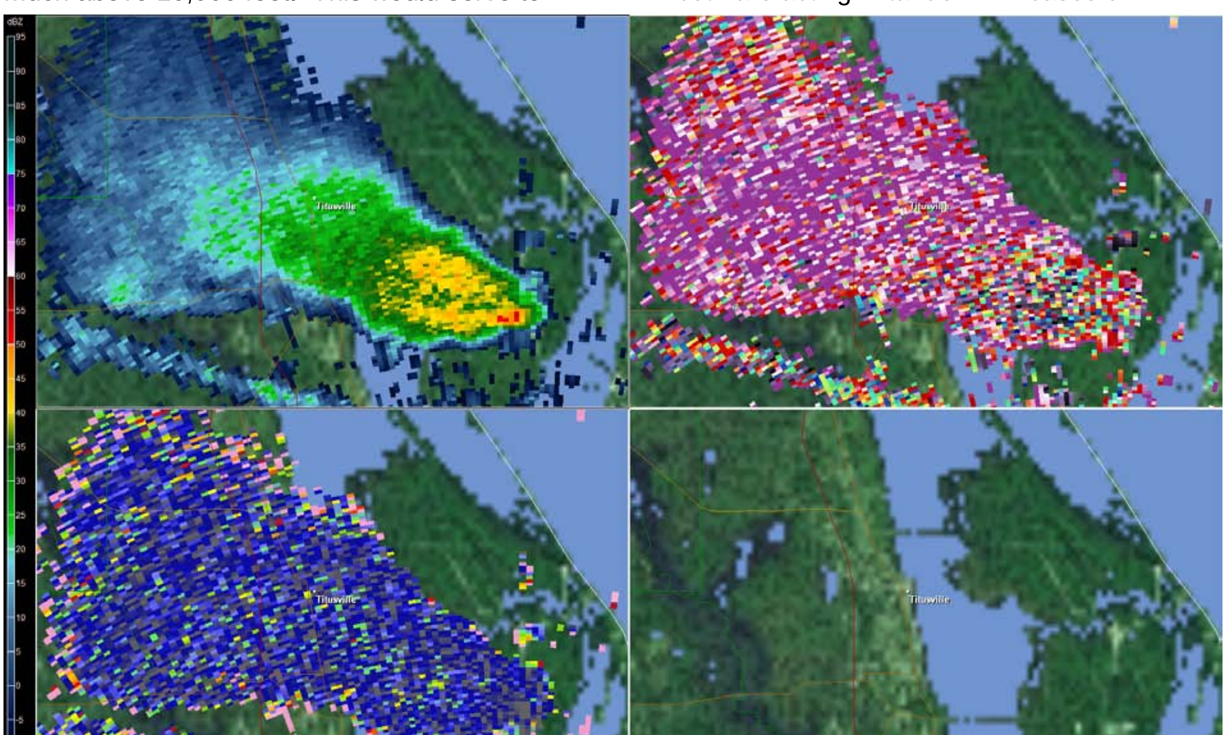

Figure 2. KMLB on January 31, 2143 UTC. Panels are as in Figure 1.

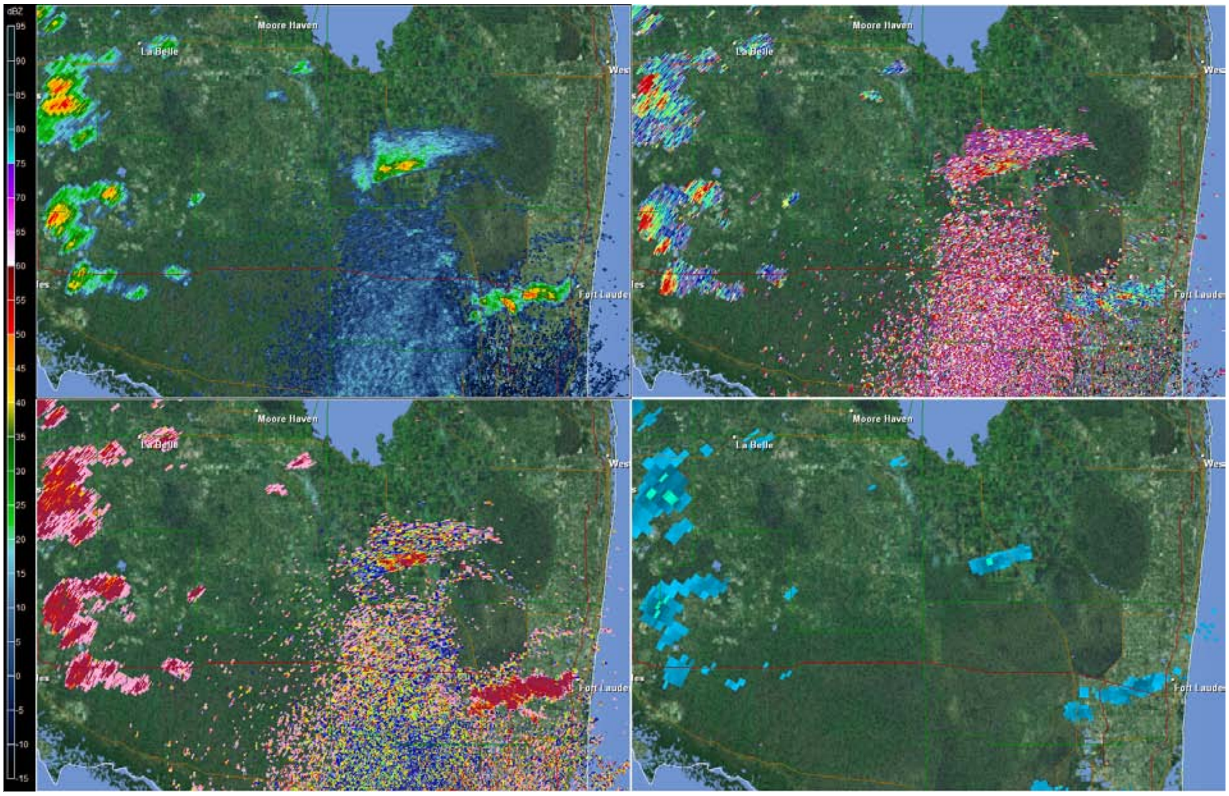

Figure 3. KAMX on May 15, 2012 at 1759 UTC. Panels are as described in Figure 1.

pyrocumulus formation, it is almost certain that some type of nucleation is taking place.

4. Unique Situations

4.1 Discerning Between Rain and Fire

Using only horizontally polarized radar data, it can sometimes be difficult to discern between a smoke plume and isolated rain showers. An example of this is shown in Figure 3, from the West Holey Lands fire in southwest Palm Beach County. Here, a key usefulness of polarimetric data is highlighted. In Florida, the period of highest fire activity blends with the onset of the summer rainy season. Plumes and isolated thunderstorms are often seen together during this time. Polarimetric variables make the task of discerning rainfall from fire related echoes very simple. The higher Z_{DR} and lower CC values in plumes stand in stark contrast to the generally lower Z_{DR} and much higher CC seen in rain. In fact, this figure potentially shows the development of rainfall from pyrocumulus clouds. At the time shown in the figure, there is already rainfall commingling with the plume. This is very difficult to determine from reflectivity alone, but the notable changes across CC and Z_{DR} show the emergence of rainfall very clearly. In subsequent scans, the area of rainfall came to dominate the area, putting an end to the smoke plume.

4.2 Interaction with Clutter and Noise

Radar detection of fire plumes is most effective at gauging fire intensity near the radar, where the 0.5 degree scan is nearest the ground. At greater distances, the resolution volume of a particular bin will be farther from the ground, and disconnected from activity happening at the surface. However, observations at close distances can be

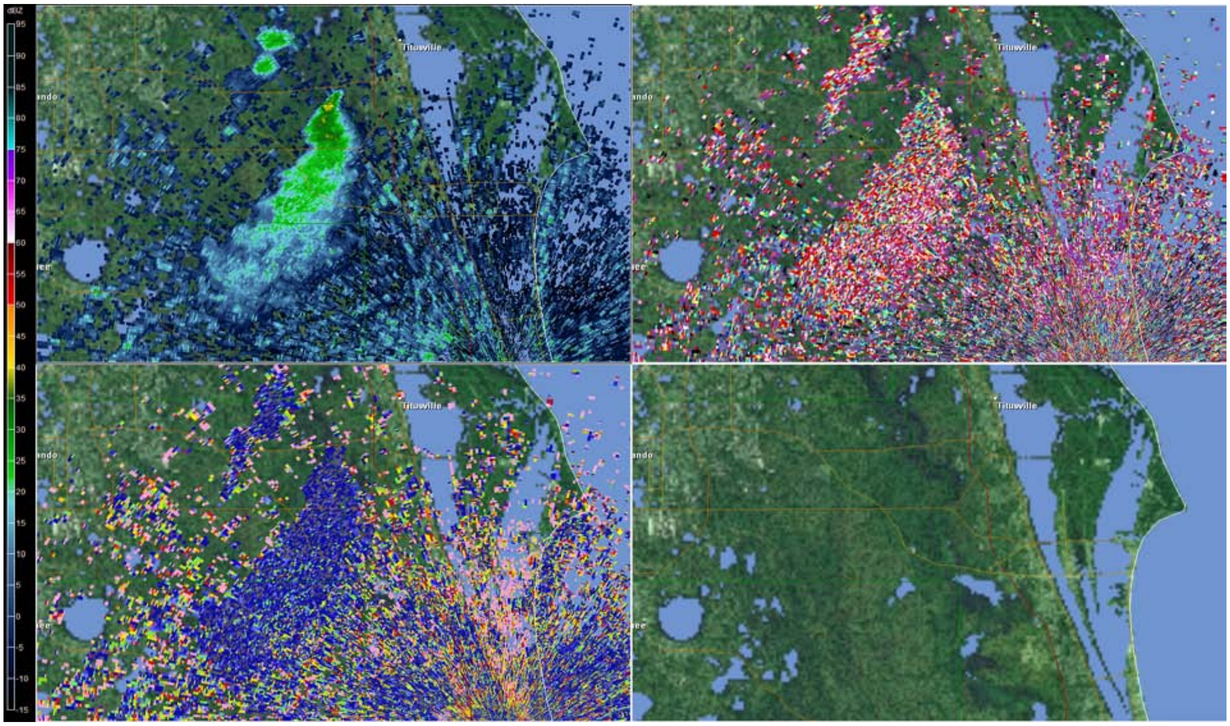

Figure 4. KMLB on February 20, 2012 at 1914 UTC. Panels are as described in Figure 1.

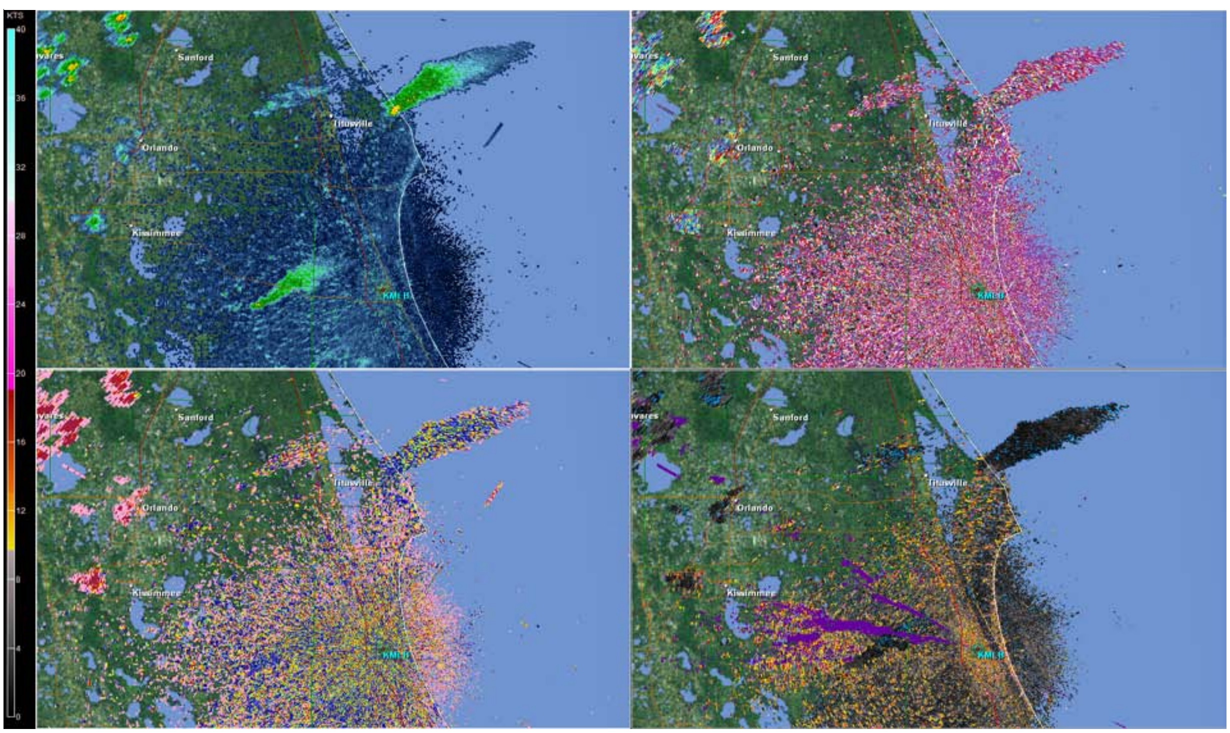

Figure 5. KMLB on July 25, 2012 at 1741 UTC. Clockwise, from upper left: reflectivity, differential reflectivity, spectrum width, and correlation coefficient

challenged by noise. There are occasions when the clutter pattern may introduce contrast between the plume and the noise in the polarimetric variables, as seen in Figure 4 with the Brighthouse Fire in East Central Florida. For both Z_{DR}, and to a somewhat lesser extent with the CC, values in the plume are sufficiently different from the background clutter that they stand out very well. Also in Figure 4, one can see the pattern of decreased Z_{DR} and CC near the fire column, and an increase in those variables downstream.

Many times, however, clutter near the radar serves to mask the smoke plume. An example of this can be seen in Figure 5. The plume from a prescribed burn on Merritt Island is outside the clutter region, and is visible both in the polarimetric variables, as well as more traditional products like reflectivity and spectrum width. The plume from a prescribed burn to the west of KMLB in Osceola County faces a different situation. While a plume can be discerned from the background noise with significant effort, it is clearly a far from ideal situation. In contrast, the burn is large enough to create a smoke plume that easily stands out from background clutter in reflectivity. Further, the very small amount in the variation of scatterer velocity (since the debris is blown on the wind) makes the plume stand out very easily from clutter in the little used spectrum width product. Polarimetric variables often provide a chance to glean information about smoke plumes, but sometimes the legacy NEXRAD products reflectivity and spectrum width display the plume best.

4.3 Plumes After Active Burning Ceases

To this point, most attention has been paid to fires while they are actively burning. Previous literature implied the plumes remained relatively

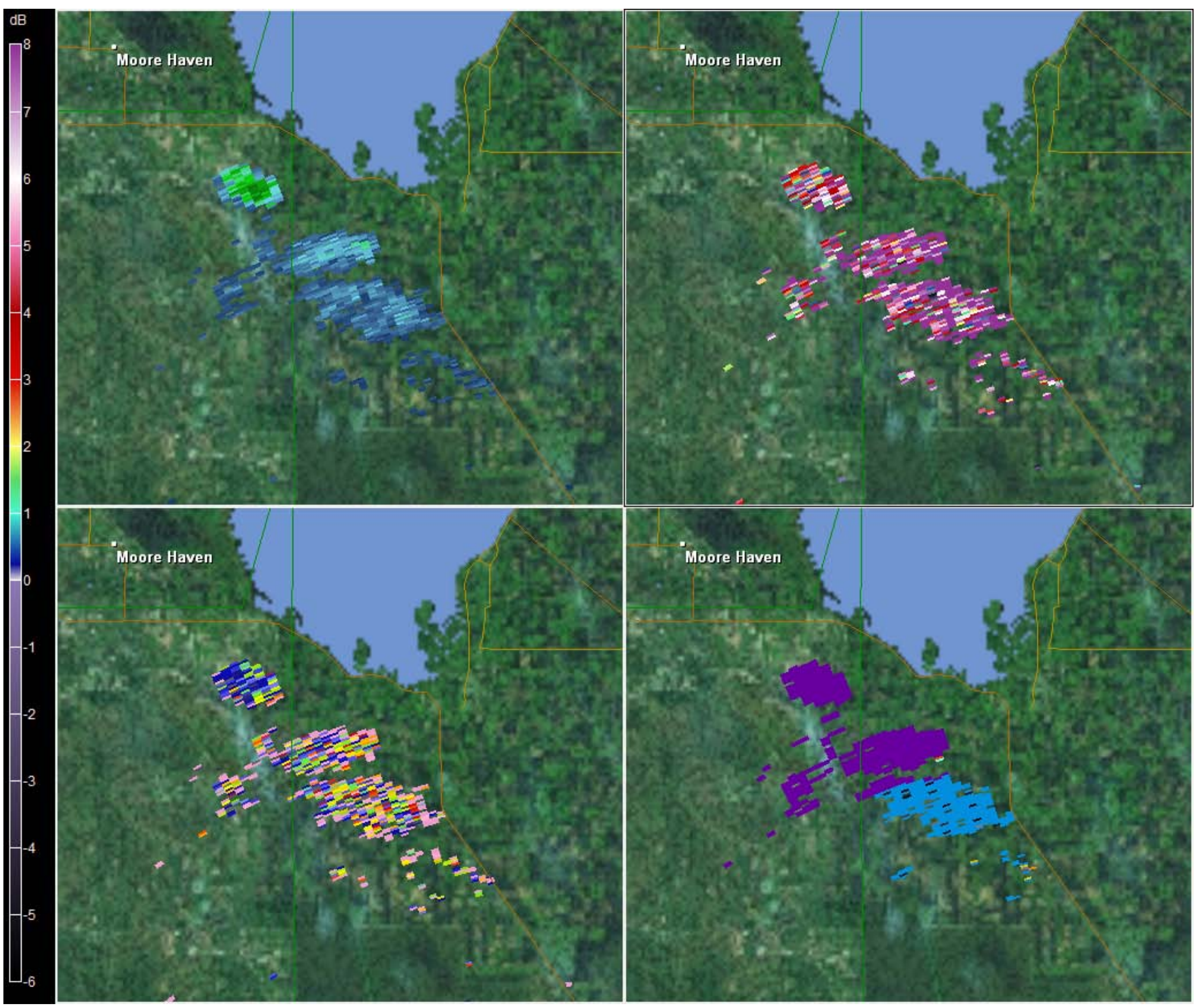

Figure 6. KAMX on April 12, 2012 at 1940 UTC. Panels as in Figure 5.

steady state spatially and temporally. However, this does not appear to be the case. The polarimetric variables do seem to show the tendency to change over time, though patterns are admittedly difficult to discern from noise within the plume.

It appears that large values of differential reflectivity and correlation coefficient present in the downstream portions of the plume come to dominate the remnant plume after the fire has stopped burning actively enough to contribute to a plume visible on radar. If the fire associated updraft column is indeed tumbling debris and/or introducing larger debris not seen in other parts of the plume, it follows that once that updraft is removed, those features and their effects on the polarimetric observations (principally Z_{DR} and correlation coefficient) should end.

This can be seen easily with sugarcane burns, which tend to be temporally short, but intense. Figure 6 shows an example of such a sugarcane burn at two different times. There is an active plume with noticeably lower differential reflectivity and correlation coefficient compared to downstream remnants of plumes to the southeast, from burns that have been completed. This particular feature can be of use to forecasters and land management personnel to remotely determine the fire's status. It may not be enough to make a solid estimate of intensity, but could at least be used as a rough estimate of whether or not a fire is actively burning.

4.4 Effects of Scan Strategy

The absolute values of the polarimetric variables in smoke plumes do tend to change depending on the scan strategy invoked on radar. When "clear-air" scan strategies are used, Both Z_{DR} and correlation coefficient tend to be lower than when "precipitation" strategies are invoked. Correlation coefficient is much more strongly affected than Z_{DR}. Because smoke plumes are often at the very margins of the NEXRAD's sensitivity, this could occur due to the small change in sensitivity by the different

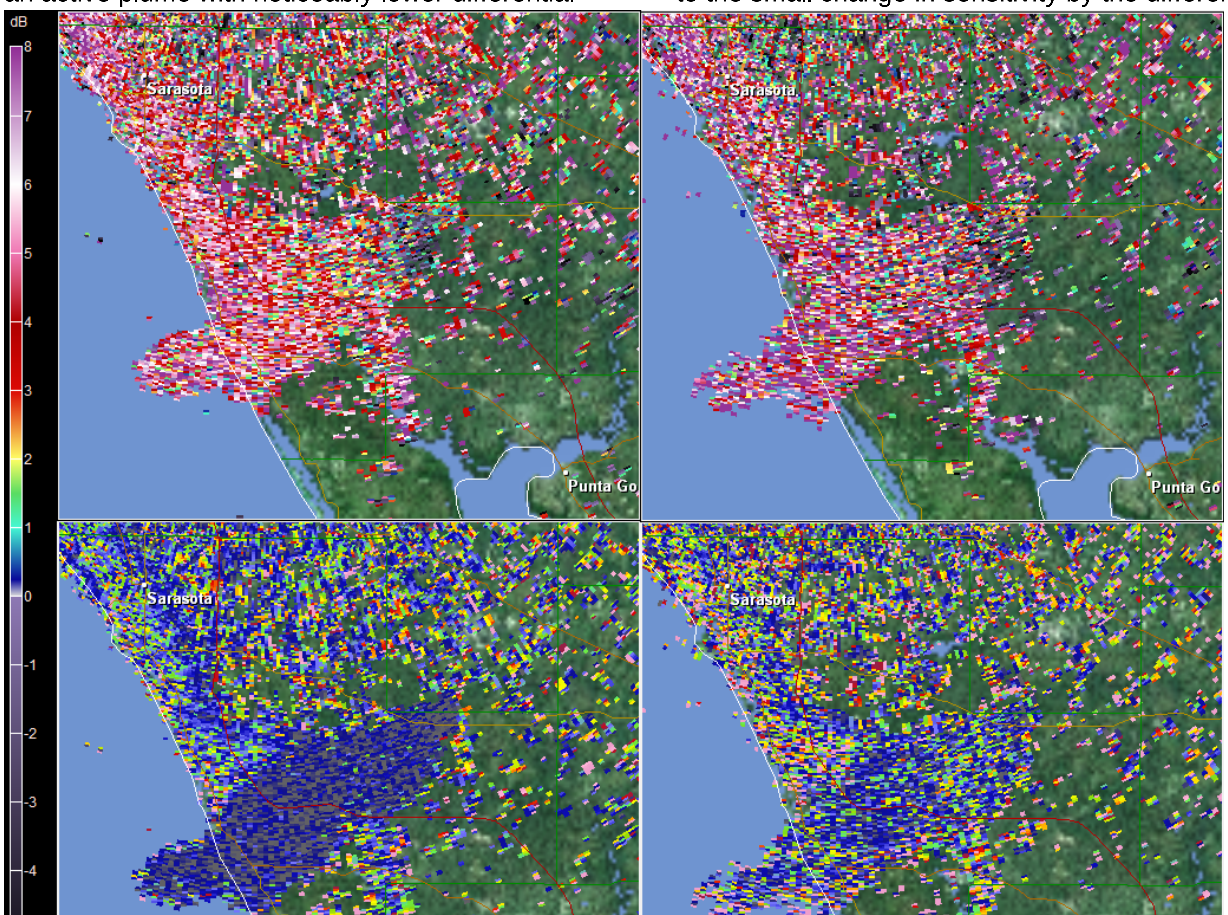

Figure 7.Polarimetric variables from KTBW for a wildfire in Myakka River State Park on May 25, 2012. The top panels represent differential reflectivity, and the bottom panels correlation coefficient.The left panels are from the 1853UTC volume scan in VCP 32. The right panels are from the next volume scan at 1902 UTC, in VCP 212.

scan modes. The slower, more deliberate clear-air scanning mode may be able to discern more species of particles within the plume than the precipitation scans.

The more heterogeneous population of scatterers within a sample volume may result in lower values of correlation coefficient in the clear air scans. Additional scatterers may not be needle-shaped or a horizontally oriented plate (or at least, not to as great an extent), which would reduce the observed Z_{DR}. This may be analogous to the incidence of increasing Z_{DR} and CC downstream in a plume, though in that case the scatterers are simply no longer present in the plume, rather than outside the sensitivity of the radar. The key is that the current scan strategy of the radar must be considered when assessing a smoke plume using polarimetric data.

This effect can be seen in Figure 7, which shows Z_{DR} and CC from two consecutive volume scans from KTBW during a wildfire in the Myakka River State Park on May 25, 2012. The leftmost panels are from a scan in VCP 32, a clear-air scan. The next scan in the rightmost panels is in VCP 212, a precipitation mode. The Z_{DR} is difficult to separate from the surrounding clutter, but the plume does tend to “purple”, or increase in value (see legend on left edge of the figure) from one scan to the next. A similar increase is seen in the correlation coefficient panels on the bottom.

5. Summary

Dual polarization upgrades to the WSR-88D network have created a greater potential for observing wildland fire plumes than has been seen before. Investigating plumes from wildfires and prescribed burns in Florida during 2012 have mostly confirmed findings from previous studies in other areas, but have also revealed additional interesting features:

- Differential reflectivity is usually higher than in rain, and is generally close to what was described in previous instances. Correlation coefficient is also similarly low to previous descriptions.
- Near more intense fire columns, differential reflectivity is lower, and can even be near zero or even slightly negative in very intense fires. Correlation coefficient also tends to be lower than usual. This may be caused by tumbling of the needle-shaped predominant scatterers, as we see with hail. Also, the strong updrafts could be lofting other debris that is not present in the plume downstream.
- Well downstream, differential reflectivity and correlation coefficient increase and are often larger than described previously. This area also tends to dominate the entire plume after the fire becomes less active or stops. This could be because the part of the plume where upward motion is weaker becomes dominated by a particular piece of debris that is very non-spherical, horizontally oriented and is very easily carried by the wind. In some instances, particularly when correlation coefficient rises to levels seen by meteorological echoes, this increase might be enhanced by the scattering particles become glaciated or water covered, which would also increase differential reflectivity and correlation coefficient.
- Scanning strategy impacts the polarimetric characteristics, and need to be considered. Correlation coefficient reacts most strongly to change in VCP, with the greatest difference between precipitation and clear air scans, though some differences can also be seen between particular scans of one type. This also impacts differential reflectivity to a smaller extent, resulting in larger values. Since smoke plumes are working at the margins of the WSR-88D’s sensitivity, it’s possible that this occurs because some scanning strategies can no longer “see” some scatterers, and preferentially select a certain, more homogeneous population, likely those that dominate the downwind portions of the plume.

These results confirm that polarimetric radar is very useful in identifying plumes from wildfires. They also imply that it may be possible to gauge the relative intensity of fires based on their polarimetric characteristics. This could potentially be of significant use to forecasters and fire management personnel. The noisy nature of the polarimetric variables, particularly in areas of low correlation coefficient makes more definitive conclusions difficult without more quantitative work.

A caveat exists for the National Weather Service. Because of this noise, the polarimetric variables are processed before being seen in AWIPS. The data visualized in GR2Analyst has not undergone this processing, which could potentially diminish or eliminate these features. While there is some indication that these patterns are still visible for particularly large and intense fires, it is unknown to what extent they can be observed in AWIPS.

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