SEARCH FOR A MATHEMATICAL MEANS OF AUTOMATED METEORITE FALL IDENTIFICATION. M. A. Broussard[1,2], M. Fries[3], A. Farnsworth[4], [1]Lunar and Planetary Institute (USRA), Houston, TX, [2]University of Louisiana at Lafayette, Department of Chemistry, Lafayette, LA, [3]Astromaterials Research and Exploration Science (ARES), NASA Johnson Space Center, Houston, TX, [4]Cornell University, Cornell Lab of Ornithology, Ithaca, NY.

Introduction: Some meteorite falls are identifiable in weather radar imagery. Since 2012, there have been 11 confirmed meteorite falls visible on weather radar. Meteorite falls are identified and located using eyewitness reports of fireballs and sonic booms. Weather radar provides an additional source when locating falls [1].

The National Oceanic and Atmospheric Administration (NOAA) operates the Next Generation Weather Radar (NEXRAD) network. The NEXRAD network consists of 160 Doppler radars that provide nearly complete spatial coverage of the United States. The radar data is continuously collected and made available in near-real-time online. Previous radar data is also available online in archives dating back to 1992 [2].

The radars collect data by sweeping at various elevations, angles above the horizon [2]. Each sweep divides into pixels with better resolution and smaller pixel sizes closer to the radar. Pixels can contain six different values (Fig. 1).

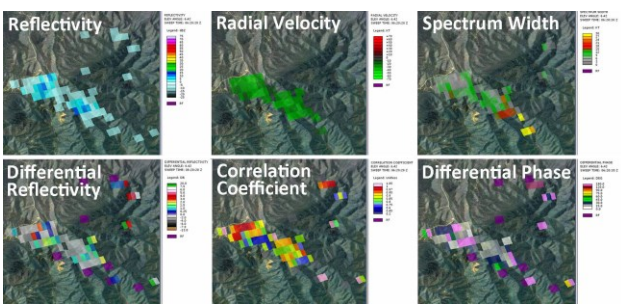

Figure 1: Radar imagery showing the six radar products for the 2012 Battle Mountain meteorite fall.

NEXRAD has collected three basic types of radar data since inception – reflectivity, velocity, and spectrum width [2]. Reflectivity is the strength of the radar return measured in dBZ, a logarithmic scale [3]. Radial velocity is the speed and direction of objects relative to the radar. Since radial velocity is not an intrinsic physical property of the detected objects, it was excluded from the statistical analysis. Spectrum Width is the variation of velocities within a radar pixel.

In 2012, the NEXRAD network was updated, to include dual polarization. This new capability made three additional data types available [4]. Differential Reflectivity represents the shape of the object. Correlation Coefficient is the consistency of the shapes and sizes within a pixel. Differential Phase is how much the horizontal and vertical pulses slow down compared to each other.

The hypothesis that meteorite falls feature a unique signature, distinguishable mathematically from other reflectors in NEXRAD weather radar data was addressed using Principal Component Analysis (PCA). If meteorite falls have a signature unique from that of other reflectors, then it can be used in the future to identify previously unknown falls in archived data and to automatically detect falls as they occur.

Methods: We created a data set containing five weather radar products for examples of meteorites and common reflectors in weather radar. The meteorite data was from ten meteorite falls that have occurred since the dual polarization update in 2012.

- Unnamed fall near Addison, AL (2012)
- Battle Mountain, NV (2012)
- Creston, CA (2015)
- Dishchii'bikoh, AZ (2016)
- Glendale, AZ (2018)
- Hamburg, MI (2018)
- Mount Blanco, TX (2016)
- Osceola, FL (2016)
- Unnamed fall in Pacific near, WA (2018)
- Sutter's Mill, CA (2012)

The unnamed meteorite falls produced recovered meteorites but are pending submission/approval into the MetSoc database. The NOAA Weather and Climate Toolkit was used to download the Level II NEXRAD Dual Polarized weather radar data. Each file contained the values for one of the products at one elevation for all the pixels in the frame. One full sweep of radar contains hundreds of thousands of pixels, so before downloading, only the pixels related to the meteorite fall were selected.

Examples of other common radar reflectors were downloaded using the same process. They included migrating birds, bats, chaff (a radar decoy used by the Air Force [5]), haboobs (a type of dust storm), fog, hail, rain, tornados, and wintry mix containing snow, hail, and sleet. Three examples of each feature at three different elevations were downloaded by zooming into an area that contained approximately 200 pixels. Seven examples of possible, yet unconfirmed meteorite falls,

and three examples of falling space debris were also downloaded.

Results: Pixels that did not contain all five of these radar products were removed from the data set. Also, "Range folding" errors were removed, which are uncertain measurements assigned a value of 800 by the NEXRAD algorithm. The reduced data set was processed using Principal Component Analysis (PCA). PCA is a statistical method that projects multivariate data so that the data can be simplified and graphically represented. The method works by creating new uncorrelated variables called principal components based on variance [6]. Orange Data Mining version 3.29.3 was used to conduct a PCA analysis of the radar data. In the PCA widget, the component selection was set to 4 to achieve an explained variance of 90% which is a typical setting for PCA analyses. The option to normalize variables was also selected. In the scatter plot widget, Orange's "Find Informative Projections" function was used to rank the different axis combinations. The plot with the greatest separation had PC1 on the x-axis and reflectivity on the y-axis.

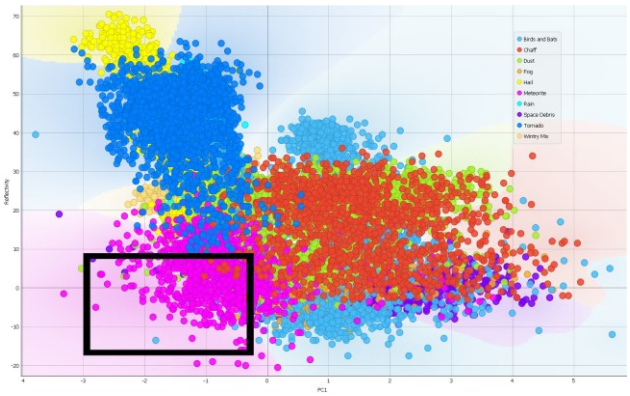

Figure 2: PCA plot of the radar data types. The x-axis is PC1 and the y-axis is Reflectivity. Magenta data points are meteorite falls and the black box indicates significant separation from other reflectors in PC1/reflectivity space.

Results of the PCA analysis show some differentiation in data types (Fig. 2). The first step in the statistical treatment of the results was the determination of the standard deviation (SD) for each data type and differences between means. Assuming a normal distribution of data points, for each data set 95% of all data points lie within two SD of the mean. To determine whether PCA products can be statistically differentiated by data type, we compared the difference between Reflectivity and PC1 values by comparing the mean + 2 SD values between all data types. We chose this approach because for the very large data volume involved in radar data, discriminating between data sets at the 0.95 level was estimated to be necessary to limit false positives. The only data type completely statistically differentiated from meteorites for 95% of all data points was tornadoes. Meteorites and possible meteorites had a differentiation of less than 95% meaning overlap exists between data types.

Discussion: PCA analysis may serve as a primary discriminator in identifying potential falls, but does not generate a fully unique solution for falls versus other reflectors. Meteorite signatures did produce a discrete result in PC1/Reflectivity space (Fig. 2) and a portion of this space is unique to meteorite falls (*ibid*, black box). Approximately half of the meteorite signatures produced a non-unique result overlapping with other reflectors. However, further avenues of investigation are available. One approach is to logically reduce the dataset to promote detection of meteorite falls. Some data sets such as dust, birds, and bats are found at low altitudes. Reducing the data set to examine only higher altitudes should preserve most meteorite signatures while excluding low-altitude signatures completely. Altitude can also be constrained to only the range above clouds, which would exclude most weather-related signatures while preserving identifiable amounts of meteorite fall signatures. Another possible difficulty lies in scatter noise near the radars, which can be excluded by reducing data to that outside of the relatively short-ranged volume where scatter noise predominates. Also, computation time and effort could be focused on times and places where meteor events are identified by eyewitnesses, drawing on data such as the publicly available database of eyewitness reports available through the American Meteor Society (www.amsmeteors.org). Further data reduction and rigorous statistical analysis may yield an automated method for rapid identification of meteorite falls.

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