PARTLY CLOUDY WITH A CHANCE OF CHONDRITES - STUDYING METEORITE FALLS USING DOPPLER WEATHER RADAR.

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Introduction: The NEXRAD Doppler weather radar network provides nearly continuous spatial coverage of the United States through around-the-clock volumetric scans collected by 159 WSR-88D radars. Data from these radars is available either by real-time data feed or can be retrieved from archives that date back as far as 1992. These radars can detect falling meteorites, as seen in imagery from several recent falls [1]. Since weather radars are designed to observe atmospheric phenomena at low altitudes, radar imagery of falling meteorites is typically seen from the "dark flight" portion of a fall. This means that radar imagery provides spatially accurate information about meteorite falls after they are no longer optically bright, where traditional methods of meteorite location such as eyewitness reports, security video capture and infrasound do not provide information. Also since radar information is produced at low altitude, this means that radar observation of meteorites can generate highly accurate information about their resting place on the ground. This should enable faster and more frequent recovery of freshly fallen meteorites. We present here two instances of meteorite falls captured in weather radar imagery, a classification scheme for radar observation, and general commentary.

Methods: NEXRAD radars collect data by sweeping their interaction volume with a series of scans at set elevation angles, known as a Volume Coverage Pattern (VCP). The number of sweeps, angles swept, and electronic parameters to optimize for different scan speeds and sensitivity regimes are described by different VCPs which are automatically selected based on local weather conditions. Each coverage pattern is repeated at set intervals, with individual sweeps starting from nearly horizontal (0.5° elevation) up to as high as 19.5°. Data is stored as radar reflectivity, velocity relative to the radar, and spectrum width (a measure of velocity variation within an image pixel) data as well as other products calculated from these data types. Complete volumetric scans are stored at the National Climactic Data Center and are available for download through an internet portal.

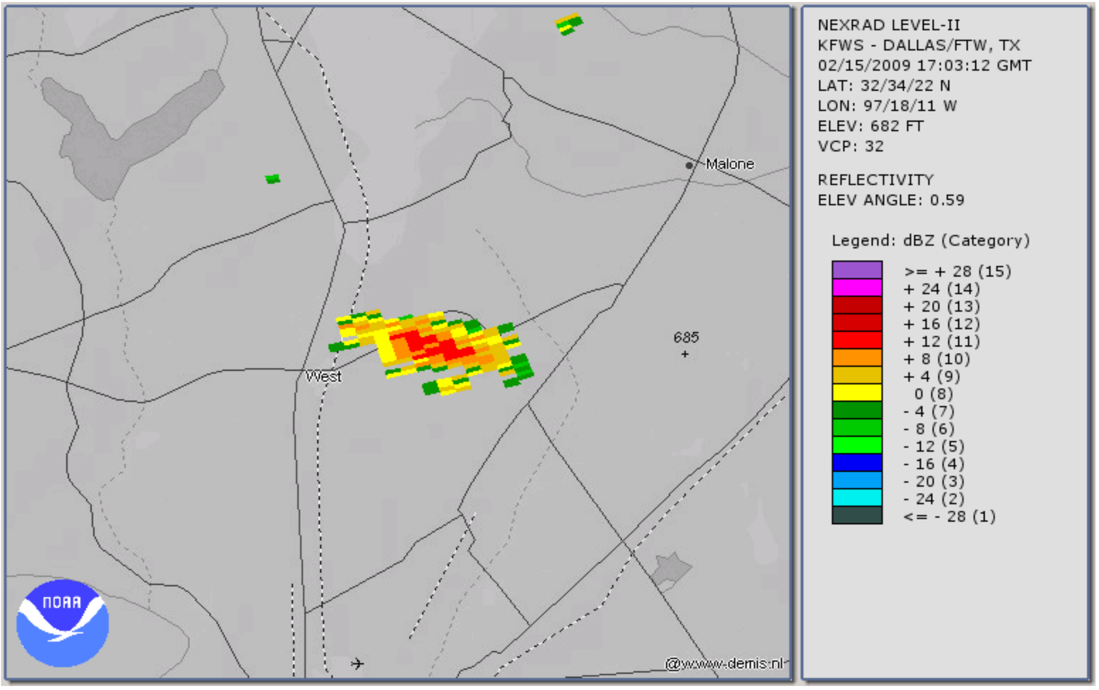

Figure 1:The Ash Creek fall outside of West, TX on 15 Feb 09 as seen in Doppler weather radar imagery. The colors in the center of the image indicate radar echoes of varying intensity reflected from falling meteorites. Meteorites were recovered from directly beneath these radar echoes.

Results and Conclusions: *Ash Creek*: The first meteorite fall to be definitively observed using weather radar was the Ash Creek fall outside of West, TX on 15 Feb 09 (Figure 1). This fall occurred within 125 km of two NEXRAD radars and is clearly seen in imagery collected by both. The first appearance of meteorites occurs at 16:59.23 UTC at an altitude of 10.6 km above local ground level (AGL). A series of images of falling meteorites are collected over about the next seven and a half minutes as the rotating radar beams interact with falling meteorites at various altitudes depending on the radar's elevation. The last recorded radar return occurs at 17:06.51 UTC and an altitude of 2.8 km AGL. Two radar returns are found at one location but different altitudes, and if we assume the radar has detected the same plume of falling material in subsequent scans then the calculated fall velocity produces a mean size of ~80g for that material. This calculation uses the generic equation for terminal velocity, assuming spherical meteorites of L chondrite density that are moving at terminal velocity. The 80g value is generally reasonable for meteorites recovered from that area of the fall, although no careful logging of finds was performed to make a definitive comparison.

El Paso: The El Paso "superbolide" of 09 Oct 1997 has been investigated and reported previously [2] but to date no meteorites have been recovered. NEXRAD radar imagery reveals new information about this event in the form of a prominent dust trail (Figure 2). This dust is observed about 38 minutes after the meteor itself at an altitude of 4-5 km AGL, placing the observed debris in the ~mg mass range based on movement at terminal velocity over a known length of time. This radar observation provides 1) the first new data on this fall in 12 years, illustrating the utility of archived radar data, and 2) a direct observation of the behavior of dust-sized meteorite debris, which historically has evaded analysis during meteorite falls.

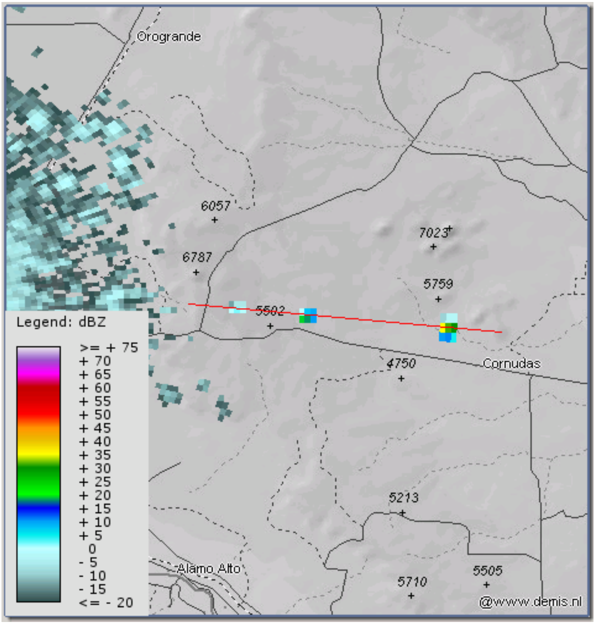

Figure 2: Falling meteoritic dust from the 09 Oct 97 El Paso "superbolide". Falling dust is seen as three bright echoes along the red line. The three echoes are points where the radar beam measures a cross-section of the linear chain of falling dust.

Classification Scheme: We classify meteorite observations into three categories based on the behavior of the meteorites at the time of observation. Type A describes a radar detection while the meteorite(s) are still in their optically bright fireball phase. This type has not actually been observed to date, mostly owing to the low altitudes of the majority of the WSR-88D's interaction volume at relatively short distances where detection sensitivity is maximized. It is probably just a matter of time before this type of observation occurs, however, as its appearance is more a matter of chance than any true physical limitation of the radar. Therefore we include it here.

Type B events describe radar observations of falling meteorites in "dark flight", when their vertical movement is aerodynamically limited. Type B examples are the most common noted out of several dozen events studied thus far. It is also the most useful of the three detection types in terms of identifying a likely strewn field for meteorite recovery.

Type C radar detections are radar observation of fine dust produced during meteorite detonation events. This dust is in the ~mg mass range and requires more than half an hour to fall into the radar's detectable volume from the 20+ km altitude where it is generated. This dust behaves like volcanic ash as far as radar detection goes, and there is sufficient development of this radar application that radars are used as dedicated volcano-watching instruments [e.g. 3]. The problem with type C events is that the dust may travel laterally many kilometers from the site of the meteor itself, diminishing the utility of this observation for locating a meteor's strewn field. The principal advantage is that observations of meteorite-generated dust allow direct analysis of the production and behavior of the dust, which is a component of meteorite falls that has generally escaped scientific inquiry.

References: [1] Fries M. and Fries J., *MAPS* In press [2] Hildebrand et al, (1999) *LPSC XXX,* Abstract #1525 [3] Marzano S., Barbieri S., Vulpiani G., Rose W., (2006) *IEEE Trans. Geo. Rem. Sens.* 44, p. 3235-3246.