DETECTING FALLING METEORITES WITH WEATHER RADARS IN AUSTRALIA.

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Introduction: Precisely calculating where meteorites land on the ground from observation of the entry phenomenon is difficult. This usually involves studying the fireball created by the hypervelocity entry, and precisely figuring out the state vector and physical characteristics of the object just before it goes into dark flight and free falls the last 20-30 km to the ground.

Weather radars operating in C or S-band can reflect off falling rocks [3]. Thanks to openly accessible weather radar data in the USA, a number of meteorites have been recovered in North America over the past decade [1,2],

These successes have been largely thanks to the availability of the data, and the radar network density across the USA. Open data and accompanying documentation allows anyone, even non-radar specialists, to easily cross-match radar detections with atmospheric events of interest. Network density increases the chance of a particular atmospheric event of interest being picked up.

These two factors taken together likely explain the success of meteorites recovered using radar in North America, and lack elsewhere in the world, even in places where radar networks exist.

Data and methods: A recent initiative [4] has made weather radar data acquired by the Bureau of Meteorology in Australia openly accessible via the Australian Unified Radar Archive (https://www.openradar.io/). Alongside this effort, example code is provided to enable easy automation of access and processing.

We have mined this dataset for meteorite reflections by cross-matching it with known meteorite falls. Australia is home to the world's largest bolide monitoring network in the world, the Desert Fireball Network (DFN) [5,6]. We first cross-match between the meteorite falls observed by the DFN and weather radar data. For each DFN bolide with a calculated surviving mass, we determine which radar stations are within a reasonable range (300 km). For each matching radar we retrieve the volume files from the time of the fireball up to 30 minutes after (typical meteorite flight time is 2-15 minutes). Finally each scan is plotted as a time animation representing reflectivity values of radar returns. These animations are manually examined for unusual looking signatures.

We also investigated fireball events detected by the US government sensors (https://cneos.jpl.nasa.gov/fireballs/) over Australia. These systems detect fireballs from orbit, and have the advantage of covering a wider area. They are also capable of observing during the day.

Results and Discussion: Over 100 falls observed by the DFN were crossmatched with weather radar data. No obvious radar returns were identified. This is likely due to the low overlap between the DFN network – set in desert areas – and the radar network – typically around farming regions and populated areas. The falls observed by the DFN are also typically small (<1 kg total surviving mass). In these cases there are neither large single meteorite pieces that can single-handedly reflect S or C-band, nor a cloud of small fragments big enough to create a significant reflection. This can also explain why no returns were identified, even in cases for which radars were working nearby.

Over Australia, 16 events were recorded by the US gouvernment sensors going back to 2002, including two independently observed by the DFN [7]. These

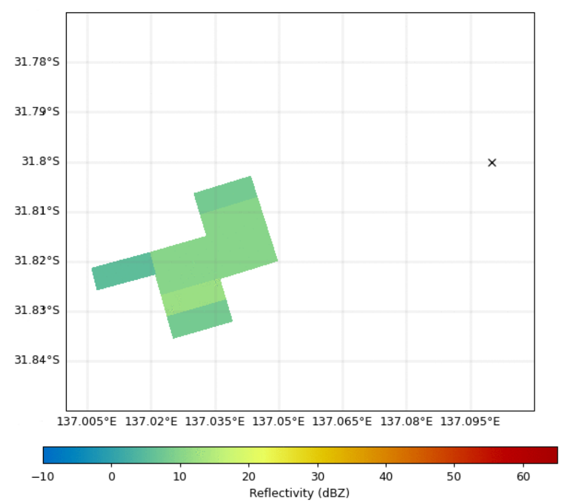

Figure 1: Reflectivity plot of the returns from Woomera radar (sweep 7). Cross marks the fireball location detected by the USG sensors.

systems only detect large events with impact energies >0.1kt. The same cross-match was applied to these events, which are significantly larger than those of the DFN. The only conclusive cross-match is for a daytime bolide that happened at 2013-07-31T03:50:14Z over South Australia. The Woomera radar (80 km distant) picked up isolated signatures, consistant in time and location with the USG bolide detection. Radar returns ([0-15] dBZ) were identified in 3 different elevation sweeps (8.5, 10.5 and 13 km) over 18 gates in total (Fig. 1). Considering the radar sweeps were made in increasing altitudes, this indicates that the meteorite cloud was already significantly size-sorted.

Based on the gates that showed a return, we calculate a strewn field using WRF atmospheric modelling and darkflight propagation code [8] (Fig. 2).

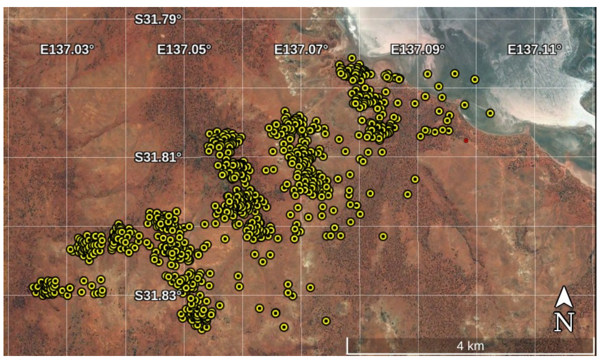

Figure 2: Initial strewn field based on Monte Carlo simulations drawn from the radar gates that returned a signal.

Future Work: We will proceed with a fine analysis of the radar returns for USG 2013-07-31T03:50:14Z, to calculate the likely mass range based on time of flight, and get a refined strewn field. As current travel restrictions are lifted, we will organise a meteorite search, likely using automated drone searching techniques [9,10].

We also aim to increase automation of the cross-match system to be able to quickly scan through large datasets, and incorporate a tool for automatically assessing the radar returns [11].

Finally, we encourage agencies collecting radar data, particularly in Europe, to make low-level reflectivity and Doppler data products openly accessible.

References: [1] Fries M., et al. (2014), Meteoritics and Planetary Science, 49, 1989. [2] Hankey M., et al. (2017), Planetary and Space Science, 143, 199. [3] Fries M. and Fries J. (2010), Meteoritics and Planetary Science, 45, 1476. [4] Soderholm J., Protat A., Jakob C. (2019): Australian Operational Weather Radar Dataset. electronic dataset, National Computing Infrastructure, doi: 10.25914/5cb686a8d9450. [5] Howie R. M., et al. (2017), Experimental Astronomy, 43, 237. [6] Devillepoix H. A. R., et al. (2020), Planetary and Space Science, 191, 105036. [7] Devillepoix H. A. R., et al. (2019), Monthly Notices of the Royal Astronomical Society, 483, 5166. [8] Towner M. C., et al. (2021), arXiv e-prints, arXiv:2108.04397. [9] Anderson S., et al. (2020), Meteoritics and Planetary Science, 55, 2461. [10] Citron R. I., et al. (2021), Meteoritics and Planetary Science, 56, 1073. [11] Smeresky B., et al. (2021), Meteoritics and Planetary Science, 56, 1585.