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Comparing eyewitness-derived trajectories of bright meteors to ground truth data

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Abstract

The NASA Meteoroid Environment Office is a US government agency tasked with analyzing meteors of public interest. When queried about a meteor observed over the United States, the MEO must respond with a characterization of the trajectory, orbit, and size within a few hours. If the event is outside meteor network coverage and there is no imagery recorded by the public, a timely assessment can be difficult if not impossible. In this situation, visual reports made by eyewitnesses may be the only resource available. This has led to the development of a tool to quickly calculate crude meteor trajectories from eyewitness reports made to the American Meteor Society [1]. A description of the tool, example case studies, and a comparison to ground truth data observed by the NASA All Sky Fireball Network [2] are presented.

Goals

(1) Describe the background and motivation for this project.
(2) Describe the ground truth data and the eyewitness data and how matches between them were identified.
(3) Describe the tool used to calculate crude meteor trajectories from eyewitness reports.
(4) Compare eyewitness-derived trajectories to ground truth data observed by the NASA All Sky Fireball Network, including example cases, and characterize tool performance.

Background

MEO Tasks

» **Characterize meteors of public interest.**
» **Report characterization to the US government.**

The NASA Meteoroid Environment Office (MEO) is the only US government agency tasked with analyzing meteors of public interest. When queried about a meteor observed over the United States, the MEO must respond with a characterization of the trajectory, orbit, and size within a few hours.

Typical Data/Tools

» **Meteor networks**
» **Public recordings**

Using observations from meteor networks like the NASA All Sky Fireball Network [2] such a characterization is often easy. If found, casual recordings from the public and stationary web cameras can be used to roughly analyze a meteor if the camera's location can be identified and its imagery calibrated.

Motivation

Problems

» **Meteor is outside meteor network coverage.**
» **Public recordings not found or cannot be calibrated.**

If the event is outside meteor network coverage, if an insufficient number of videos are found, or if the imagery cannot be geolocated or calibrated, a timely assessment can be difficult if not impossible.

Solutions

» **Make use of eyewitness reports.**
» **Create a tool for characterizing meteors from reports.**

Visual reports made by eyewitnesses may be the only resource available. This has led to the development of a tool to quickly calculate crude meteor trajectories from eyewitness reports made to the American Meteor Society [1].

Data Sources

Two data sources were used for this work. Meteor data, that taken as "ground truth", was taken from the NASA All Sky Fireball Network. Eyewitness reports came from the website of the AMS. Matches between data sources were identified temporally and spatially.

Ground truth data: NASA All Sky Fireball Network

Purpose Network of 15 cameras set up to observe bright meteors caused by cm-sized meteoroids in 2008

Organization NASA MEO

Equipment Watec 902H2 Ultimate CCD video cameras (30 fps), 2 mm f/1.4 lenses, GPS receiver, Linux computer

Software Automated meteor detection and analysis using ASGARD [3, 4]; trajectory and orbit analysis via Ceplecha [5] and Borovicka [6]; manual analysis using METAL [7] and SMETS [8]

Map of the NASA All Sky Fireball Network

Eyewitness data: Website of the AMS

Purpose Promote meteor research by amateurs and professionals; collect reports on meteors

Organization American Meteor Society (AMS) Ltd.

Software Web application for the collection of eyewitness reports of meteors

Data selection

(1) Find meteor data within 30 min of AMS events with 5+ eyewitnesses (398).
(2) Identify meteor-eyewitness matches spatially (96).
(3) Keep meteor data with good trajectories (33).

To find eyewitness reports matching meteors in the NASA All Sky Fireball Network, an automated script was used to find meteor data within 30 min of AMS events with 5+ reports. Matches between meteor data and eyewitness data were identified via manual inspection and were judged by spatial location. Matches with poor trajectory data, i.e. the observation is solely on the edge of the FOV, were removed.

Tool Description

The software tool used to quickly calculate crude meteor trajectories from eyewitness reports is described. Its performance was characterized based on the comparison to meteor data.

Inputs

» Meteor date and time
» Eyewitness location
» Meteor start/end azimuth and elevation
» Meteor duration
» Eyewitness experience level

Outputs

» Crude meteor trajectory (start/end position)
» Crude apparent radiant
» Crude average speed
» Map of meteor ground track and eyewitness locations

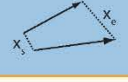
Methodology

(1) Identify eyewitness reports of interest from the AMS fireball log
(2) Import eyewitness reports
(3) Remove outliers
(4) Fill in missing data
(5) Remove reports with missing data
(6) Calculate start/end sightlines for each observer
(7) Find a model track that minimizes the error for all observations using a distance error metric (*track 1*)
(8) Identify and remove outliers with large standard deviations
(9) Refit the model track (*track 2*)

Performance Characterization

Tool outputs were compared to meteor data observed by the NASA All Sky Fireball Network on the basis of

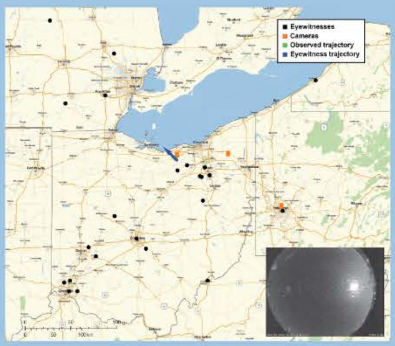
» Meteor start/end position
» Meteor start/end height
» Apparent radiant
» Average speed
» Average distance error, $\frac{1}{2}|x_e - x_s|$



Results

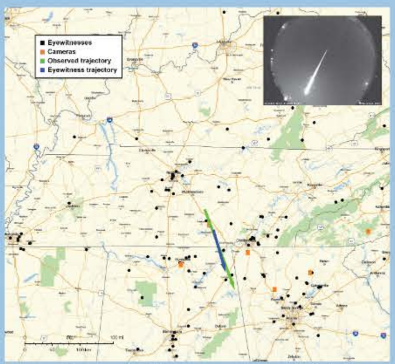
The trajectory tool was run on the 33 cases of eyewitness reports that had matching meteor observations from the NASA All Sky Fireball Network. Below are four example cases: two with good results and two with poor results. Given for each case: a map with ground tracks, a meteor image, and a table with errors for the two eyewitness-derived trajectory solutions.

Example cases: Good results



	Number of reports	Avg. dist err (km)	%err H_s	%err H_e	Radiant err (°)	%err Speed
track 1	19	28	39	6	11	26
track 2	17	23	10	28	12	36

This event received 31 eyewitness reports, 19 with complete data. Solution *track 1* (pictured) performs better than *track 2* for radiant, speed, and end height calculations, but *track 2*'s start height estimate and average distance error are improved. That track's position is comparable to the observed position. This fireball is considered well-characterized by the tool. It was beneficial to the solution that eyewitnesses reported the event from many different vantage points.



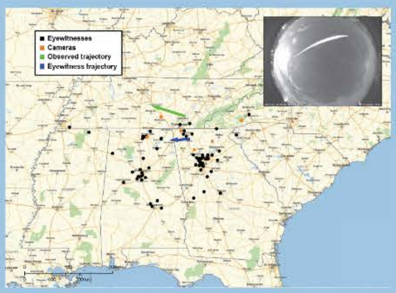
	Number of reports	Avg. dist err (km)	%err H_s	%err H_e	Radiant err (°)	%err Speed
track 1	70	47	24	121	8	6
track 2	55	44	9	97	7	2

This event received 123 eyewitness reports, though only 70 and 55 reports were used in the track solutions, *track 1* and *track 2* (pictured); a large portion either had incomplete data or were rejected as outliers. The two solution tracks are comparable to each other in most respects, though *track 2* performs better across all metrics. Both *track 1* and *track 2* do well predicting the location, radiant, and speed and as a result, this fireball is considered well-characterized by the tool. Both solutions have difficulty, however, matching the end height; the fireball was observed quite low in the atmosphere (29 km).

Example cases: Poor results

	Number of reports	Avg. dist err (km)	%err H_s	%err H_e	Radiant err (°)	%err Speed
track 1	6	73	123	94	36	198
track 2	5	54	94	118	33	104

This event received 9 eyewitness reports, though only roughly half remained after outlier rejection. The two solution tracks do manage to capture the approximate position of the fireball, but do not characterize the speed, direction of travel, or start/end heights. The start of the tracks begin too high and the end heights are similarly too high, failing to capture the observed end of the trajectory. *Track 2* (pictured) is an improvement over *track 1*, but still performs poorly. These issues may be due to the fact that there are simply too few eyewitnesses and/or the eyewitness reports are too inconsistent to predict this fireball.

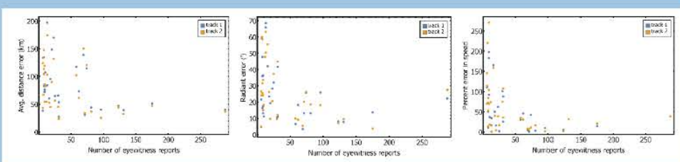


	Number of reports	Avg. dist err (km)	%err H_s	%err H_e	Radiant err (°)	%err Speed
track 1	40	115	15	8	25	42
track 2	38	120	6	22	26	11

This event received 74 eyewitness reports, though only slightly more than half of those were used; the remainder either had incomplete data or were rejected as outliers. The two solution tracks are comparable to each other in most respects except for speed; *track 2* better characterizes the speed. Neither *track 1* (pictured) or *track 2* does well predicting the location. This may be due to the fact that most eyewitnesses were located south of the fireball. As a result, the eyewitness-derived trajectory is pulled southward when compared to the observed trajectory. This fireball trajectory is not well-characterized by the tool.

General trends

To find general trends, the average distance error, radiant error, and percent error in speed were plotted as a function of the number of eyewitness reports.



The following general trends were observed:

» As the number of eyewitness reports increase, the errors in avg. distance, radiant, speed, and start/end heights decrease.
» *Track 2* is better at predicting the speed, and marginally better at predicting the location and heights; *track 1* is marginally better at predicting the meteor radiant.
» The start height is predicted better than the end height.
» Widely distributed eyewitness locations reduce errors.

Breaking up the cases into two categories, those with less than 75 eyewitness reports (27 cases) and those with greater than 75 reports (6 cases), the mean error metrics:

Mean	Number of reports	Avg. dist err (km)	%err H_s	%err H_e	Radiant err (°)	%err Speed
track 1	<75	93	63	82	28	72
track 2	<75	87	50	76	29	68
track 1	>75	44	17	72	15	17
track 2	>75	37	15	58	14	19

Summary and Future Work

To quickly characterize meteors of public interest observed outside the coverage of meteor networks, a tool was created to calculate meteor trajectories based on eyewitness reports. The performance of the tool was evaluated by comparing to meteor data collected by the NASA All Sky Fireball Network for 33 cases. Larger numbers of eyewitness reports per case yielded better eyewitness-derived trajectories.

Areas for future work include:

» Investigate weighting by observer experience level.
» Improve methods for outlier rejection.
» Develop method for estimating confidences.
» Run more test cases.

References

[1] Hankey et al. (2014) Proc. IMC 2013, 115-119.
[2] Cooke & Moser (2012) Proc. IMC 2011, 9-12.
[3] Weryk et al. (2008) EMP 102, 241-246.
[4] Brown et al. (2010) WGN JIMO 38, 25-30.
[5] Ceplecha (1987) BAIC 38, 222-234.
[6] Borovicka (1990) BAIC 41, 391-396.
[7] Weryk & Brown (2012) P&SS 62, 132-152.
[8] Edwards, personal communication.

Acknowledgements

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