ARTICLE IN PRESS

Planetary and Space Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Comparing eyewitness-derived trajectories of bright meteors to instrumentally-observed data

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ARTICLE INFO

Keywords:
Meteor
Fireball
Eyewitness reports
Trajectory

ABSTRACT

The NASA Meteoroid Environment Office (MEO) is often called upon to analyze meteors of public interest observed over the United States. Data from meteor networks are often utilized to accomplish this, as are recordings from the general public. When these methods fail, eyewitness reports are the only resource which can be leveraged. The MEO developed a tool to crudely calculate the trajectories of bright meteors from the eyewitness reports submitted to the American Meteor Society. The tool was tested on eyewitness data for 33 cases and compared to observed data from the NASA All Sky Fireball Network. The tool performed better for cases with more than 75 eyewitness reports than those with fewer than 75, by almost a factor of two across all metrics except for the end height. For these cases, the eyewitness-derived trajectory was about 50 km from the observed trajectory, the radiant was within 15°, and the speed was within 20% of that observed on average. A description of the tool, example case studies, and general trends are described.

1. Introduction

The NASA Meteoroid Environment Office (MEO) is the only U.S. 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. Using observations from meteor networks like the NASA All Sky Fireball Network (Cooke and Moser, 2012) or the Southern Ontario Meteor Network (SOMN) (Weryk et al., 2008), such a characterization is often readily performed. If found, casual recordings from the public and stationary web cameras can also be used to roughly analyze a meteor trajectory if the camera's location can be identified and its imagery calibrated. Performing this sort of analysis is more time-consuming and the result may be more prone to uncertainty. The MEO utilizes casual recordings, however, when data from meteor networks is unavailable. The analyses of several meteorite falls have made use of casual recordings quite extensively, including the Chelyabinsk meteorite fall in 2013 (Borovička et al., 2013).

If the event occurs 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. Under these circumstances, visual reports made by eyewitnesses may be the only resource available. This situation led the MEO to develop a tool to quickly calculate crude meteor trajectories from eyewitness reports made to the American Meteor Society (AMS). An assessment of the performance of this tool, accomplished by comparing the eyewitness-derived trajectory to instrumental data, is the main focus of this study. A description of the data sources utilized, the methodology behind the trajectory tool, four example case studies, and a comparison of the tool's results to meteor data observed by the NASA All Sky Fireball Network for 33 cases are discussed herein.

2. Data

Two data sources were used for this work. Instrumentally-observed meteor data was acquired by the NASA All Sky Fireball Network. Eyewitness reports were those submitted to the AMS by members of the public. Test cases for measuring the performance of the trajectory tool were identified by comparing the databases of these two data sources.

2.1. Instrumental data: NASA All Sky Fireball Network

The NASA All Sky Fireball Network was established by the MEO in 2008. It consists of 14 meteor video cameras in the United States set up to observe and study bright meteors caused by cm-sized meteoroids. As shown in Fig. 1, six camera stations are located in the southeastern United States, five are in the southwest, and three are in the north. All-sky cameras in each subcluster were placed 65–145 km apart in order to obtain overlapping fields of view.

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http://dx.doi.org/10.1016/j.pss.2017.02.016
Received 13 September 2016; Received in revised form 24 February 2017; Accepted 28 February 2017
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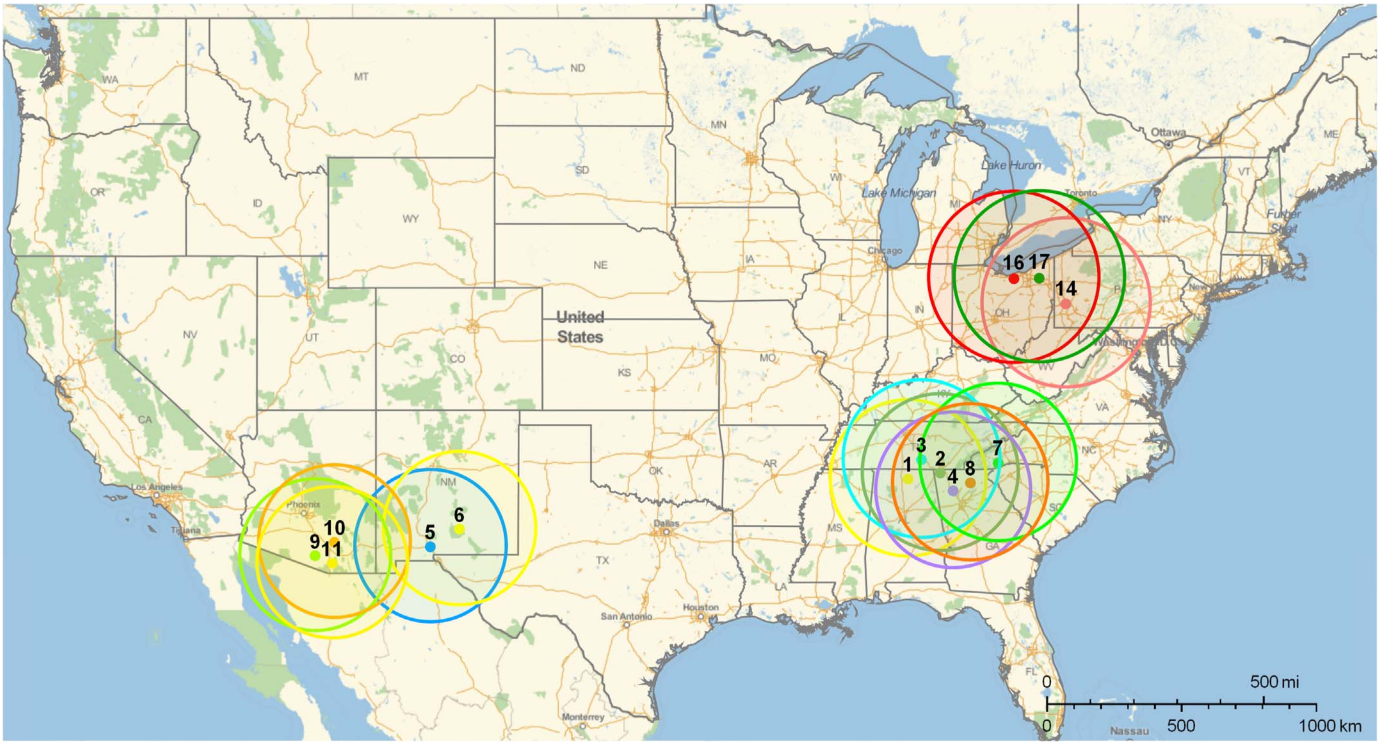

Fig. 1. Map of the NASA All Sky Fireball Network. Each camera station is numbered and color-coded corresponding to the maps on the NASA Fireballs results webpage http://fireballs.ndc.nasa.gov. A range circle with a 300 km radius is also depicted for each station for reference. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article).

The camera design and ASGARD real-time meteor detection and analysis software were adopted from the SOMN, run by the University of Western Ontario in Canada (Weryk et al., 2008; Brown et al., 2010) and has similar resolution[1] and sensitivity. Each all-sky station consists of a Linux desktop machine running ASGARD, with a monochrome Watec 902H2 Ultimate CCD video camera operating at 30 fps, outfitted with a 2 mm *f*/1.4 fisheye lens, an on/off daylight sensor, and a GPS receiver for time-keeping. The weatherproof camera housing consists of a PVC pipe and a clear acrylic dome, with a heater to prevent dewing. Fig. 2 shows a typical all-sky camera.

In standard operation, the ASGARD software automatically detects meteors, correlates meteors seen by multiple camera stations, and analyzes the meteor video to determine trajectories and orbits. Astrometric calibration of each camera is performed by creating a plate mapping the image coordinates to celestial coordinates using stars identified in stacked video frames and their corresponding positions in the SKY2000 catalog (Myers et al., 2002). Meteor positions are automatically chosen by ASGARD in each video frame through an intensity-weighted center-of-mass algorithm, giving sub-pixel resolution. To calculate trajectory solutions and orbits, ASGARD utilizes the programs MILIG (Borovicka, 1990) and MORB (Ceplecha, 1987). The data pipeline and analysis are automated and meteor results are stored in a database, reported to a public website, http://fireballs.ndc.nasa.gov, and disseminated to users each morning via e-mail. As of mid-2016, after about 7.5 years of operation, the network has automatically detected roughly 20,000 multi-station meteors.

In cases where the automated analysis routines poorly tracked the meteor's position, usually due to bad data points introduced by nearby stars or bright flares, a manual astrometric analysis was performed using the METeor AnaLyzer program, METAL (Weryk and Brown, 2012). For each camera station, a METAL user consistently picked a position near the leading edge of the meteor in each video frame, which was then refined by weighting nearby pixel intensities. MILIG was then used to compute the trajectory solution.

Fig. 2. NASA All Sky Fireball Network meteor camera, pictured here on the roof of a building near Tucson, Arizona.

Uncertainties in the trajectory solutions were computed using a Monte-Carlo simulation code, as in Musci et al. (2012) and Weryk and Brown (2012). Gaussian distributions with a standard deviation of one pixel were applied to model the random and systematic errors in the meteor location picks. These were propagated through the

[1] The NASA All Sky Fireball Network was designed for statistical studies of the meteoroid environment; it is a low-precision network compared to photographic networks like the European Fireball Network (Oberst et al., 1998).