CHARACTERISTICS OF A WELL RECORDED, BRIGHT, METEORITE-DROPPING FIREBALL, BRITISH COLUMBIA, CANADA, SEPTEMBER 4, 2017.

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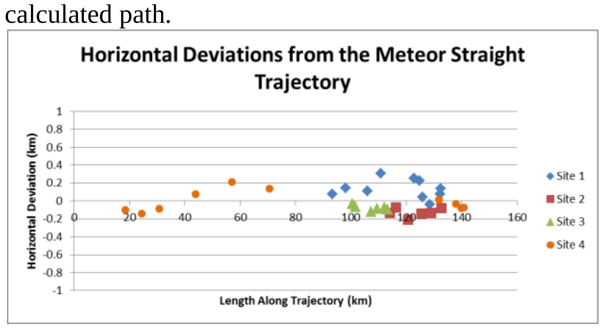
Introduction: A bright fireball was widely observed across British Columbia, Alberta, Saskatchewan, Washington, Idaho and Montana on September 4, 2017; one nearby dash cam recording established occurrence from ~22:11:21 to 22:11:29 MDT (UT-7). Investigation of the fireball was notably easier than in past cases due to 1) evolution of web based fireball reporting systems (particularly the American Meteor Society site), 2) social media, and 3) development and widespread use of digital security cameras of ever increasing capability. The fireball was also large enough to be recorded by satellite systems, seismic arrays, and infrasound stations of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Development of better atmospheric models also allow better predictions of meteorite fall zones.

Atmospheric Trajectory: Although many more serendipitous video systems record fireballs now (or their shadows), triangulation of the atmospheric trajectory still requires careful calibration of individual videos unless a bright fireball happens to occur within a dedicated camera network. The latter only cover a small fraction of the Earth's land area, so investigating bright fireballs (and recovering their meteorites) still requires field work to take advantage of these opportunities. The Sept. 4, 2017, fireball was recorded by only one dedicated all-sky camera.

We use the trajectory program MILIG [1] to solve for the atmospheric trajectory. Recordings of the Sept. 4 fireball were slightly compromised by thick forest fire smoke distributed across southern BC. Four recordings of shadows were prioritized for detailed calibration based upon their proximity to the fireball and locations bracketing the trajectory. Together these constrain the fireball location and azimuth; the dedicated all-sky camera at the College of the Rockies (COTR) in Cranbrook best constrains the trajectory elevation angle and provides (to date) the best timing to determine velocity. Our experience with shadow calibration is that angles to individual points on the trajectory can be measured to 0.1° uncertainty (corresponding to ~200 m uncertainties at the trajectory from relatively nearby stations (Figs. 1a & b). This requires use of theodolite-type capability in the field to determine orientations of shadow casting obstacles. Checks of shadow casting calibrations may also be done by measuring shadows cast by the Sun at known times.

Fig. 1 shows the horizontal and vertical deviations from the MILIG-derived trajectory for three shadow videos of the Sept. 4 fireball and the COTR all-sky camera; the latter recorded the entire ~123 km-long visible atmospheric path. Note that the horizontal (and vertical deviations) of the individual "sightlines" from the shadow recordings are almost all <200 m from the calculated path.



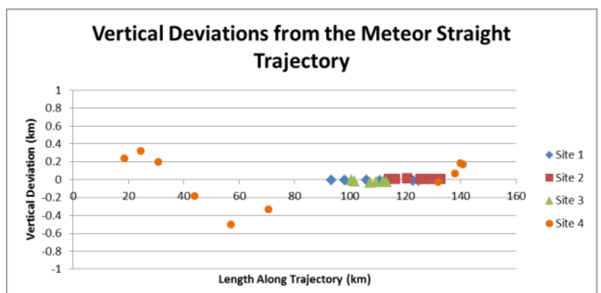


Figure 1 a & b: Horizontal and vertical deviations from the calculated Sept. 4 fireball trajectory. Note that the Site 4 COTR all-sky camera shows relatively large vertical deviations in a systematic pattern indicating that some lens (or weather cover) distortion remains.

The Sept. 4 fireball moved towards 357.6º azimuth with an elevation angle of 36.2º near the end of visible flight. All cameras record a series of fragmentation events with the largest beginning at ~35 km altitude. The preliminary prefall orbit is low inclination although with a relatively large aphelion compared to those of most meteorite-dropping fireballs. With a precise trajectory and an atmospheric model, calculation of the meteorite fall zone was done and meteorites were recovered beginning Oct. 29, 2017. Most of the projected fall zone is forested mountain slopes.

Infrasound observations: Infrasound from the Sept 4 fireball was recorded at three CTBTO stations and automatically triggered an event recording (Reviewed Event Bulletin event 14811804). The fireball start point was only 75 km ground distance from station I56US in Washington state (Fig. 2), resulting in a rich record (Fig. 3) including an early ballistic arrival and the later fragmentation events.

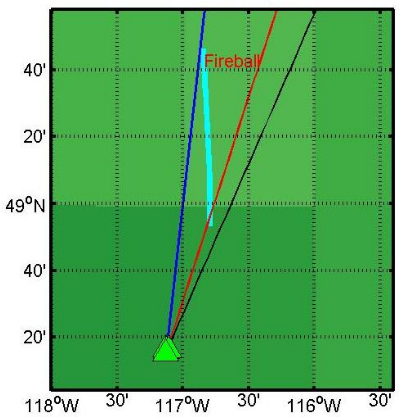


Figure 2: Apparent arrival directions at I56US (triangle) for the initial N-wave (black line), later acoustic arrivals (50-150 seconds after the initial arrival – red line) and the final arrivals (blue line). The latter correspond to the series of five fragmentation points near the end of the trail.

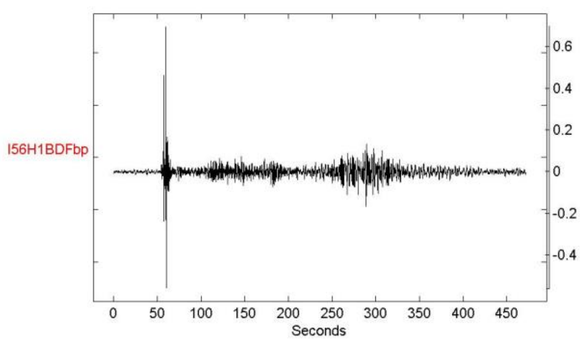


Figure 3: The pressure (y-axis) versus time (where 0 here represents 05:15 UT) for array element 1 of I56US. The signal is bandpassed from 0.2 – 9 Hz. The strong impulsive arrival near 50 sec is the ballistic arrival from the early portion of the trail near 90 km altitude. The arrival between 100-200 sec is from the mid-point of the trail, approximately from 85 – 60 km height. The final arrival from 250 – 330 sec represents acoustic emission from the final series of five bursts between 35-25 km altitude.

The total bolide energy may be estimated using the multi-station average dominant period of stratospherically ducted signals [2]. The three station averaged period is 2.4 seconds, which produces an estimate of 0.09 ± 0.01 kT TNT. Alternatively, the total integrated bolide signal energy may be used as a comparatively robust measure of yield and is insensitive to wind corrections [3] (which we have not applied in this analysis). Using this relation applied to the two distant stations having clear stratospheric arrivals produces an average yield estimate of 0.23 ± 0.08 kT.

Spacecraft observations: The Sept. 4 fireball was observed by satellite systems maintained by the US Government and information was rapidly posted on the NASA CNEOS website. The reported total impact energy estimate of 0.13 kT is comparable to the infrasound results; the location and altitude of maximum light from the fireball is within ~30 km of the correct position. However, the reported heading azimuth and elevation angle (~100º, ~13º) are widely divergent from the fireball's, and the reported velocity (14.7 km/s) is ~10% lower than our preliminary result (~16.5 km/s). This large discrepancy in fireball orientation is similar to that observed for the Buzzard Coulee fireball of Nov. 20, 2008.

The fireball was also observed by the Geostationary Lightning Mapper on the GOES-R weather satellite. The geo-located positions (Fig. 4) are in good agreement with the calculated trajectory after that is projected against the lightning ellipsoid [4].

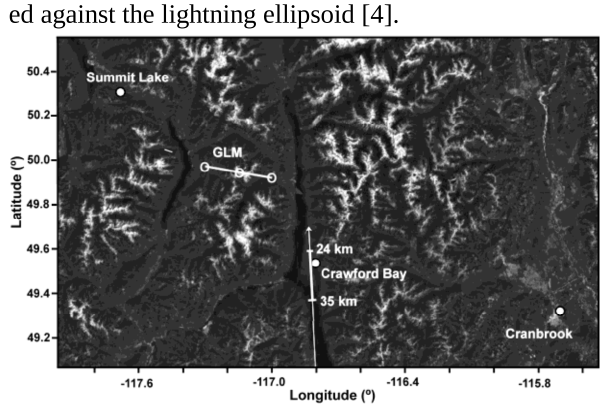


Figure 4: Map of calculated trajectory and geo-located GLM pixels positions of events associated with the fireball.

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