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THE MILLMAN FIREBALL ARCHIVE

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Abstract. The Millman Fireball Archive is a collection of 3876 report cards relating to 2129 visually-observed fireball meteors, seen from across Canada in the time interval 1962 to 1989. We provide an overview of the origin of the archive and present tables describing the monthly and yearly fireball numbers. We also present a selection of statistical results relating to fireball sounds (both sonic and simultaneous), finding that approximately one in fifteen of the observed fireball events was identified as producing some distinctive sound phenomenon. It is found that if sonic booms are associated with a given fireball event then some 12.8 ± 9.0 percent of the reports note the occurrence; if simultaneous sounds are associated with a fireball then 5.7 ± 1.8 percent of the reports acknowledge its detection. In addition, a comparison between the visually observed fireballs and the MORP camera survey results reveals that on average the visual observers recorded about one in five of the photographed fireball events. Finally, we find that a remarkably good, linear relationship exists between the average number of fireball events recorded per year and population density.

As oft along the still and pure serene,
At nightfall glides a sudden trail of fire,
Attracting with involuntary heed,
The eye to follow it, ere while it rest,
And seems some star that shifted place in heaven

Dante Alighieri,
The Divine Comedy, Il Paradiso, Canto XV

Résumé. L'archive des bolides Millman comprend une collection de 3876 rapports au sujet de 2129 bolides météoriques observés visuellement à travers le Canada durant une période allant de 1962 à 1989. Nous fournissons un aperçu de l'origine de l'archive et des tableaux auxquels sont décrits les nombres mensuels et annuels de ces bolides. Nous présentons aussi une sélection des résultats statistiques concernant les grondements (soniques et simultanés) de ces bolides, où nous trouvons qu'environ un sur quinze des cas des globes de feu sont accompagnés d'un son distinct. Nous constatons que si des bangs supersoniques sont associés à certains bolides, quelques 12,8 ± 9,0 pour cent des rapports notent le fait; si des grondements simultanés sont associés à des bolides, 5,7 ± 1,8 pour cent des rapports indiquent une détection de sons. De plus, une comparaison entre les bolides observés visuellement et les résultats de l'enquête de la caméra MORP révèle qu'en moyenne les observateurs visuels notent environ un sur cinq des bolides photographiés. Enfin, nous trouvons qu'une correlation linéaire remarquable existe entre le nombre moyen de bolides notés par année et la densité de la population.

Comme dans les cieux tranquilles et purs
glisse de temps à autres un feu soudain,
faisant mouvoir les yeux qui étaient immobiles,
et semble une étoile changeant de lieu,

Dante Alighieri
La Divine Comédie, Il Paradiso, Chant XV

1. Introduction

It is the unexpected brightness and rapid, transitory nature of fireballs that attracts eyewitness attention and makes them newsworthy events. Not only is the media interested in receiving accounts of fireball events, but so too is the astronomical community since a fireball possibly heralds the arrival of a new meteorite on Earth. Indeed, it is through this latter context that the compilation of fireball reports is of great scientific importance since they bring together multiple eyewitness accounts of a large meteoroid's passage through the Earth's atmosphere, and they potentially aid in the ground recovery of new meteorite samples. In Canada the Meteorites and Impacts Advisory Committee (MIAC) maintains a fireball reporting page at its internet Web site (`miac.uqac.ca/MIAC/fireball.htm`), and typically several reports are received per month from the public concerning bright meteors. Before the present MIAC fireball reporting Web page came into existence, however, the National Research Council (NRC), from the beginning of 1962 to the end of 1989, maintained an extensive and systematically collated catalogue of fireball report cards gathered from across the nation. The card set that constitutes the NRC fireball record, hereafter called the Millman Fireball Archive (MFA) in honour of Dr. Peter Millman[1], who oversaw its initiation, has recently been housed in Campion College at the University of Regina, and this article is a review and analysis of its contents.

2. Origins

The forerunner of the present day MIAC, the Associate Committee on Meteorites (ACOM), was formed as a direct result of the fall of the Bruderheim meteorite in Alberta on March 4, 1960 (Millman 1960; Millman 1962; Halliday *et al.* 1978). During the first ACOM meeting, Chaired by Dr. S.C. Robinson (of the then Dept. of Mines and Technical Surveys) on October 24, 1960, Millman outlined the essential purpose and duties of the committee[2]. The first two duties being described as follows:

(a) To arrange the establishment of a Canadian Centre to which all fireball and meteorite data would be reported.

(b) To prepare and circulate the necessary forms and instructions for the uniform recording of observational data on fireball and allied phenomena.

These two 'principal' duties were, in fact, soon discharged by the committee, and the Meteor Centre at the NRC became the national fireball reporting centre[3], and designs for fireball report cards were being discussed and distributed at ACOM's second meeting[4] on May 5, 1961.

The minutes to the May 5, 1961, meeting of ACOM indicate that some considerable discussion had taken place as to how the committee might establish mechanisms for the enhanced gathering-in of fireball reports, and especially fireball reports from rural communities. In this respect it was soon realized that amateur astronomers, such as those attached to regional RASC Centres could play a pivotal role in the acquisition of fireball data. Help was also sought from professional workers whose jobs required them to be outdoors at nighttime. Indeed, during the inaugural ACOM meeting in 1960 it was reported that formal discussions with the Royal Canadian Air Force had been initiated with respect to the forwarding of fireball sightings. Protocols for the reporting of fireball sightings were later established with the Royal Canadian Mounted Police, and the Department of Transport[5].

The minutes to the April 27, 1962 ACOM meeting record that "30 fireball reports had come in to the Meteor Centre in the period October 1961 to April 26 [1962]. This was compared with a rate of 4 or 5 [fireball reports] per year before the establishment of the committee's reporting system." The minutes go on to further note that "the reports are being filed systematically for future study or reference." Clearly, the initial ACOM efforts were beginning to pay off, and by the April 19, 1963 meeting of the committee, Millman reported, "the Meteor Centre now had on file 287 reports on 119 fireballs."

Millman continued to present annual fireball reports to ACOM until 1987, at which time Ian Halliday (Herzberg Institute of Astrophysics, NRC) assumed charge of the reporting systems subcommittee. It seems generally clear from a 'between the lines' reading of the ACOM minutes[2] that the NRC was beginning to struggle with the upkeep of the fireball reporting system from about the mid-1970s onward[6], its staff either being assigned to other duties or lacking in fireball investigation experience. Further, by the time of the October 26, 1990 ACOM meeting, Halliday observed that because of recent retirements, the entire Planetary Sciences Section at the NRC had 'disappeared', and as such, he suggested that it was time to disband the reporting systems subcommittee. Indeed, the final card entry in the MFA is dated as being received on October 12, 1989.

Following its October 1991 meeting ACOM took on new terms of reference and became a subcommittee to the Canadian Space Agency (CSA). The new alignment of ACOM with the CSA resulted in the formation of MIAC. At the first MIAC meeting held on October 23, 1992, it was agreed that, while a fireball reporting subcommittee would no longer exist, a central fireball data bank would be maintained by Robert Hawkes (Mount Allison University). Regional MIAC and RASC representatives were then asked to forward fireball information to the central data bank (Hawkes & Lemay 1993).

3. General Overview

As indicated above, the MFA constitutes a series of fireball report cards systematically gathered from across Canada in the time interval January 1962 to October 1989. Reports were also received from observers in the United States during the same time interval, and several 'historical' reports were received with respect to fireballs witnessed as far back as 1927. Prior to 1962 only a very few reports were catalogued. Two 'historical' fireball reports are listed for 1950, five reports were catalogued during the years 1958 and 1959, two fireball reports were received in 1960, and nine were recorded in 1961. We note that over 275,000 visual meteor observations were collated and analyzed by the NRC meteor group between 1957 and 1986 as a result of studies begun during the International Geophysical Year (Millman 1956; 1986), but the data on those meteors are not contained in the MFA.

In our analysis we shall distinguish between reports and events. An 'event' constitutes the observation of a particular fireball; the 'reports' relate to the total number of cards received at the NRC concerning a particular event. During the 28 years over which records were kept a total of 2129 fireball events constituting 3876 report cards were collated at the NRC Meteor Centre from observers located within Canada. Table 1 shows a breakdown of from where the various fireball reports were gathered. In the same 28-year interval, 410 reports on 351 events were received from U.S. observers. Three fireball report cards were received from Iceland, with single report cards being received from observers in Norway, Puerto Rico, and the Bahamas.

Table 1 indicates that the greatest number of fireball reports was received from observers in Ontario, with Quebec and British Columbia being the second and third most 'active' regions. Saskatchewan observers produced the greatest average number of reports per event, with an average of 2.5 reports per event, while observers in British Columbia and Ontario were the next most 'active' reporters with averages of 2.0 and 1.9 reports generated per event respectively. We find that the number of events reported by each of the Provinces and Territories correlates in a linear fashion with the population density (see column 4 of Table 1). Indeed, as one might well expect, it appears that the more people there are per square kilometre then the greater

Table 1.

Province / Territory	Events	Reports	Pop./km^2
Yukon	37	54	0.04
British Columbia	248	501	2.76
Alberta	202	381	2.88
Saskatchewan	113	285	1.62
Manitoba	121	164	1.86
Ontario	623	1200	9.01
Quebec	299	517	4.59
Atlantic	268	382	4.36
North West Territories	78	93	0.01

Table 1 – MFA events and reports according to the geographical location of observers. The appellation 'Atlantic' has been used in column one for the combined Atlantic Provinces of Newfoundland, Prince Edward Island, Nova Scotia and New Brunswick. The fourth column gives the population density in people per square kilometre as recorded in the 1976 national census. The 'Atlantic' population density is calculated according to the total population and total area of the Provinces included in its definition.

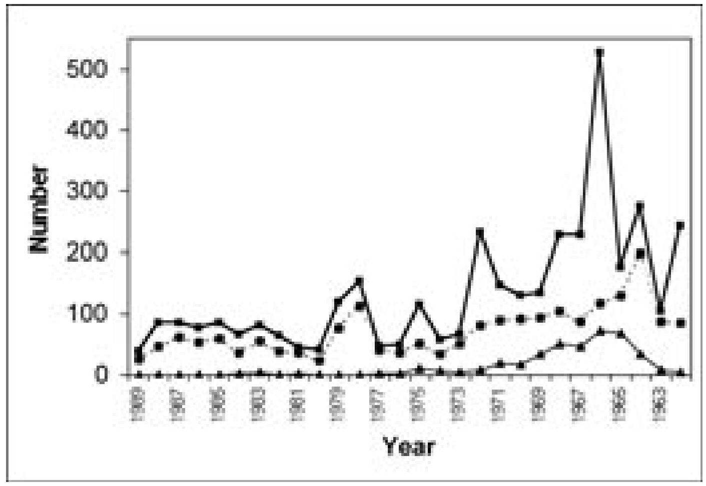

Figure 1 – Yearly variation in the number of fireball events witnessed by Canadian observers (dashed line with circles) and the number of reports received for those events (heavy solid line and squares). Also shown is the yearly number of reports received from U.S. observers (light solid line and triangles).

the number of fireball events observed and reported. A linear, least-squares fit between the average number of fireball events observed per year, E, and the population density (the number of people per square kilometre), P, yields the relationship $E = 2.46 \times P$, with a goodness of fit coefficient $r^2 = 0.974$. The population density data used in the derivation of the least squares fit to E was taken from 1976 Canadian census (Leacy 1983) — that year being about the midway point of the collecting time interval of the MFA. The good correlation found between the population density and the average number of fireballs reported is rather surprising and is interestingly much stronger than the correlations found to exist between the number of fireballs reported per year and the Provincial/Territorial populations and areas considered separately. Clearly, however, the relationship between population density and the number of fireballs reported must become non-linear at some stage and level off, there being a finite number of 'actual' fireballs occurring in any given year. This turnover limit appears to have not been reached, however, at a population density of nine people per square kilometre.

The yearly variation in the total number of fireball events and reports observed in Canada is shown in Figure 1. There are several interesting trends discernible in Figure 1. We note, for example, that the average number of fireball events recorded per year in the first decade of the program (1962 to 1972) is 111.7 ± 32.0 events per year, while that in the last decade of the program (1979 to 1989) is 48.3 ± 12.6 events per year. The reasons for the decline in what might be called 'reporting efficiency' in the last decade are no doubt complex but are possibly linked to diminishing NRC resources combined with a lower priority (*i.e.*, conflicts with other duties) for reporting events by the RCMP, the armed forces and Transport Canada[6]. The average number of reports per year was 74.2 ± 19.0 during that last decade of the program, compared to 224 ± 116.0 during the first decade of the program. This variation in the reports received suggests some additional reasons for the dramatic change in the 'reporting efficiency', and these are outlined in Table 2. In 'broad brush form,' it would appear that the time period from 1962 to 1972 was 'rich' in well-publicized meteorite falls and numerous, well-observed, very bright fireball events. And, general experience indicates that the publicity surrounding a particularly noteworthy fireball will often spur eyewitnesses into submitting reports on previously seen but unrelated events – a process that feeds back into elevation of the historical number of reports. The last decade of the program, however, saw no meteorite falls and recorded only a few fireball events that produced more than 20 reports. Even the spectacular Grande Prairie fireball (Halliday 1985) of February 23, 1984 (UT) produced only 22 reports in the MFA. The reports

Table 2.

Year	Day	Province	Object	Comments
1962	May 29	BC	Fireball	142 reports, sonic booms heard
1963	Mar. 31	AB	Meteorite	Fall at Peace River
1965	Mar. 31	BC	Meteorite	Fall at Revelstoke
1966	Apr. 26	ON+QC	Fireball	246 reports, sonic booms heard
1966	Sept. 18	ON+QC	Fireball	127 reports, sonic booms heard
1967	Feb. 5	AB	Meteorite	Fall at Vilna
1967	Feb. 6	AB	Fireball	26 reports
1967	Apr. 6	ON	Fireball	24 reports; also bright fireballs on June 15 and Sept. 11 seen in ON for a further 17 and 15 reports respectively
1967	Dec. 15	SK	Fireball	30 reports
1972	Aug. 10	AB	Fireball	56 reports, sonic booms heard
1975	Feb. 16/17	SK	Fireballs	Two very bright fireballs seen on successive nights for a total of 41 reports
1977	Feb. 5	AB	Meteorite	Fall at Innisfree, MORP recovery

Table 2 – Meteorite falls and years in which the total number of fireball reports was greater than twice the total number of fireball events. Typically the high report count years are those years in which just one or a few well-observed fireballs were seen. Most fireball events in the catalogue have just a single report card.

received 'peak' in 1975 is due to two very bright fireballs, seen on consecutive nights, in Saskatchewan and the 'peak' circa 1978 is perhaps an enthusiasm 'ripple-on effect' resulting from the fall and recovery of the Innisfree meteorite in February of 1977. We also note a clear distinction in the number of reports received from U.S. observers in the first and last decades of the program. The number of U.S. reports received at the NRC peaked in 1966 and declined steadily thereafter with just the occasional few reports being received from 1975 onwards. A study of the U.S. report cards reveals that they were received from just a few observers, and the decline in reporting presumably reflects their individual circumstances. In addition, the Smithsonian Astrophysical Observatory started its own fireball reporting system in the mid-1960s, as a consequence of the establishment of the Prairie Network of fireball cameras (Norton 2002), and presumably, this move 'diverted' some of the U.S. fireball reports away from the NRC Meteor Centre.

The monthly distribution of fireball events is shown in Table 3. The greater number of recorded fireball events per year in the first decade of the program is clearly seen in the table (last column). It is also evident from Table 3 that the number of fireball events reported through the year generally decreases from January to June, but rises again from July through to December. The month in which the least number of fireball events was reported is June; the month in which the greatest number of fireball events was reported is August. The same variation in monthly activity as seen in the MFA data is also evident in the sporadic background of the fainter visually observed meteors (Murakami 1955). Interestingly, however, the June minimum is not evident in the fireball data gathered by satellite borne optical sensors (Tagliaferri *et al.* 1994), and nor is it present in the monthly distribution of meteorite falls (Hughes 1981). These latter observations suggest that the June minimum in the MFA data is a selection effect related to the reduced number of nighttime hours at that time of year.

4. MFA and Sounds

The fireball report card developed and distributed by ACOM had "sounds" as one of its entry headings. The reason for including such a heading is explained by the fact that sonic booms are often generated during the decent of a meteoroid through the Earth's lower atmosphere (ReVelle 1975, 1997). The presence, therefore, of reported 'sounds,' typically described as 'loud bangs' or 'thunder-like rumblings,' is an extra indicator of a meteorite-dropping event having possibly occurred. In addition to sonic booms, bright fireballs may also be accompanied, on occasion, by simultaneous sounds. Since sonic booms propagate through the Earth's atmosphere at the speed of sound they are often heard several minutes after the optical fireball has passed. Simultaneous sounds, on the other hand, are heard at the same time as the fireball is seen. Keay (1980) has explained the origin of simultaneous sounds in terms of an interaction between the ionized fireball trail and the Earth's magnetic field. In this manner, simultaneous (or as they are often called, electrophonic) sounds are produced by the transduction of long wavelength ($\lambda \sim$ tens of kilometres) electromagnetic radiation into audible sounds by objects in the locality of the observer.

Table 3.

Year	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.	Σ
1989	6	6	1	4	3	4	3	1	3	0	0	0	31
1988	8	3	6	7	0	0	2	3	2	5	7	7	50
1987	6	6	4	9	4	1	6	9	3	7	2	14	68
1986	10	7	5	1	4	2	1	3	5	8	5	10	61
1985	8	2	4	2	1	1	3	4	7	14	13	4	63
1984	3	7	3	2	1	0	2	3	2	5	4	11	43
1983	14	9	1	6	0	1	2	3	8	6	6	7	63
1982	2	4	1	2	4	6	1	5	5	5	6	4	45
1981	2	2	2	1	2	0	8	3	3	4	11	2	40
1980	6	2	2	5	2	0	4	0	3	1	2	0	27
1979	11	6	5	6	1	4	7	10	6	5	4	15	80
1978	18	7	16	6	12	3	4	12	8	10	17	8	121
1977	2	4	5	5	6	1	2	10	2	2	6	3	48
1976	1	4	2	8	0	2	6	7	0	6	2	2	40
1975	3	5	4	6	1	2	3	8	4	5	4	7	52
1974	2	4	4	2	5	5	2	4	2	4	4	1	39
1973	8	5	5	5	6	1	5	6	2	2	7	5	57
1972	7	4	8	6	7	4	10	9	11	4	8	6	84
1971	11	4	4	5	3	3	7	8	9	19	10	9	92
1970	11	8	8	2	4	12	6	11	3	11	7	13	96
1969	5	6	10	8	9	6	7	17	7	11	10	1	97
1968	4	9	12	9	4	3	13	16	11	11	7	7	106
1967	7	7	4	5	5	9	8	12	11	4	12	16	100
1966	10	6	7	12	4	8	14	19	20	6	10	3	119
1965	11	10	13	10	11	4	12	18	13	9	18	8	137
1964	9	5	10	3	8	16	27	41	14	28	23	13	197
1963	14	5	12	2	0	8	6	15	5	8	8	4	87
1962	3	3	5	14	6	2	1	25	9	7	6	5	86
Σ	202	150	163	153	113	108	172	282	178	207	219	185	

Table 3 – Monthly fireball event counts. The last column is the annual sum of fireball events, the variation of which is shown in Figure 1 (dashed line with circles). The last row is the sum of monthly fireball events.

Within the MFA there are a total of 268 reports, from 141 events, that mention distinctive sounds being heard. The breakdown of reports is such that 155 (58% of reports) related to sonic booms, with 95 (35% of reports) being simultaneous. Six of the report cards mention that sounds were heard, but the sounds were not described, and twelve of the reports mention that seismic effects occurred (*e.g.* windows rattling). We also note that a number of the report cards mention that both sonic booms and simultaneous sounds were heard, while others mention that both sonic booms and seismic effects occurred. Figure 2 shows the yearly variation of the percentage of fireball reports and events for which 'sounds' were noted. On average, in the time interval from January 1962 to September 1989, it appears that one fireball event in fourteen produced some distinct sound, and one report card in fifteen contained mention of an audible occurrence. A summary of those fireball events that produced more than ten eyewitness reports and for which sound phenomena were noted is given in Table 4. We have distinguished between 'sonic booms' and 'simultaneous' sounds according to the descriptions given in the reports. Comments such as 'booms,' 'rumbling like thunder,' 'roaring like a jet aircraft,' 'explosions,' and 'bangs' are taken to be sonic booms, and especially so if there is a delay in hearing such retorts. Whereas, when comments like 'crackling,' 'popping noise,' 'hissing,' 'screeching,' 'like a sky rocket,' and 'air-rushing noise' are used we count the description as being simultaneous (Keay 1994; Kaznev, 1994), and especially so when the sound is stated as being heard concurrently with the passage of a fireball.

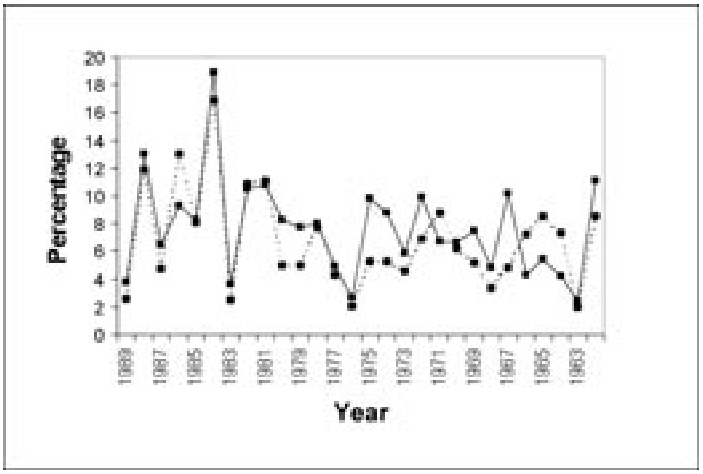

Figure 2 – Yearly variation in the percentage of fireball events (dashed line and circles) and reports (solid line and squares) where observers specifically noted sonic and/or simultaneous sounds.

On average it appears that if sonic booms do accompany a fireball event then 12.8 ± 9.0 percent of the observers actually 'hear' the 'booms' at a sufficiently distinctive level to comment upon them. Likewise, if simultaneous sounds are reported to accompany a fireball event then 5.7 ± 1.8 percent of the observers actually 'hear' them in a distinctive fashion.

5. MFA and MORP

With Peter Millman in the Vice President's chair the members of Commission 22 at the 1961 IAU gathering in Berkeley, California passed a resolution calling for the introduction of "systematic programmes of fireball photography with all-sky cameras … in order to determine orbits and to recover newly fallen meteorites" (Sadler 1962). Shortly after this resolution was passed, and taking its directive to heart, the initial planning of the Meteorite Observation and Recovery Program (MORP) began in Canada at the Dominion Observatory (Halliday *et al.* 1978). Site research and construction took place during the mid-1960s and the first cameras became operational in 1968. The full twelve-station network of cameras, housed at observatories situated in Manitoba, Saskatchewan, and Alberta, started routine operations in 1971 and continued to gather data through to early 1985. The MORP produced an immense wealth of fireball data, enabling numerous detailed studies of both meteoroid structure and meteoroid orbital dynamics to be made (see *e.g.* Halliday *et al.* 1996), and the program fully vindicated its conceptual origins with the recovery of the Innisfree meteorite on February 5, 1977.

Although not strictly an integrated part of MORP, the fireball reporting network did, on occasion, provided useful information additional to the photographic record. Information on fireball colouration and sounds, for example, were not recorded by the MORP equipment, but were potentially available from eyewitness accounts. While we have discussed meteor sounds above, the one direct comparison we can make between the MFA reports and the MORP results is that of the observational acuity, OA, here defined as the MORP fireball count divided by the eye-witness fireball event count recorded in the same time interval. An OA of unity would indicate that all of the photographed fireballs had eyewitness counterparts, but the greater the OA, the greater the number of photographed fireballs without eyewitness counterparts. Table 1 of Halliday *et al.*

Table 4.

Event, Time (UT)	Location	Total reports	Sonic (%)	Simultaneous (%)
Apr. 18, 1988	NB, NS	17	2 (11.8)	1 (5.9)
Oct. 24, 1985	ON	9	3 (15.8)	0 (0.0)
Feb. 23, 1984	AB	22	3 (13.6)	2 (9.1)
Jun. 02, 1982	AB	13	3 (23.1)	1 (7.7)
Sep. 23, 1978	SK	24	4 (16.7)	1 (4.2)
Aug. 10, 1972	AB, BC	56	6 (10.7)	4 (7.1)
Oct. 28, 1971	ON	31	7 (22.5)	1 (3.2)
Sep. 20, 1968	NS	33	1 (3.0)	2 (6.1)
Dec. 26, 1967	SK	25	1 (4.0)	1 (4.0)
Apr. 06, 1967	ON	24	1 (4.2)	0 (0.0)
Feb. 06, 1967	AB	26	0 (0.0)	2 (3.8)
Sept. 18, 1966	ON, QC	127	12 (9.4)	9 (7.1)
Apr. 26, 1966	ON, QC	246	8 (3.3)	7 (2.8)
July 02, 1965	MB	13	1 (7.7)	1 (7.7)
Apr. 01, 1965	AB, BC	18	6 (33.3)	1 (5.6)
July 20, 1964	BC	33	8 (24.2)	2 (6.1)
May 29, 1962	BC	142	1 (0.7)	8 (5.6)

Table 4 – Summary of those events for which ten or more reports were received at the NRC and in which 'sounds' were noted. The first three columns correspond to the time of the event, the Province over which the event occurred and the total number of reports received. The last two columns indicate the number of reports mentioning sonic booms and/or simultaneous sounds. The numbers in brackets give the percentages of reports mentioning sonic and/or simultaneous sounds. We note that the percentages given are probably lower bounds since in many cases the reports were received from observers in moving cars and from aircraft in flight — locations that will typically mitigate against hearing external sounds. We also note that some report cards were summaries of observations gathered by multiple observers.

(1996) provides the monthly totals of MORP recorded fireballs, from April 1974 to March 1985, and Figure 3 here shows a comparison of the number of fireballs photographed by MORP and the number of eyewitness reported fireballs. The reported events correspond to just those fireballs observed in Alberta, Saskatchewan, and Manitoba (*i.e.*, the provinces containing the MORP cameras) during the interval of the survey[7].

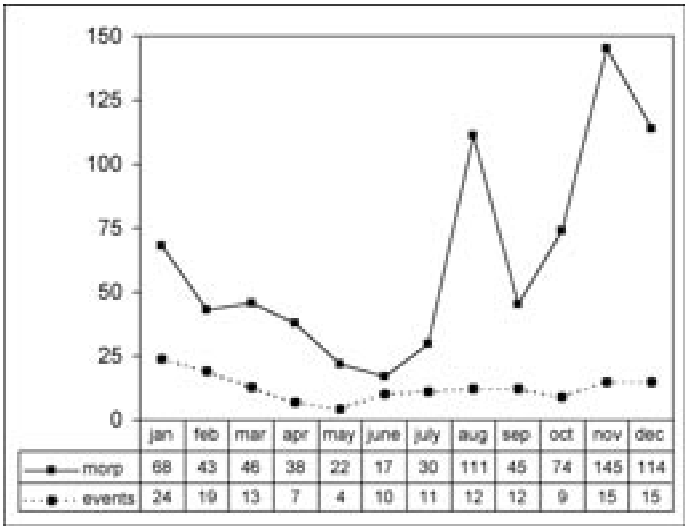

Figure 3 – Monthly totals of MORP detected (solid line and squares) and eyewitness recorded fireballs (dashed line and circles) in the time interval between April 1974 and March 1985. The eyewitness data are for the provinces of Alberta, Saskatchewan, and Manitoba only.

Figure 3 shows a number of interesting trends. The MORP data clearly indicate that more fireballs are recorded in the later part of the year, with especially high counts occurring in August, November, and December. The high fireball counts in these three months is probably a reflection of the occurrence of the Perseid, Southern and Northern Taurid, Leonid, and Geminid meteor showers — all of which showers are known for their fireball producing capabilities. A minimum in the fireball count occurs between May (visual accounts) and June (MORP observations), and this is possibly a reflection of the fewer nighttime hours available for observations near to the time of the summer solstice, and in the MORP case to scheduled instrument servicing. Interestingly, the fireball events recorded in the MFA do not show the same enhanced count in the latter half of the year. Between January and July, the average OA is 3.4 ± 1.4 which indicates that the visual observers witnessed and reported about two out of every seven fireball events. From August through December the number of reported events is remarkably constant at 12.6 ± 2.2 fireballs per month, but the average OA is 7.7 ± 2.1, indicating that only about one in eight of the actual fireballs recorded by the MORP cameras were eyewitness events. It is not clear to the author why the OA should double during the latter half of the year; however, it might be simply a result of low number statistics.

6. Discussion and Future Studies

The MFA is quite literally a national treasure, and it affords a great wealth of data on visual fireball observations gathered from across Canada during the time interval 1962 to 1989. We have presented in this article an overview of some of the more general statistics that have been gained by an initial study of the archive. Since the 'gathering efficiency' of the fireball data varied considerably over the time that the archive was actively maintained we do not feel that a detailed statistical analysis of monthly and annual fireball fluxes is possible. We are confident, however, that general trends may be safely extracted from the data. The mid-summer minimum and latter half of the year enhancement in fireball rates, for example, have been noticed before (Halliday *et al.* 1996) and our analysis simply re-affirms their presence. The enhanced visual fireball counts in the latter half of the year can be contrasted against the minimum in meteorite falls over the same time interval (Hughes 1981). This observation and comparison suggests that we are 'seeing' a richer selection of cometary-derived fireballs between June and December at the present epoch.

The sound generating capabilities of fireball meteors is deserving of much greater study, and we plan to expand upon the analysis presented above. In particular the distribution of observers reporting sounds relative to the fireball ground track can be extracted for a number of the events contained in the MFA, and these data can be compared against the classification schemes proposed by, for example, Annett (1980) and Kaznev (1994). The percentage of observers reporting sonic booms and/or simultaneous sounds that we derive from the MFA (6.9 % of all reports) is consistent with the 4 to 8 percent of reports quoted by Norton (2002).

We have found a tantalizing linear correlation between the average number of fireball events per year and the population density. The correlation indicates that the more people there are per square kilometre the greater the fireball 'detection' and reporting rate. There must be, however, a limit to such a correlation. As found by Beech (2002), with respect to meteorite fall recovery, it does not necessarily follow that the greater the number of potential observers, the greater the number of observations (or meteorite falls) reported. The population density for PEI, for example, is given as 54.51 people per square kilometre in the 1975 Canada census, and yet very few fireball reports were received from that location[8]. The reason why the observers in some Provinces are more 'efficient' than others at reporting fireballs is not just a consequence of the population density; additional, complex social factors must also, at some level, play a role in dictating what is actually reported. In future studies we hope to address in detail the issue of fireball detection 'efficiency' as a function of population density and location.

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Notes:

(1) The development of meteor astronomy in post second World War Canada, and an indication of Millman's pivotal role in those developments, can be found in Jarrell (1988), but see also Millman & McKinley (1967). Halliday (1991) provides a more personal

account of Millman's life and career.

(2) The entire set of ACOM and MIAC minutes from 1960 through to 2000 have been gathered together by Damien Lemay, and while presently only available in CD format, it is planned that access to the minutes will eventually be made public through the MIAC Web page.

(3) The NRC Headquarters in Ottawa was, in fact, well-positioned to take on the role of a national fireball reporting centre since it had previously established a network of workers to analyze the hundreds of thousands of visual meteor observations gathered during the International Geophysical Year (IGY) held between 1957–58. In addition, Millman, who was affiliated to the NRC, was a prominent member of the International Astronomical Union's (IAU) Commission 22 (then *commission des meteores et des meteorites*) and would have been well aware of the great international interest in the relationship between fireballs and meteorites (see *e.g.* Beech 2002). Indeed, a call to improve upon the speed of reporting fireball events had been made by Charles P. Olivier during the 1958 IAU Commission 22 meeting in Moscow (Sadler 1960). This call was further re-iterated by Zedenic Ceplecha at the 1961 IAU meeting of Commission 22 (Sadler 1962).

(4) The report card design is described in Appendix I of the minutes to the May 5, 1961 meeting of ACOM. Although it did undergo some re-design, the 'mass production' of the report cards proceeded before the November 6, 1961, committee meeting. The ACOM members came back to discuss the design of the report cards repeatedly, some members feeling that the cards were too complex in their layout for the 'typical' untrained observer to use.

(5) The protocol for fireball reporting established with the Department of Transport is outlined in Appendix 2 of the April 20, 1964 minutes. The actual memorandum was published in D.O.T. Air Services Circular Letter, no. 2-H95-64. The fact that training sessions on fireball reporting to new RCMP officers had taken place is also mentioned in the minutes to the April 20, 1964 meeting.

(6) During the November 24, 1972 ACOM meeting Millman is recorded as noting "staffing problems exist in the Meteor Centre, NRC, and that there are no experienced personnel actually on strength." Also, and with respect to the declining number of fireball reports being received at the NRC, it was suggested during the October 11, 1974 ACOM meeting that the drop-off might be due to a decrease in the "awareness [of] meteoritic phenomena among the services and police force."

(7) Halliday (1985) comments, "the camera network ... normally records one or two fireballs per week during those 30 per cent of night hours that are essentially clear." Nighttime weather statistics have been kept at Campion College, for each night since April 19, 2000 as part of the Southern Saskatchewan Fireball Array (a network of three all-sky video camera systems) data analysis program (see *e.g.* Beech & Illingworth 2001). We find that 30.1 per cent of nights are cloud free at Regina, Saskatchewan, 26.6 per cent of the nights are partially clear, and 43.3 per cent of the nights are completely cloudy.

(8) To the authour's knowledge PEI has never had an ACOM or MIAC representative. In this respect the low number of fireball's reported from that Province may be due simply to a lack of public unawareness of 'what to do with' any observations gathered. Indeed, one of the key preoccupations of present day MIAC members is the 'development' of public awareness concerning the scientific importance of fireball observations, and the collection of new meteorites.

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