Fireballs and Meteorites

Human Casualties in Impact Events

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It is a widespread error to believe that people were never killed by meteorites. It was concluded that there were no human casualties due to meteorite falls because there were no reports about such incidents, but there are reports of these rare events. The statement of no one ever being killed by a meteorite may intend that the danger even of asteroid and comet impacts onto the Earth is only fiction, but the danger is real. It is a low-probability-high-consequence event for large impactors (more than 1 km). Even from meteorites, however, people were reported struck to death. This article gives a survey over reports of human casualties from 616 A.D. well to our century.

1. Introduction

Collisions of near-Earth asteroids and comets (NEOs) with our planet are rare events, but coupled with high consequences depending on their size. Even small impactors (smaller than 100 m) cause severe local damage, and if they are larger than some 1 km to 3 km there will be a global climate change with dramatic consequences for life on Earth. The number of casualties for such global events is assumed to be on the order of millions to billions. This large number is derived mainly from indirect causes such as tsunamis, fires, and the lack of food after crop failures due to changes in climate.

However, even the relatively frequent impacts of small sized NEOs (less than 100 m) may cause considerable damage and should have been noticed and reported by our ancestors. It is very often believed that humans have never been killed by meteorites falling from the sky, but this statement seems to be wrong if we look into the details of historical reports.

2. Historical reports

In 1994, Yau et al. [1] presented their results of the search for meteorite falls in old Chinese history reports. Yau et al. found over 300 records of recovered witnessed meteorite falls in the period from 645 B.C. to 1920 A.D., and they found 7 events where people were reported to be killed by meteorites, the first one in the year 616 A.D. These reports seem to be reliable due to the fact that they are official reports of a Chinese dynasty, even though the large number of casualties in the 1490 event (more than 10 000 people killed) is doubtful. Other reports as presented by Lewis [2] were also included in the following listing:

- *January 14, 616 A.D.*: More than 10 people were crushed to death when a large shooting star fell onto the rebel Lu Ming-yueh's camp destroying a wall-attacking tower, China [1].
- *July/August 1020*: Some people killed by many stones in an unknown place in North-Africa [3].
- *around 1341*: It rained iron in the Province of Yunnan, China. Most of the people and animals struck by them were killed [1].
- *February/March 1490*: Stones fell like rain. They struck dead more than 10 000 people in the Ch'ing-yang district of Shansi Province, China. The stones had a weight from about 1.0 kg to 1.5 kg [1].
- *September 14, 1511*: Monk and several animals were killed at Cremona in Lombardy, Italy [2]. Many stones of at least 50 kg fell near the river Adda [4].
- *1633–1664*: Monk died after being struck on the thigh by a meteorite in Milan, Italy [2].
- *1639*: A large stone fell onto a market place killing several tens of people and destroying houses in the Ch'ang-shou county, China [1].
- *1648*: Two sailors killed by an eight-pound meteorite which fell on the ship Malacca going from Holland to Batavia [2].

- *July 24, 1790*: A meteorite crushed a cottage and killed a farmer and some cattle in Gascony, France [2].
- *January 16, 1825*: One man reported killed and one woman injured by a meteorite fall in Oriang, Malwate, India [2,4].
- *June 30, 1874*: During a thunderstorm, a huge stone fell from the sky in Chin-kuei Shan, China. It crushed a cottage and killed a child [1].
- *January 31, 1879*: Farmer reported killed by meteorite in Dun-le-Poelier, Indre, France [2].
- *September 5, 1907*: A stone fell and crushed a whole family to death in Hsin-p'ai Wei, China [1].
- *June 30, 1908*: Two men died of their injuries and several hundreds of reindeers were reported killed due to the Tunguska event in Siberia, Russia [5].
- *December 8, 1929*: A meteorite hit a bridal party and killed one person in Zvezvan, Yugoslavia [2].

The dates of the 1341 event in Yunnan, China, and the 1633–1664 event in Milan, Italy, are not certain, because there are several reports referring to the same event, but giving different dates. This may originate from errors when copying the reports in former times or from mistakes in the original reports.

Boschke [3] and Graham et al. [4] quote Chladni, who reported a meteorite fall in "Cassandria" or "Cassandra in Mazedonia" that burned a city and killed enemies by "stones of burnt soil." Graham et al. [4] and Aumann [6] mention that some stones were preserved as holy objects, but a date or more details of the fall are not available. Boschke [3] and Graham et al. [4] also report of a meteorite fall in the city of Elbogen (Zapadocesky) in Bohemia, Czech Republic, around 1400. There exists a legend that the tyrannical viscount was struck to death by this iron mass when calling his subjects to do compulsory work. Another version of this legend says that the viscount turned into this iron mass, which was therefore called "the Bewitched Viscount." The 107 kg iron mass was preserved in the town hall until 1811 and is of meteoritic origin, but the killing of the viscount is only delivered as a legend and is not officially confirmed.

Yau et al. [1], Lewis [2], Boschke [3], and Graham et al. [4] present as well reports where people were reported to be hit by meteorites but not killed and where also a lot of structural damage due to meteorite falls was reported. But these reports seem to be much more incomplete than reports of people being killed, especially in former times.

3. Interpretation

It can be seen from the listing in the previous section that individuals were hit directly by a single meteorite fall or during a meteorite shower whereas more people were killed by secondary effects such as collapsing walls and houses or by subsequent fires. It is not yet clear if meteorites can start fires due to their higher temperatures after passing the atmosphere [2,7], but they can start fires as well by secondary effects, e.g., when a collapsing house is ignited by its own fireplace. The high number of people being reported killed in the 616 event in China, in the 1639 event in the Ch'ang-shou county, China, in the 1907 event in Hsin-p'ai Wei, China, and especially in the 1490 event in the Ch'ing-yang district of Shansi Province, China, may result from such secondary causes. The description that "stones fell like rain" from reports of the 1490 event in China rises parallels to the meteorite showers at Pultusk, Poland (1868), Sikhote-Alin, Russia (1947), and Jilin, China (1976), where several thousands of meteorites fell to the ground. There were no reports of human casualties because these falls happened to occur in unpopulated areas.

Assuming an average surface of $AI = 0.3$ m^2 for everyone of the 6×10^9 humans on our planet as seen from a falling meteorite at some 70° above the horizon the individual risk (RI) being hit by a meteorite is given by equation (1). It is assumed that the Earth is homogeneously populated.

The land surface of the Earth AL is 1.325×10^{14} m^2, LT is the average human life time assumed to be 65 years, and $Nmet/y$ is the number of meteorite falls per year. As stated by Hughes [7], the influx of meteorites that were recovered is about 150 to 500 single meteorites over the globe each year or 40 to 130 single meteorites on land. The estimated influx is total 10 000 to 50 000 meteorites worldwide each year or 2800 to 39 000 on land. All further calculations are based on the numbers on land, because the number of people living on the sea is negligible:

$$RI = (AI/AL) \times Nmet/y \times LT. \tag{1}$$

The individual risk RI of being hit by a meteorite once in a lifetime is shown in Table 1. The worldwide average hit interval MHI is shown in equation (2). The factor RI/LT is the individual risk RI per year. In equation (2), WP is the world population:

$$MHI = \frac{1}{(RI/LT) \times Nmet/y \times WP}. \tag{2}$$

The average hit interval for the year 1997 corresponds to a world population WP of 6×10^9 people. The results represent people hit but not necessarily killed by meteorites. Because most meteorites are small (some 10–1000 g), people were often slightly injured but not killed. For establishing a rate of people being killed, an additional factor has to be considered. This factor could be 0.25 assuming that one out of four persons being hit by a meteorite would die due to their injuries, but this value is highly speculative and therefore not further considered.

It is obvious that the individual risk RI is always the same over the centuries when assuming a constant meteorite influx rate, whereas the average hit interval depends on the number of people living on our planet. While there are about 6×10^9 people living on our planet today, there were only 3×10^9 in 1960, 1.6×10^9 in 1900, and about 5×10^8 in 1500 [9]. For the 1892 to 1992 period, a mean Earth population of 2.9×10^9 people was assumed.

Table 1 – Individual meteorite hit risks and hit intervals for several influx rates.

Meteorite influx rate on land ($Nmet/y$)	Comments	Individual risk per lifetime (RI)	Meteorite hit interval (MHI) as of 1997 [yrs]	MHI average for 1892–1992 [yrs]
40	recovered, lower bound	5.88×10^{-12}	1840	3810
130	upper bound	1.91×10^{-11}	570	1180
2 800	predicted, lower bound	4.24×10^{-10}	27	55
39 000	upper bound	5.74×10^{-9}	2	4

Lewis [2] describes 8 events where people were hit by meteorites over the last 100 years (1892–1992). In this period, we have the largest number of such events and the most detailed reports. In these 8 events, more than 40 people were hit, injured, or killed. The resulting hit interval MHI of one event every 12.5 years fits well to the expected average hit interval MHI for the period from 1892 to 1992 (see Table 1), which was corrected for the changing world population in that time (2.9×10^9 persons in average). This result indicates that the predicted meteorite influx rates of 2800 to 39 000 individual falls per year over the land surface of the Earth as presented by Hughes [7] may apply, even when assuming uncertainty factors of 3 to 4. Therefore, a mean annual influx rate of about 8000 to 10 000 meteorites may apply for the 100 year interval from 1892 to 1992.

Nevertheless, there are some uncertainties due to possible variations in the influx rate, a growing number of people being protected by solid houses, missing reports, and other factors.

The expected number of human casualties due to larger events when explosions occur during the impact is much higher. According to Adushkin and Nemchinov [10], the average number N of people killed by an impact depending on the explosion energy E (in MT—megatons of TNT) is given by equation (3):

$$N = 2 \times 10^3 \times E^{2/3}. \quad (3)$$

The known number of people killed in the 10–15 MT Tunguska event is 2, the expected number from equation (3) is 9200–12 200 for a homogeneously inhabited Earth, and could have been as high as millions if a large city as Moscow, Berlin, or New York would have been hit. The real number of casualties is that low, because the impact area was in the sparsely populated Siberian taiga. From crater statistics [11] on Earth and Moon Tunguska-like events are assumed to occur once every 300 years or in even shorter intervals [12], but their effects may much more often be negligible (as in 1908 at Tunguska) than a catastrophe (when hitting a major city), because large parts of the Earth as the seas, deserts, and polar regions are nearly unpopulated.

For NEOs ranging from some 15 m to 200 m in diameter, depending on their density, the radius of destruction is larger in case of an airburst than it would be if the energy would have been released on ground [13]. Whether an incoming NEO will reach the ground or whether it will explode in the atmosphere depends on many factors such as its density, diameter, velocity, entry angle, and strength.

The record of human casualties due to impacts of asteroids and comets would be higher if tsunamis would be taken into account. Tsunamis (Japanese for "harbor waves") are large sea waves generated by earthquakes or impacts. Tsunamis are of low altitude at the sea (some centimeters to meters) but their height multiplies by factors of 15 to 25 or more when reaching the coast. Yabushita and Hatta [14] have shown that there is a 1% chance that a 200 m NEO will drop into the Pacific Ocean in the next century. Such an impact would produce a tsunami with a height range of 15 m to 60 m which will destroy nearly all buildings and cities located at the coastline. Tsunamis are reported having killed many thousands of people, even in our century, but it is mostly impossible to prove an impact origin.

It is not clear what fraction of all impact events was reported in human history. The lack of these reports may be due to the following reasons:

- impact records are not yet discovered in the archives;
- they were recorded only as myths, and are therefore not yet discovered or not reliable;
- they were lost (wars, fires, ...);
- they were not recorded (potential recorders may have been casualties);
- the impacts were not directly observed due to a sparsely populated world in ancient times; or
- meteorite falls were not recognized as what they are.

4. Conclusions

There are reports of human casualties due to meteorite falls from all over the world (but mostly from Europe and China) and from different ages. Those reports are often highly reliable especially when they are part of official historical documents or when they originate from several independent sources.

It was shown that the number of human casualties due to meteorite falls reported worldwide over the last 100 years (1892 to 1992) fits pretty well to the expected events derived from meteor observations.

There are discussions [15–17] about ancient impacts of small NEOs (more than 100 m) which may have caused severe destruction or even regional climate changes in former times, but these theories are not yet proved. Therefore, further studies have to be done to show that impacts have occurred in human history. But the danger from NEO impacts is real. Large impact

events happen with statistically large impact intervals, but this has to be combined with high consequences for the inhabitants of our planet [18], and even more ordinary meteorite falls are causing human casualties.

Protection against NEOs is already technically feasible [18,19] and preserving our planet from NEO impacts will become the great task of mankind one day. The question is not if this will happen—the question is when.

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