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Study of Fall Meteorites Over a Century (1922-2021)

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Abstract

Fall meteorites represents to those meteorites whose fall has been witnessed and are later collected from earth surface for further studies. Mass, number of fall events, types, type mass and mass trend of observed fall meteorites are analyzed over a period of recent century (1922-2021) in this paper. The total number of fall meteorites was found to be 706 with total mass of 42800 kg. Decade 2012-2021 and 1932-1941 had the highest number of recorded fall which was 94 times and 89 times respectively. Type L6 meteorite was found to have the greatest number of falls which is 151 times, followed by type H5 and L5 with 109 times and 55 times respectively. The meteorite of type, Iron III AB had the greatest meteorites mass of 23480 kg followed by H5 and L6 with mass 6615 kg and 2347.362 kg respectively. The massive meteorite fall of this century was of Iron III AB type (1947) which weighed 23 tones. The decade 1942-1951 had the highest fall meteorites mass of 24806kg and 1972-1981 had 4858 kg. Various regression model is fitted for the trend analysis of the mass. Over a period of this century, meteorites having mass greater than 100 kg has struck the earth for 32 times while mass greater than 1000 kg has struck for 6 times. The average time between two impacts of meteorite with mass greater than 100kg was calculated to be 3.12 years while mass greater than 1000 kg was found to be 16.6 years.

Keywords meteorites, asteroid, fall, mass trend

1. Introduction

Any rocks travelling in space of size ranging from dust grain to small asteroids are called meteoroid [1]. The dust size meteoroids are called micrometeoroids. Due to their small size, micrometeoroids settle down slowly to the earth's surface without interacting with the earth atmosphere [2], whereas meteoroids other than micrometeoroids get ablated at temperature nearly 1922 K engendering a trail of light in the earth's atmosphere called meteor or shooting stars [3]. Some of these meteoroids gets completely burned in the atmosphere and few of them manage to reach the surface. These fortunate meteoroids which make it up to the surface of earth are named as meteorites [4]. Meteorites having size smaller than 1 km are thought to have not much serious environmental and global effect on earth, however meteorites greater than 1 km in size can cause problems like; massive earthquake (up to 13 Richter scale), tsunami, acid rain, green house effect, disruption in photosynthesis, fire/lightning, species extinction, global winter condition and many more [5,6]. Meteorites are the fragments of larger bodies called parent bodies. Parent bodies for most of the meteorites are asteroids. Big asteroids undergo collision to form meteoroids. Study of different types and chemical composition of meteorites have led us to a fact that larger asteroids also go through internal differentiation. Beside asteroids, comets, moon and mars are also considered to be the parent bodies of meteorites. Eccentric orbits of comets, collision of asteroid with moon and volcanic eruption in mars are responsible for the formation of meteoroids [5]. Meteorites whose parent body is moon are called lunar meteorites and those whose parent body is mars are called martian meteorites. The core aim of our research work is to analyze how many and what mass of different types of fall meteorites actually hit the earth in this century including the study of their mass trend and average impact time. The word "fall" here represents to those meteorites whose fall has been witnessed and was collected later from the earth's surface for their further studies.

1.1 Types of meteorites

Nickel and Iron are principal constituents of meteorites forming minerals. On the basis of proportion of Nickel and Iron present in a meteorite, meteorites are classified into three broad classes;

1. Stony meteorites: These meteorites are usually rocky and contains small traces of iron. They contribute about 94% of total mass of all known meteorites [7].
2. Iron meteorites: These meteorites are made up of pure Iron and Nickel including some impurities like Graphite and Troilite. They contribute about 5% of total mass of all known meteorites. They are divided into groups such as; Ataxites (D), Octahedrites (O), etc. [8].
3. Stony iron meteorites: They can be understood as the mixture of both stony and iron meteorites. Since there is small region inside the asteroids where metallic and rocky materials could mix up, this type of meteorites are super rare contributing only about 1% of all known meteorites. They are divided into groups such as; Pallasites (P), Siderophyre (S), etc. [8].

The most abundant meteorite- stony meteorites can further be divided into two parts;

- Chondrites: These meteorites have not gone through any changes and alternation since their formation. They carry information about the early universe and are made up of chondrites. They are the oldest rocks which dates back to billions of years and hence, also known as primitive solar system materials. These are subdivided into; Ordinary Chondrites, Carbonaceous Chondrites and Enstatite Chondrites. For systematic study of meteorites, these three subdivisions are again divided into several groups such as; Hypersthene (L), Bronzite (H), etc. [8,9].
- Achondrites: These meteorites have gone through changes and alternation like melting since their formation and carry information about their parent bodies. They do not contain chondrites and are much younger than chondrites meteorites. They are also divided into several groups such as; Aubrite, Eucrite, etc. [8,9]

Table 1.1: Classification of meteorites [9]

Class	Symbol	Principle minerals
	Chondrites	
Enstatite	E	Enstatite, nickel-iron

Bronzite	H	Olivine, bronzite, nickel-iron
Hypersthene	L	Olivine, hypersthene, nickel-iron
Amphoterite	LL	Olivine, hypersthene, nickel-iron
Carbonaceous	C	Serpentine, olivine
	Achondrites	
Aubrites	Ae	Enstatite
Diogenites	Ah	Hypersthene
Chassignite	Ac	Olivine
Ureilites	Au	Olivine, clinobronzite, nickel-iron
Angrite	Aa	Augite
Nakhlite	An	Diopside, olivine
Howardites	Aho	Hypersthene, plagioclase
Eucrites	Aeu	Pigeonite, plagioclase
	Stony-irons	
Pallasites	P	Olivine, nickel-iron
Siderophyre	S	Orthopyroxene , nickel-iron
Lodranite	Lo	Orthopyroxene, olivine, nickel-iron
Mesosiderites	M	Pyroxene, plagioclase, nickel-iron
	Irons	
Hexahedrites	Hx	Kamacite
Octahedrites	O	Kamacite , taenite
Ataxites	D	Taenite

2. Method and methodology

2.1 Secondary data acquisition

The data in this paper is retrieved from the database of meteorite bulletin [8]. In this paper, only those meteorites have been taken into account whose fall was observed in recent one century (1921AD - 2021AD).

2.2. Observations and calculations

The number of fall meteorites witnessed and total mass of these meteorites weighed on the earth surface in each year of this century is given in the table 2.1 below. Since no any error was mentioned primarily in the data source; we are unable to provide the observational error on the dataset below.

Table 2.1: Mass of falling observed meteorites over century

Year	No. of falling observed event	Total mass (in kg)
1922	7	25.8070
1923	6	177.2750
1924	9	43.1970
1926	7	18.0125
1927	8	181.7980
1928	6	24.0841

Year	No. of falling observed event	Total mass (in kg)
1929	7	79.0000
1930	11	505.5920
1931	8	17.0820
1932	9	41.3770
1933	17	167.3630
1934	10	102.7490

Year	No. of falling observed event	Total mass (in kg)
1935	9	136.3781
1936	7	7.8624
1937	7	528.2600
1938	11	118.8893
1939	10	81.4960
1940	5	8.9210
1941	4	15.5050
1942	8	53.5050
1943	3	57.5000
1944	7	5.8390
1945	4	32.4340
1946	6	179.1500
1947	8	23034.5300
1948	3	1124.5000
1949	14	215.8296
1950	12	41.3860
1951	8	61.7740
1952	7	122.6941
1953	3	0.2988
1954	6	33.9760
1955	5	9.0620
1956	8	115.6376
1957	6	8.7492
1958	4	16.4740
1959	7	162.9033
1960	5	669.0729
1961	7	100.5451
1962	7	60.0750
1963	8	66.5780
1964	8	50.7834
1965	4	68.2010
1966	5	295.6100
1967	9	165.1217
1968	5	26.14010
1969	6	2111.2550
1970	8	39.2700
1971	8	24.5210
1972	3	57.2880
1973	4	5.4574
1974	7	20.7030
1975	4	62.0800
1976	12	4057.1225
1977	10	117.6430
1978	3	54.4980
1979	2	22.1000
1980	6	15.3200
1981	7	446.2784
1982	3	6.4850
1983	6	173.2830
1984	10	195.7195
1985	3	65.0430
1986	10	405.4814
1987	1	14.2500
1988	6	11.5420
1989	7	60.1870
1990	7	349.4910
1991	5	135.9310
1992	3	168.9500
1993	4	59.4660
1994	6	94.5090
1995	6	137.5400
1996	5	55.9930
1997	3	102.8550
1998	12	1389.9350
1999	7	37.4150
2000	4	16.3300
2001	5	49.5000
2002	9	122.8870
2003	10	87.9617
2004	7	37.1730
2005	0	0.0000
2006	6	49.2200
2007	9	176.9274
2008	11	312.4700
2009	8	116.7748
2010	7	25.3345
2011	7	41.4570
2012	10	129.6420

Year	No. of falling observed event	Total mass (in kg)
2013	7	1067.4500
2014	7	45.1279
2015	8	35.0740
2016	12	102.1917
2017	8	34.0090
2018	14	280.5872
2019	9	123.3667
2020	13	142.9703
2021	6	16.4190

From the above tables we have calculated:
The number of fall observed in one century = 706
The total mass of fall meteorites in one century = 42800.6556 kg.

The number of fall meteorites and total mass of these meteorites weighed on the earth surface in each decade of this century is shown in the table below.

Table 2.2

Decade	No of falls	Total mass in kg
1922-1931	79	1303.0000
1932-1941	89	1208.8010
1942-1951	73	24806.4500
1952-1961	58	1239.4130
1962-1971	68	2907.5550
1972-1981	58	4858.4900
1982-1991	58	1417.4130
1992-2001	55	2112.4930
2002-2011	74	970.2054
2012-2021	94	1976.8380

Types of meteorites according to chemical composition and the total mass of fall meteorites weighed on the earth surface in each decade of this century is shown in the table below.

Table 2.3

Types	No of falls	Mass in kg
L6	151	2347.3620
H5	109	6615.3570
L5	55	661.0299
H6	48	696.1082
H4	31	254.9440
LL6	28	551.8048
L4	15	92.4574
LL5	15	1611.2700
CM2	12	144.5322
Stone-uncl	12	6.8844
Iron III AB	8	23480.1080
Aubrite	5	1180.2500
CV3	2	2005.3000

2.3 Analysis

Different graph obtained after fitting the data from the tables above are shown below:

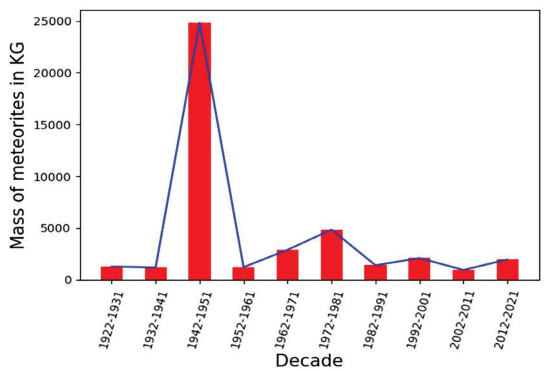

Fig. 2.1: Total mass of fall meteorites in each decade of this century.

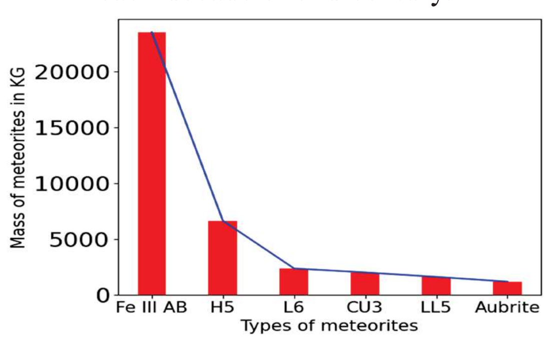

Fig. 2.2: Mass of different types of fall meteorites in this century

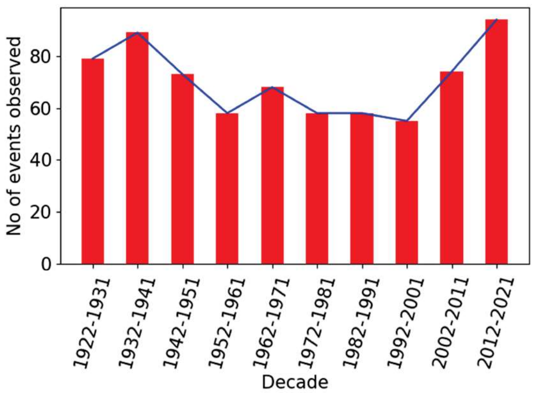

Fig. 2.3: Numbers of fall observed events in each decade of recent century

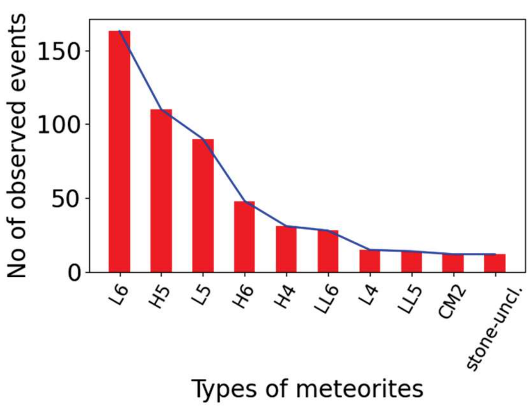

Fig. 2.4: Numbers of fall observed events of different types of meteorites

Analyzing above graphs, we have found that the greatest number of falls observed in this century was for meteorite type L6. This is the type 6 meteorite of class; Hypersthene (L) classified under chondrites meteorites of stony meteorites. The principal minerals of L class meteorites are olivine, hypersthene and nickel-iron. After L6, the most fall observed in this century was for meteorite type H5. This is the type 5 meteorite of class; Bronzite (H) classified under chondrites meteorites of stony meteorites. The principal minerals of H type meteorites are Olivine, Bronzite and nickel-iron. Following H5, L5, H6 and H4 takes the stand for the greatest number of falls observed respectively. These meteorites also fall under the category of chondrites meteorites of stony meteorites. This indicates the abundance of meteorites in outer space having chemical composition similar to that of chondrites meteorites.

The number of observed events over each decade of the century seems to be nearly equals with the average of 70.6 and standard deviation of 13.74 and it is maximum in the decade 2012-2021 and 1932-1941 respectively. However, total mass of fall meteorites on these two decades are comparatively minimum signifying that most of the meteoroids reach earth with lesser meteorite mass due to the ablation process.

Although observed fall events for Iron III AB is comparatively very low, it has the highest mass among all types of meteorites. In year 1947 a single Iron III AB fall meteorite of 23 ton was found, which is also the massive fall meteorite of this century. This gives us the idea that whenever Iron III AB meteorites strikes on earth, it strikes with a high mass (exception: Iron III AB meteorite weighing 0.73kg in 1939 AD). The fall of heavy meteorite Iron III AB might also be a sign towards the fact that heavy asteroids undergo internal differentiation and it may consist of heavy iron core.

2.3.1 Mass trend

In this section, we have plotted the graph between mass of fall meteorites and year in continuous pattern in order to analyze peaks and trends.

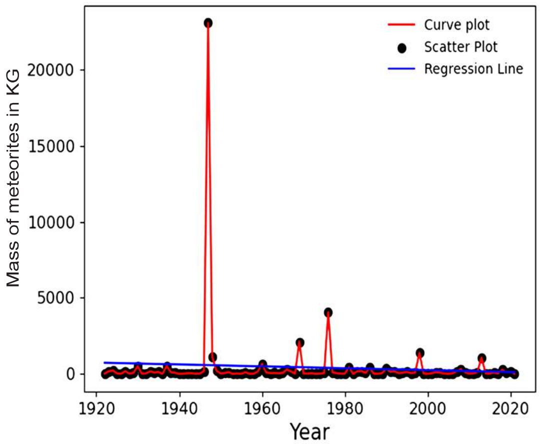

Fig. 2.5: Mass trend of this century

A regression line is fitted on the curve whose regression coefficient is found to be -6.1614 and the root mean square error (RMSE) on the mass is calculated as 2316.9 kg.

After elimination of the massive fall meteorite of the century (1947 AD, 23 ton mass) the mass trend looks like this

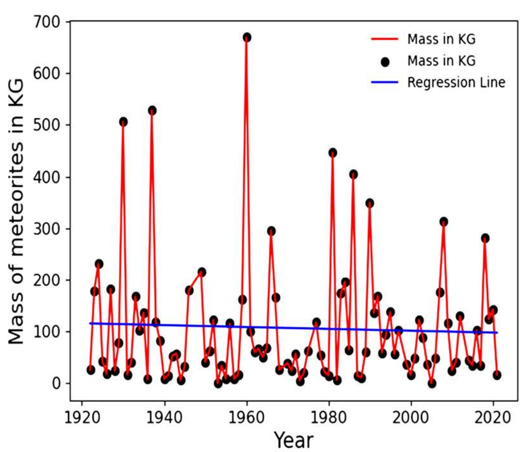

Fig. 2.6: Mass trend after the elimination of meteorite of 23 ton

We have again fitted a regression line on the curve. The regression line possess the regression coefficient of 0.4360. The root mean square error on the mass is calculated as 487.9 kg.

Again, on eliminating the mass of fall meteorites that weighed one or more than one ton solely, the obtained mass trend is shown below:

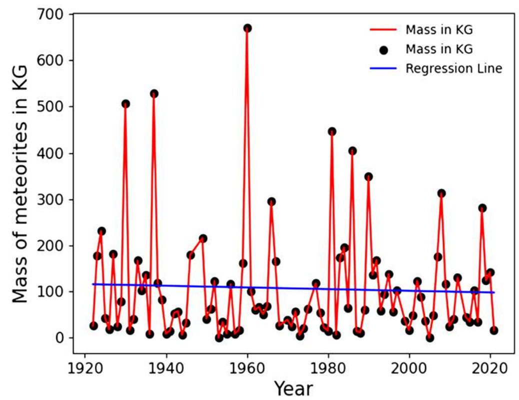

Fig. 2.7: Mass trend after the elimination of meteorites greater or equals to one ton.

Fitting of regression line is again repeated on the curve of selective mass for further analysis. The regression coefficient of the line in the figure 2.6 is -0.1806 and the root mean square error on the mass is 122.599 Kg.

The regression line in the above figures are nearly parallel to x-axis which shows that the mass of fall observed meteorites is almost constant over the century excluding very few remarkable falls: 1947(23 ton), 1976 (4 ton); as the heavier mass is neglected the regression coefficient is approaching to zero which supports the constant nature of mass of meteorites over the years. Coefficient of determination (R squared) of the regression lines drawn in the Figure 2.5, Figure 2.6, Figure 2.7 are 0.00585, 0.000679, 0.00183 respectively and are quite low which may create some hesitations to rely on the forecast given by

the model but they clearly suggest us that the phenomena is stochastic.
Over a period of this century, meteorites having mass greater than 100 kg has struck the earth for 32 times while mass greater than 1000 kg has struck for 6 times. The average impact time between two meteorites having single mass greater than one hundred kg is calculated and found to be per 3.06 year and for meteorites having single mass greater than one ton it is per 16.6 year.

2.4 Tools used for project

This project is written in MS word and python programming tool is used for the calculation and plotting graph. Different libraries of python: numpy, scipy, pandas, matplotlib and scikit-learn are used for basic calculations, csv file handling, graph plotting and regression analysis respectively.

2.5 Error analysis

No any instrumental, observational and calculation error was mentioned in the data primarily so we are not able to mention it. Root mean square error (RMSE) of the data used on section 2.3.1 is already mentioned there.

3. Conclusion

Although falling of extraterrestrial objects like meteoroids is a stochastic process, we can now predict and model their strike on earth in a greater extent by monitoring and analyzing different aspects of these events. Monitorization of Amor objects, Apollo objects and near-earth objects are found to be very helpful in predicting and minimizing risk of their impact events. Similarly, analysis of previous meteorites event has not only helped us predicting the strike but also have given us idea about the outer space and the early universe.
Total mass of fall meteorites over the century is calculated as 42800.6556 kg which was contributed by 706 events. The average of 70.6 events were observed in each decade of this century with standard deviation of 13.74 which suggest a constant nature. L6, H5, L5 types meteorites are respectively are fallen for more times dominating other types. The mass of Fe III AB type meteorite has highly dominated the mass of other types. The average impact time of meteorite of a single mass greater than one ton in this century is calculated as 3.06 year and for a solo mass greater than 100 kg is 16.06 times. We can infer that the meteorites with larger mass strike the earth less frequently.

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