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The variability of meteoroid falling

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We analysed a historical catalogue of meteoroid falling during the last 400 years. We report here for the first time the synchronization between observed meteors and solar barycentric parameters in 19.6 and 13.2 years periodicities using a new multiple cross wavelet. The group of moderated number of meteors is distributed around the positive phase of the solar barycentric periodicity of 13.2 years. While the group of severe number of meteors are distributed on the positive phase of the solar barycentric periodicity of 19.6 years. These periodicities could be associated with Jupiter periodicities. So understanding the modulation of meteoroid falling is important for determining the falling patterns of these objects and for knowing when it is more likely to expect the entry of one of these objects into the Earth's atmosphere, because bodies falling onto the Earth can cause damage from minor impacts to mass-extinctions events. One of the most extreme events was the formation of the Chicxulub impact crater 65,000,000 years ago that caused one of the five major mass extinctions in the last 500,000,000 years. During the 20th and 21st centuries, a series of events demonstrated the importance of collisions between planets and small bodies (comets and asteroids), which included our own planet. In the case of the Earth, we can cite three examples: Tunguska, Curuça and Chelyabinsk. These events invite us to think that perhaps the occurrence of this phenomenon might be more common than we realize, but the lack of communication or people in the area where they happened prevents us from having a complete record. Modern man has not witnessed the impact of large asteroids or comets on our planet, but it has been observed on other planetary bodies. The most spectacular of these events was the collision of fragments of the comet Shoemaker–Levy 9 with Jupiter in 1994. The total energy of the 21 impacts on Jupiter's atmosphere was estimated as the equivalent of tens of millions of megatons of TNT.

1. Introduction

"Shooting stars" must have attracted the attention of human beings from time immemorial. Korean, Chinese and Japanese observers kept records of meteors, meteor showers and meteorites from as early as 645 BC (Yang et al., 2005). A meteoroid is an object of asteroidal or cometary nature, a meteor is the light phenomenon associated with meteoroid ablation due to its interaction with the atmosphere, and a meteorite is what survives of a meteoroid after its passing through the air. In the chronicle Ch'unch'iu (Spring and Autumn Annals), Chinese observers made the first historical report of the fall of five stones on December 24, 645 (Yau et al., 1994). While meteors are harmless events, they demonstrate an important reality: the entry into Earth's atmosphere of asteroidal and cometary material could cause harmful effects on the terrestrial biosphere. This damage can range from impacts on individuals to the level of mass extinctions. Perhaps the oldest record of damage caused by the impact of cosmic objects on human beings was when a meteoroid fall caused the death of 10 people in 616 AD (Yau et al., 1994). Records from the Ming dynasty show that in 1490 stones fell from the sky and killed thousands of people (Ostro, 1997). An extreme event of this kind resulted in the formation of the Chicxulub impact crater 65,000,000 years ago, which caused one of the five major mass extinctions in the last 500,000,000 years (Alvarez et al., 1980; Keller et al., 2004).

During the 20th and 21st centuries, a series of events demonstrated the importance of collisions between planets and small bodies (comets and asteroids), which included our own planet and Jupiter. In the case of the Earth, we can cite three examples: Tunguska, Curuça and Chelyabinsk. On the morning of June 30, 1908, an object of between fifty and one hundred metres in length suddenly broke apart at a height of 5–10 km releasing a blast of energy equal to 10–50 Mt of TNT (Svetsov and Shuvalov, 2008). The blast completely destroyed the object in question, so no impact crater was formed, but the shock wave produced during the fragmentation had enough energy to tear down trees inside an area of 2150 km^2 (Farinella et al., 2001). That same shock wave produced a 4.7 magnitude earthquake (Ben-Menahem, 1975).

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A similar phenomenon occurred in the Brazilian Amazon on August 13, 1930 (Bailey et al., 1995; Reza et al., 2004). This event did not create impact craters, at least not any that are now recognizable, but the energy of the explosion was much more modest than Tunguska's, probably equal to a few kilotons of TNT. The Curuça event occurred in a sparsely populated area around the Curuça river area, near the border between Brazil and Peru. At this point, it is important to emphasize that this event is only known about thanks to a Catholic missionary who arrived at the scene a few days after and made a report that was published in the Vatican newspaper in 1931 (Cordero and Poveda, 2011).

Even though some authors think that the Curuça event was a forest fire (Svetsov and Shuvalov, 2008), we think it was a different event. Inhabitants of the forest know their environment and they know the difference between a forest fire and another kind of phenomenon. These two events make us to think that the entry of extraterrestrial material to the Earth's atmosphere is more common than we imagine; but the lack of communication and/or people, in the area where they happened, prevents us from having a complete record.

A more recent event occurred on February 15, 2013, in the Chelyabinsk region of Russia. It is estimated that a rocky (chondritic) asteroid of about 19.8 m in diameter with an initial kinetic energy between 470 and 590 kT entered the Earth's atmosphere, where it suffered a couple of fragmentations above an altitude of 27 km. This object, as well as those that produced the other two events, was not detected before its impact with the Earth, even though we now have more technology and resources than we had in the previous century. This is due to several causes: (a) because they were too small to be observed, (b) because there were not enough telescopes searching for them, or (c) they collided with the Earth on our planet's dayside, so it was impossible to observe them because there were no optical telescopes observing the sky during the day. The shock wave produced by the explosion of this asteroid in the atmosphere caused cracks in walls and broken windows. Pieces of shattered glass injured more than one thousand and five-hundred persons (Popova et al., 2013).

Fortunately, human beings have not witnessed in person the impact of large asteroids or comets over a kilometre in diameter with the Earth (Urrutia-Fucugauchi and Perez-Cruz, 2009), since this would certainly imply our extinction. However, we have been able to observe the consequences of the impact of asteroidal and cometary bodies with other planetary bodies. The most spectacular of these events was the collision of fragments of a comet with Jupiter. The comet Shoemaker–Levy 9 was discovered on March 24, 1993, around one year after it was torn apart by tidal forces during its penultimate close encounter with Jupiter (Mac Low et al., 1994). The comet fragmented into 21 pieces, the largest being 4 km in diameter. The total energy of the 21 impacts on Jupiter's atmosphere was estimated at the equivalent of tens of millions of megatons of TNT (Sekanina, 1996).

In Mexico, we have been studying these types of events for almost six years. The first one happened on February 10, 2010, in central Mexico. Our estimates, based on several eye-witness testimonies, are that a meteoroid entered the atmosphere following a trajectory with an azimuth between 55 and 90. Even though we were not able to assess the energy of the explosion, we think that it was less than that released by the Curuça explosion. From this event, we have learned that such phenomena cause panic among the population and that the members of civil protection bodies waste many hours of time and energy because they do not know what to look for Cordero et al. (2011).

As we have shown in the preceding paragraphs, it is necessary to study and observe the behaviour of asteroidal and cometary material that can collide with our planet and look for orbital patterns. In this regard, we propose that there may be a relationship between the fall of meteoroids and the movement of planetary bodies around the solar system barycentre (SSB).

Solar motion around the SSB has been claimed as one of the possible origins of solar variability (Jose, 1965; Charvátová, 1988). This movement and the change in the angular momentum of the Sun are attributed to the gravitational attraction of our star by Jupiter, Saturn, Uranus and Neptune (Simon and Francou, 1981; Ellis and Murray, 2000; Cionco and Abuin, 2016).

Many authors tried to explain the influence of the planets on sunspot numbers or solar cycles (Brown, 1900; Jose, 1965; Charvátová, 1988; Cionco and Compagnucci, 2012); they assume that the cause of periodicities in solar activity is the motion of the sun around the mass centre of the solar system or, in other words, that there is a very strong coupling between the gravitational field of the solar system and the solar electromagnetic field; however, a clear physical mechanism has not yet been identified. It has been suggested that a 179-year periodicity (solar barycentric periodicity) modulates the amplitude of the 11-year sunspot cycle (Cohen and Lintz, 1974; Leal-Silva et al., 2012).

The possible relationship between solar motion and climate phenomena is established in Charvátová and Střeštík (2004). The relationship between climatic phenomena and the sun's movement around the barycentre they have quantified in Leal-Silva et al. (2012). In this work we study the relationship between the fall of meteoroids (or their associated meteors or bolides,[1] and solar barycentric parameters (barycentric ecliptic longitude, solar barycentric distance, solar barycentric angular momentum and solar barycentric torque) using multiple cross wavelet analysis to identify any coherent relationship between these time series.

2. Data and method

2.1. Data

Objects of cometary and asteroidal nature of different sizes are constantly hitting the Earth's atmosphere. There are several methods to record the entry of these objects: Optical (naked-eye, photography, and video cameras), Radar, Lidar and Infrasound. Radar systems are able to record meteoroids whose sizes are between 40 μm and 900 μm; Lidar systems sample meteoroids in the size range of 0.2 mm to 10 mm, and Infrasound look for small meteoroids from millimetres to metre size and larger objects. Historically, optical methods have permitted to observe the entry of objects about tens of microns to several tens of metres (Murad and Williams, 2002; Campbell-Brown, 2007).

We analysed a historical catalogue of meteorite falls during the last 400 years. There are 1100 records in The Catalogue of Meteorites, web page: http://www.nhm.ac.uk/our-science/data/metcat/, for the period 1600–2001.

The first edition of this Catalogue was published in 1847 and the last one (the fifth edition) was published in 2000. This contains information of all well-authenticated meteorites that were known up to the end of 1999. The information in the Catalogue shows the name of the meteorite, coordinates, if it is a find or a fall, date, recovered weight, group, petrologic type, bandwidth, shock stage and weathering grade (Grady, 2000).

We focus only on meteorites that were reported as “falls”. When ground-based observers witness the fireball that precedes the arrival of meteorites to Earth's surface, we call these meteorites “falls”. Also, it is known the geographic coordinates where meteorites were recovered and we know the date when the meteorite arrived on Earth's surface.

[1] Bolides are meteors brighter than Venus.