Bayesian time series analysis of terrestrial impact cratering

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ABSTRACT

Giant impacts by comets and asteroids have probably had an important influence on terrestrial biological evolution. We know of around 180 high velocity impact craters on the Earth with ages up to 2400 Myr and diameters up to 300 km. Some studies have identified a periodicity in their age distribution, with periods ranging from 13 to 50 Myr. It has further been claimed that such periods may be causally linked to a periodic motion of the solar system through the Galactic plane. However, many of these studies suffer from methodological problems, for example misinterpretation of p-values, overestimation of significance in the periodogram or a failure to consider plausible alternative models. Here I develop a Bayesian method for this problem in which impacts are treated as a stochastic phenomenon. Models for the time variation of the impact probability are defined and the evidence for them in the geological record is compared using Bayes factors. This probabilistic approach obviates the need for ad hoc statistics, and also makes explicit use of the age uncertainties. I find strong evidence for a monotonic decrease in the recorded impact rate going back in time over the past 250 Myr for craters larger than 5 km. The same is found for the past 150 Myr when craters with upper age limits are included. This is consistent with a crater preservation/discovery bias modulating an otherwise constant impact rate. The set of craters larger than 35 km (so less affected by erosion and infilling) and younger than 400 Myr are best explained by a constant impact probability model. A periodic variation in the cratering rate is strongly disfavoured in all data sets. There is also no evidence for a periodicity superimposed on a constant rate or trend, although this more complex signal would be harder to distinguish.

Key words: methods; data analysis, statistical – Earth – meteorites, meteors, meteoroids – planets and satellites: surfaces

1 INTRODUCTION

About 180 terrestrial impact craters are known. The high velocity of the impact means that even relatively small comets or asteroids produce large craters. The meteor which cratered the 1.2 km diameter Barringer crater in Arizona, for example, was probably only 50 m across. Since the discovery of evidence for a large impact 65 Myr ago at the geological boundary between the Cretaceous and Tertiary periods (the K-T boundary) (Alvarez et al. 1980) and its implication in the mass extinction event at that time (including the demise of the dinosaurs), it has become clear that bolide impacts have had a significant impact on the evolution of life.

The large impactors are believed to be either asteroids from the main asteroid belt, or comets from the Oort cloud (Shoemaker 1983). The multi-body dynamics involved in putting these on a collision course with the Earth implies that cratering is a random phenomenon, but the rate of impacts is not necessarily constant in time. It has been suggested that gravitational perturbations of the Oort cloud due to the Galactic tide, passages of the solar system near to molecular clouds, or an unseen solar companion, may send large numbers of comets into the inner solar system as a comet shower, increasing the impact rate (Davis et al. 1984, Torbett & Smoluchowski 1984, Rampino & Stothers 1984, Napier 1998, Wickramasinghe & Napier 2008, Gardner et al. 2011). Simple dynamical calculations indicate that the Sun oscillates vertically about the Galactic midplane with a period of 52–74 Myr, depending on the mass density assumed (Bahcall & Bahcall 1985, Shuter & Klatt 1986, Stothers 1998). In parallel to this, several studies claim to have found evidence for a temporal periodicity in the impact cratering record over the past few hundred million years, with numerous periods ranging from 13 to 50 Myr being identified (Alvarez & Muller 1984, Rampino & Stothers 1984, Grieve et al. 1985, Monnari et al. 1998, Napier 1998, Yabushita 2004, Chang & Moon 2005, Napier 2006). Some authors make a causal link, suggesting that each midplane crossing increases the impact rate. It has also been suggested that periodicities in cratering may be associated with alleged periodicities in mass extinctions or in biodiversity variations, although there is little evidence linking any mass extinc-

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