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A confidence index for forecasting of meteor showers

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A R T I C L E I N F O

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A B S T R A C T

The forecasting of meteor showers is currently very good at predicting the timing of meteor outbursts, but still needs further work regarding the level of a given shower. Moreover, uncertainties are rarely provided, leaving the end user (scientist, space agency or the public) with no way to evaluate how much the prediction is trustworthy. A confidence index for the forecasting of meteor showers is presented. It allows one to better understand how a specific forecasting has been performed. In particular, it underlines the role of our current knowledge of the parent body, its past orbit and past activity. The role of close encounters with planets for the time period considered is quantified as well. This confidence index is a first step towards better constrained forecasting of future meteor showers.

1. Introduction

The prediction of meteor showers on Earth has been the topic of many research since the XIXth century. The observation of recurrent outburst (such as e.g. the Leonids every 33 years more or less) has been the first motivation to conjecture about future events. In addition, the link between meteor showers and comets was established by Schiaparelli (Romig, 1966) and shortly later the first forecasting were based on the orbit of the parent comet. One famous failure was however the expected return of the Leonids in 1899, as well as in the three following perihelion returns of comet 55P. It was not before Kondrateva and Reznikov (1985) and later on McNaught and Asher (1999) that an estimate of the time of a shower outburst was correctly predicted.

If the timing of meteor showers is currently well constrained by todays works, the level of the shower still poses a challenge to astronomers. Failures at predicting a correct level of a shower has consequences for researchers, space agencies and the public. Beside the disappointment aspect of missing on an opportunity which might end up being a waste of time, protection procedure for spacecraft require lots of time and energy.

The success of predicting a shower was enabled by understanding that meteoroids and comets have similar yet independent orbit and orbit evolution. Today methods are more or less all the same and are based on the propagation of the orbit of test particles released from the parent body, from the time of ejection until it passes near the Earth. Refinement include: ejection over an arc of orbit, massive simulation of tests particles, update of the ejection velocity (i.e. taking into account the physics behind the ejection process). Among the authors performing such forecasting, we find McNaught and Asher (1999), Lyytinen and Van Flandern (2000), Vaubaillon et al. (2005a), Watanabe and Sato (2008). However, apart from those, no new method has been developed recently.

Surprisingly, in spite of the quality of the work dedicated to meteor shower forecasting, no uncertainty has ever been published to my knowledge. The first reason probably comes from the dynamical approach of the forecasting, which was the Achilles heel until 1999, and the focus of many works. However, seventeen years later this has not improved. The second reason most probably comes from our ignorance in so many physical quantities of the parent body as well as its past dynamical behavior.

The difficulty of providing uncertainties can certainly be overcome, by going through a rigorous analysis of every step leading to a given forecast. However, one might argue that such a refinement might not tell us much, again because of our uncertainty in e.g. the parent body parameters. In other words, it might be hard to define a credible uncertainty of a physical quantity for which even orders of magnitude cannot be estimated.

Because the end users of the forecasting still needs a way to know how much (s)he can trust a given prediction, this paper presents a different approach. The idea is to provide the scientists, space agencies and amateurs some knowledge regarding the circumstances under which the predictions were performed, and inform them regarding the chances of success, especially in terms of the level of the shower. I hope that by doing so every reader of future forecasting can have a proper idea of how much (s)he can trust the forecasting.

The paper first presents in Section 2 a reflexion on the way meteor showers predictions are performed today and underlines the location of greatest uncertainties. Then in Section 3 a confidence index is presented that provides the end users with enough information to have an idea of how much one can trust the forecasting. Last but not least in Section 4 some confidence index are listed for past and future showers.

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2. Strategy

In order to perform the forecasting of the timing (T) of a meteor shower, one needs to know:

T1 the parent body

T2 the past orbit of the parent body

T3 how meteoroids are ejected from the parent body

T4 how meteoroids orbits evolve in the Solar System.

In order to perform the forecasting of the level (L) of a meteor shower, one needs to know L1 or L2 as well as L3, as explained below:

L1 the past activity of the shower

L2 the past activity of the parent body

L3 a way to convert this activity into a ZHR.

Point T4 is quite well understood today, and point T3 does not matter much, since the knowledge of an order of magnitude is good enough to perform a correct prediction. The reason if that anyway meteoroids are ejected with a distribution of velocities and a distribution of heliocentric distances. The identification of a parent body has recently seen a huge development thanks to multi-years survey (Jenniskens et al., 2011; Rudawska et al., 2015; Colas et al., 2014). The accumulation of tens of thousands of meteoroid orbits allows one to better recognize otherwise undetected showers, and dynamical links are based on orbital similarity. In a similar way, the discovery of new thousands of NEOs makes it more likely to find a parent body for a given new shower. In other words, point T1 is being currently revolutionized by huge amount of data and data mining. Similarly, point L1 is being currently refined for the same reasons. However, if the basic knowledge of the activity of a shower is poorly constrained, needless to say that any estimate of future shower cannot be accurate. This is particularly preventing the performance of prediction on other planets as Earth (Mars and Venus being the currently most wanted one). Point L3 is usually straightforward by convertir a 3D particle density into a 2D density, or by comparing the past encounters circumstances (e.g. distance between the center of a trail with the path of the Earth) with the forecasted one McNaught and Asher (1999).

What is left are points T2 and L2, forming the source of most uncertainties, in my opinion. The past orbit of famous parent bodies (such as 1P/Halley, 109P/Swift-Tuttle) can be useful by telling us that their orbit is stable enough and that their activity spent several centuries. However, this might not directly explain today level of e.g. the Orionid and Perseids if the encountered particles are older than the oldest record of the comet. This is unfortunately indeed the case for 1P and109P, and the reason why the prediction of the Perseids are mainly performed by the International Meteor Organization and based on past observations of the shower L1, provided it is stable enough.

In most cases, the past orbit of a parent body is problematic, by lack of past observations. Even if one can dig in historic records, one cannot find anything beyond 5000 years ago, which might not be enough for long period bodies (Neslušan et al., 2016). Fortunately, as long as the orbit of the parent body is stable enough (see comment below regarding this notion), and its cometary activity either non existent or constant from one passage to another, it is easy to find its past returns, yielding to the forecasting of future showers. However, usually the past activity if even less constrained than the orbit of the parent body.

Another problem is the stability of the orbit of the parent body. Even if its today orbit is well constrained, close encounters are prone to dissipate any hope to know its orbit past a certain date. One famous example is comet 67P/Churyumov-Gerasimenko (Maquet, 2015), for which it is hard to clearly know its orbit before the 1950s.

Are we therefore doomed in our ignorance of so many important parameters? Several works tend to provide constrains on the origins of meteor showers, which by such enables to better perform the predictions of future events. However this is not always feasible.

In this paper, the approach first considers that in complement to all these research, it is useful to provide informations regarding the way predictions are performed, in order to sense the difficulty and uncertainties considered in a given prediction. The idea is to consider each main source of uncertainty and either label or quantify it. The confidence index is therefore a code providing information on how the ephemeris of a given meteor shower was performed.

3. The confidence index

The confidence index is built as a succession of letters and numbers, each having its own meaning and dealing with a specific challenge to perform an accurate forecasting.

3.1. First letter: the trail index

The first consideration deals with the number of trails the forecasting process is dealing with. In the most usual and simple case, one trail encountered by the Earth results in a single prediction. In such a case, the trail index contributing to the confidence index is set to “S” (as in Single trail).

However such a method is unable to e.g. predict the usual background level of the Perseids, as is consists of the superposition of very old trails (>10 k years old), for which the exact origin is unknown. The simulation of such many trails, providing a global information of the shower is feasible but needs to be documented to allow the end user to be warned that the exact origin of the trails is not accurately known (beside the knowledge of the parent body). In such a case, the trail index is set to “G”, meaning that the Global level of the shower was computed. The end user can therefore quickly know by examining the first letter that a “G” will a priori provide a less accurate prediction than an “S”. Put it in another way, a “G” means that the background of the shower is forecasted, rather than an outburst. This is of particular use for e.g. the Leonids, known to present rare exceptional outbursts and a low activity otherwise (15/h).

3.2. Second letter: year index

The second consideration deals with the uniqueness of the time period for which the prediction is performed. Most of the time, meteor shower forecasting are computed by considering the particles approaching the planet during a short time period (usually of a few days (Brown and Jones, 1998; Vaubaillon et al., 2005b)). Most of the time a given trail is not perturbed enough to present more than one encounter with the Earth for a given year. In such case, the “year index”, contributing to the confidence index is set to “Y” (as in Year), meaning that the prediction is valid for a given year and includes only the particles crossing the planet at this time.

Now, in the case of a low level shower and even by considering several tens of thousands of particles in the simulations, there might not be enough test particles to compute a level that really makes any physical sense. One solution is to greatly increase the number of simulated particles (Jenniskens and Vaubaillon, 2008). However another solution is possible. In such a case, the idea is to concatenate the contribution of all the particles encountering the planet over several years. This provides us with an idea of the background activity of the shower, and the location of the stream, rather than the individual location of several given trails. Such an approach is useful also for parent bodies for which the orbit is not well constrained. Note that in order to derive a correct timing of the background activity of the shower by following this method, the location of the planet still has to be computed for a short period of time (e.g. several days) and should of course not be concatenated over several years. By doing so, the change of timing from one year to another can be computed. In such a case, the “year index” is set to “B”, as in “Background”.

3.3. Third element: observation index

The third element of the index deals with points T2 and L2. It is a