Low dispersion meteor velocity measurements with CABERNET

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We present here a method to determine the meteor velocities in a more robust way than what is usually done, working with the images provided by the CABERNET project. Thanks to an electronic shutter coupled to the cameras, meteors look like a succession of centroids in the photographic records. We are able to determine the position of the meteor in the image across the time, as well as its apparent velocity, by plotting the light curve along the track of the meteor. To minimize the measurement errors of the centroids position, we use the RANSAC algorithm to fit the apparent velocity. Thanks to this fit, the position the meteor would have at a time t + δt is computed. After an astrometric reduction process, we finally obtain two sets of values (t, α, δ) and (t + δt, α, δ). By projecting those positions at time t and t + δt on the 3-D trajectory, we compute a 3-D velocity which is not as sensitive to the measurement errors as other methods and which shows a lower data dispersion.

1 Introduction

Nowadays, the lack of high-accuracy orbits for many meteors showers hampers significantly the research of their parent bodies and the determination of the age of the showers. This situation is caused by the difficulty of precisely measuring the velocity and changes of velocity induced by the atmosphere. In order to link a meteor with his parent body, it is then necessary to focus on the reconstruction in the heliocentric frame. The CAmera for BEtter Resolution NETwork (CABERNET), was developed to measure accurate orbits of meteors, in order to study the dynamics of meteoroids streams and to reliably determine their parent body. The minimum requirement for the project was to improve the accuracy of meteoroids orbits measurements at least by a factor of ten. This network provides 40 x 27° images of the sky from three stations (Atreya et al.,2006). An electronic shutter interrupts the signal at a tunable frequency. Meteors then look like a succession of dashes, which is useful to accurately determine the position and the velocity of the object (see Figure 1). We present here a way to determine the meteoroid velocity from digital photographic records provided by the CABERNET cameras. It mainly relies on the determination of the apparent velocity in the image, helped by the use of the RANSAC algorithm. By limiting the influence of noise on the velocity determination, this method allows us to determine the 3-D velocity of meteors more robustly and more accurately than before.

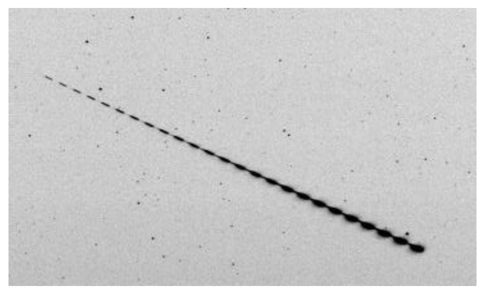

Figure 1 – Meteor detected by the Guzet station, (13/12/2010).

2 Usual method to compute the 3-D velocities of meteors

The usual way to determine the 3-D velocity of meteors starts by measuring the location *(x,y)* of the meteor in the image. Usually, the barycenter of the meteor is taken for this step. After an astrometric reduction process, which provides us with the sky coordinates, we use a method to reconstruct the 3-D trajectory of the meteor (like the intersect plane method, Ceplecha, 1987). From this trajectory and time information, we are then able to deduce the 3-D velocity of the meteor and velocity changes. Indeed, knowing the 3D location of the meteor (X_{3D}) through the time t, we can compute the 3-D velocity:

$$V_{3D} = \frac{\Delta X_{3D}}{\Delta t} \qquad (1)$$

However, this approach can be limited because of the image contamination by the noise, which hinders the position determination of the meteor. An error at this step can have an important impact on the subsequent computation of velocity. Having the advantage of working with photographic records, and so the possibility of treating the whole meteor at once, we developed a more robust method to compute the 3-D velocity.

3 New method

The main idea of this method is to use the apparent velocity of meteors in our images to compute more precisely the 3-D velocity of the objects afterwards. To do that, we first need to accurately determine the position of the meteor in the image over time. As we see from Figure 1, a meteor in our images looks like a succession of dashes (at each time stamp t), which centroids are determined by extracting the light curve along the trail. After smoothing the light curve using the Savitsky-Golay algorithm (Savitsky et al.,1964), the centroids location are associated to the position of the light curve's maxima. However, this method was not robust enough because of the noise of the light curve, which caused several numbers of false maxima detection and then aberrant values for the apparent velocity. To overcome this, we decided to apply the RANSAC algorithm to remove the aberrant values of the apparent velocity caused by the false maxima detections. The RANdom SAmple Consensus (RANSAC) is a way to determine a mathematical model (here linear), from a set of data which contains outliers. It firstly chooses a random subset of the original data (values of apparent velocity) of size n defined by the user. Then, a model is fitted to this subset and we search in all the data which values follow it satisfactorily (distance criteria). We iterate the process until finding the best result, i.e. the more accurate model (minimal distances between the inliers and the fit) for a higher set of points. The RANSAC algorithm is an iterative method which provides a correct result with a defined probability. That is why it is necessary to iterate the whole algorithm k times to be sure to obtain the optimal solution with a sufficient high probability of success (99% or more). This number k can be computed each time we choose a new subset (Fischler et al., 1981), and it determines the end of the iteration process. To summarize, if we consider enough values of the apparent velocity (which decreases linearly with time), we are able to exclude the aberrant values thanks to the RANSAC algorithm with a probability of success higher than 99 %. Thanks to the fit of the apparent velocity, we can compute the apparent position (in the image) the meteor would have a short time δt (here 1 ms) after the position (x, y) measured at t. We then obtain two sets of values, (x, y, t) and $(x', y', t + \delta t)$. After projecting them on the 3-D trajectory (Ceplecha, 1987) to get (X_{3D}, t) and $(X'_{3D}, t + \delta t)$, we can finally compute the 3-D velocity

$$V_{3D} = \frac{X_{3D} - X'_{3D}}{\delta t} \quad (2)$$

This allows a better robustness of the determination of the velocity against errors in the measurement of the apparent meteor position. Indeed, with the usual way, a velocity value depends on the measurement error of two centroids position. But with our method, thanks to the RANSAC algorithm, the errors made in the centroids position determination are minimized in the fit of the apparent velocity. With our method, the 3-D velocity is then not so much sensitive to the measurement errors.

4 Results

In Figures 2 and 3, we show an example of results obtained with the usual method and the method presented here, of a double station meteor. We mainly see the great improvement of the results quality. In the first case, we have an important dispersion (about 1/5 of the velocity 6 km/s^{-1} / 30 km/s^{-1}), and in consequence the deceleration is hard to measure. With our method, the dispersion represents 1/300 of the signal (0,1 km.s^{-1} / 30 km.s^{-1}) and the deceleration is easily measurable (1,83 km.s^{-2}).

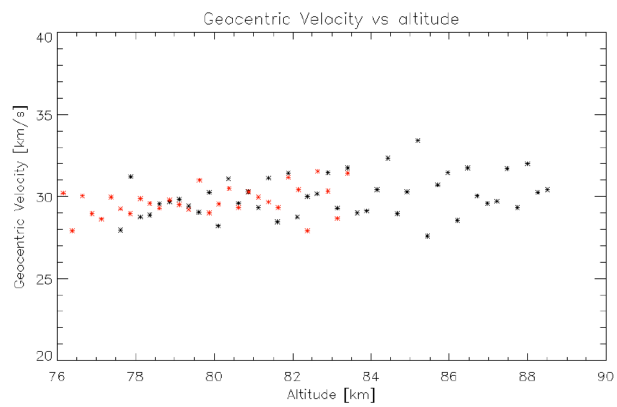

Figure 2 – Determination of the 3-D velocity with usual method. The result is very noisy, and it is extremely hard to recognize the change in velocity.

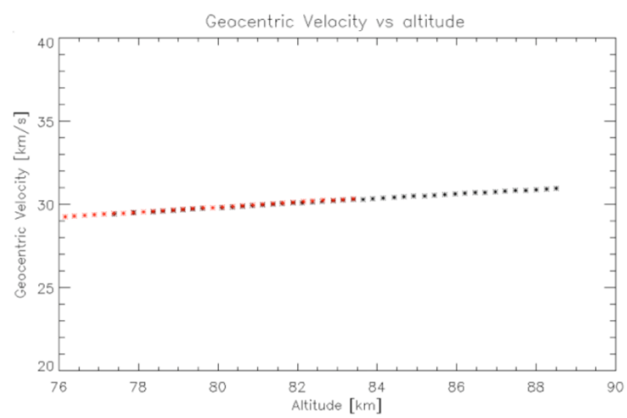

Figure 3 – Determination of the 3-D velocity with our method. The spread is much smaller and the change in velocity is measurable.

The method presented in this work results in a much more robust determination of the velocity, in a lower data dispersion and allows us to measure changes of the 3-D velocity. This process can be fully automated to fasten the data reduction, and we estimate a benefit of one or two orders of magnitude on the velocity accuracy. However, some improvements are still necessary to fully exploit the potential of the CABERNET project.

5 Conclusion

We have developed a method to accurately compute the 3-D velocity of meteors from CABERNET measurements, based on the work of Atreya et al. (2006), and modified for our needs. The computation of the apparent velocity allows us to better define the 3-D velocity in a robust way, thanks to the RANSAC algorithm. Many improvements still remain to be included in order to further improve the accuracy this promising method can provide.

Acknowledgements

The CABERNET project is supported by IMCCE, Observatoire de Paris, the City of Paris and PNP. We are grateful to R. Arlt (at IMC2010), J. Borovička (Ondrejov observatory) and Geert Barentsen for their personal communications, which have greatly helped us during this work.

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