Meteor science

Exhaustive error computation on 3 or more simultaneous meteor observations

SonotaCo [1]

Error computation for all combinations of 3 or more simultaneous observations of a meteor enables the automated selection of one combination that gives the best accuracy. This method applies the radiant direction error Er computation using Monte Carlo simulation for $2^N - N - 1$ subsets in the power set of N simultaneous observations. By this method on a case of a meteor that has 12 simultaneous observations, a combination of 5 observations was selected and its Er was improved from $10\overset{\circ}{.}7$ to $0\overset{\circ}{.}11$. Applying this method for actual 73 636 meteors that have 3 or more simultaneous observations, the accuracy of 54 103 (73%) meteors were improved, the average Er reduced from $1\overset{\circ}{.}75$ to $0\overset{\circ}{.}89$, and the number of highly accurate orbits ($Er < 1\overset{\circ}{.}0$) was increased from 46 102 to 55 436 (+20%). This method will be used in the aggregation of SonotaCo Network meteor data.

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1 Introduction

In the optical meteor observation network 3 or more simultaneous observations of one meteor occasionally happen. They may come from multiple cameras at multiple stations, or multiple measurements of parts one trajectory. The SonotaCo Network has observed 231 872 meteors in the past 10 years, with 73 636 meteors having 3 or more simultaneous observations. This is over 30%, and the improvement of their orbit accuracy is expected to contribute to the precise clustering of meteor showers. In this paper, using an automated procedure for 3 or more simultaneous observations, a new orbit determination method that was developed in the aggregation of SonotaCo Network data is presented.

2 Past approach

The most primitive radiant determination method with optical observations is using a pair of simultaneous observations and computing the intersection of 2 observation planes that each contain an observing station and the observed trajectory. When applying this method to all pairs of N simultaneous observations, there will be ${}_NC_2$ different results, and some post processing to unify the results is necessary. UFOOrbitV2 (UO2; SonotaCo, 2007) uses another method named “Unified radiant computation” that computes one radiant direction from multiple observations by a least squares method. It determines the radiant direction as the least error pole direction of a plane that contains all observation plane poles. Because this method stably outputs one result on any number of simultaneous observations, it has been used on the SonotaCo Network Meteor database since 2007 (SonotaCo, 2009; SNM: SonotaCo, 2009-2017). However the unconditional use of all observations contains the possibility of decreasing the accuracy by including some low accuracy observations or error amplifying factors. By this reason, UO2 checks the quality of each single station observation beforehand and rejects some observations that might decrease the total accuracy. But it is just a heuristic method and there was no mathematical assurance for the accuracy. For this situation, the overall observation error computation method using Monte Carlo simulation on SonotaCo Network data was developed (SonotaCo et al., 2014; SonotaCo, 2016). This method results in one error value Er that represents the radiant direction uncertainty. By using this Er, now we can evaluate the accuracy of any computation method mathematically.

3 Exhaustive computation

As the perfect and the simplest way, the new method generates exhaustive combinations of simultaneous observations, computes each Er, and selects the best combination that gives the least Er. There can be $2^N - N - 1$ subsets that have more than 1 element in the power set of N elements set. And on one Er computation by Monte Carlo simulations, UO2 performs 1 000 time trial computations. Therefore, the required number of orbit computation times becomes $1\,000 * (2^N - N - 1)$. For example it is 4 083 000 times for $N = 12$. Because it increases exponentially, a ceiling on N is necessary. In the stacked SonotaCo Network data, the biggest N was 29 (an earth grazing meteor happened in 2016 November), and the second was 20. The actual processing time of $N = 20$ case was 6.7 hours by 4.1 GHz processor. However for $N = 29$ it computation time was estimated as 133 days, and was not processed, but its observations are selected by the observation angle length beforehand. Including those, the total processing time for all 231 872 meteors in 10 years was 31.1 hours.

4 Improvement of the accuracy

The first sample is a meteor that happened on 2017 April 29 at $15^{h}58^{m}18^{s}$ UT. It was recorded by 12 cameras from 11 stations of the SonotaCo Network in Japan. In this case, through error computation on all 4 083 combinations, a set of 5 observations were selected. The

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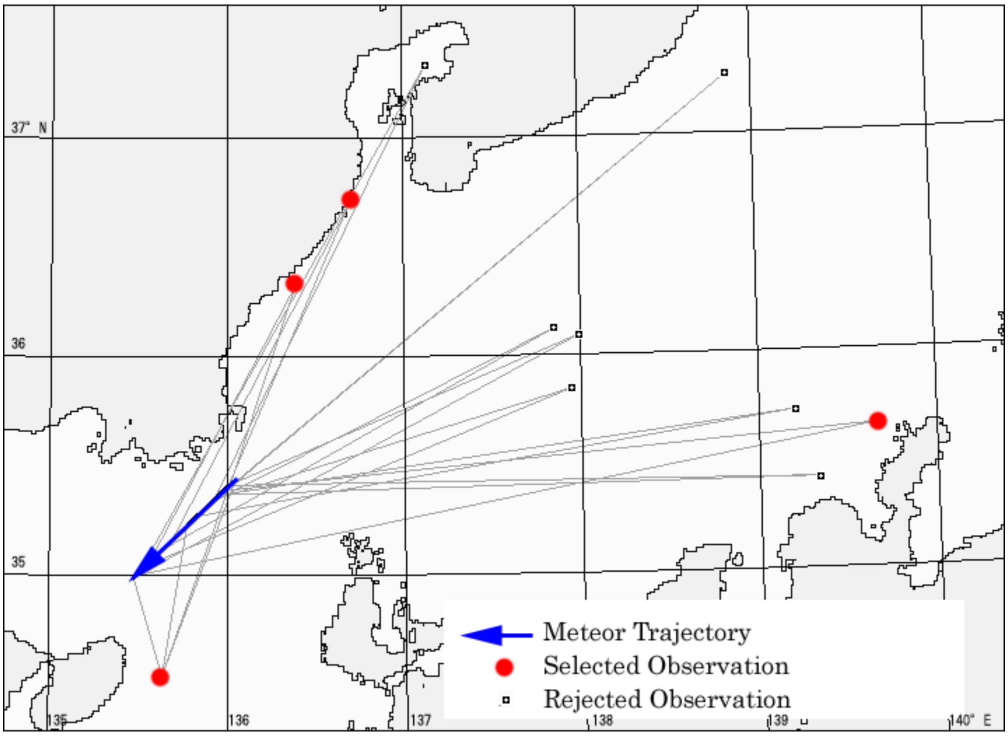

Figure 1 – Geographical relation of 12 simultaneous observations.

original Er on 12 observations was 10°.7. It was improved to 0°.11 on the selected set. The least Er in all pairs, that uses only 2 observations at a time, was 0°.23. The improvement of accuracy by using unified radiant computation and the combination selection on 3 or more observations was clear on this case. Figure 1 shows geographical relation on this case, and Figure 2 shows the original simulated radiant distribution with the Monte Carlo method that uses all observations. Figure 3 shows the result of the selected 5 observations.

The second sample is the 73 636 meteors that have 3 or more simultaneous observations in the 10 years of SonotaCo Network observations. Figure 4 shows the distribution of the number of simultaneous observations used. The average number of selected observations changed from 4.1 to 2.5. Figure 5 shows their Er improvement. Its average becomes 0°.89 from 1°.75. The number of number of highly accurate meteors ($Er <$ 1°.0) was increased from 46 102 to 55 436 (+20%).

5 Conclusions

The unified radiant computation method enabled the utilization of the 3 or more simultaneous observations, and the observation error propagation using Monte Carlo simulation enabled the mathematical comparison of the results. And the exhaustive error computation on all possible combinations assures automated selection of an observations combination that results the best accuracy. Therefore progress has been made on the accuracy of the radiant direction that may contribute the precise meteor shower clustering. This method will be used in the aggregation of SonotaCo Network data.

However the accuracy of velocity measurement from video observation is still not satisfactory. It is an im-

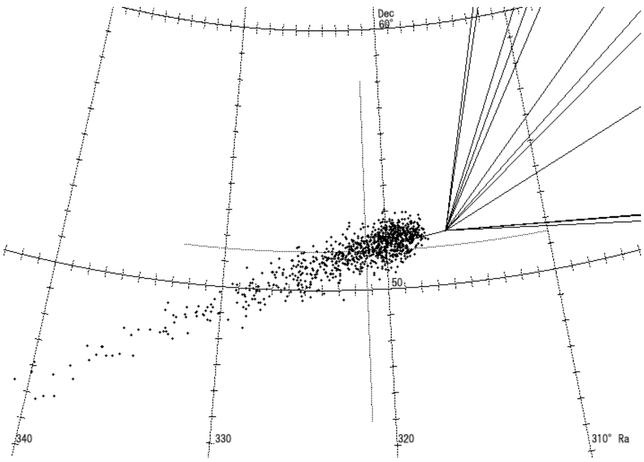

Figure 2 – Radiant distribution on Monte Carlo simulation of using all 12 observations. $Er = 10°.7$.

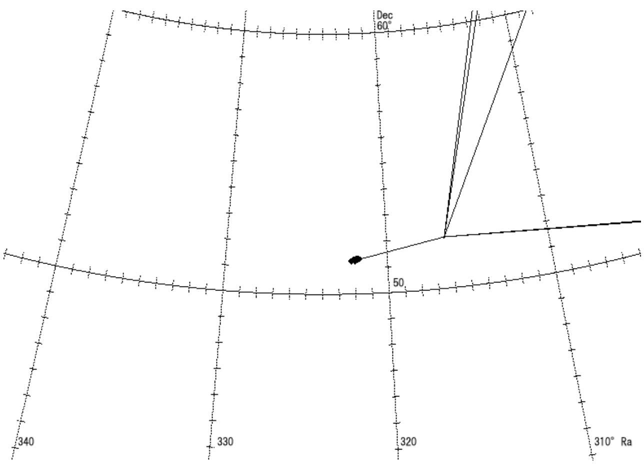

Figure 3 – Radiant distribution on Monte Carlo simulation of using selected 5 observations. $Er = 0°.11$.

portant aspect for heliocentric orbit research and is expected to be solved in the future.

Acknowledgements

SonotaCo Network video meteor observation in Japan has been in operation for over 10 years. This network is supported and operated by individual volunteer observers. It has published almost 20 000 meteor orbits every year and contributed to many aspects if meteor science. This paper is one of its fruits. I appeal my best appreciation and respect for the scientific efforts of observers who are listed in the SNM note files.

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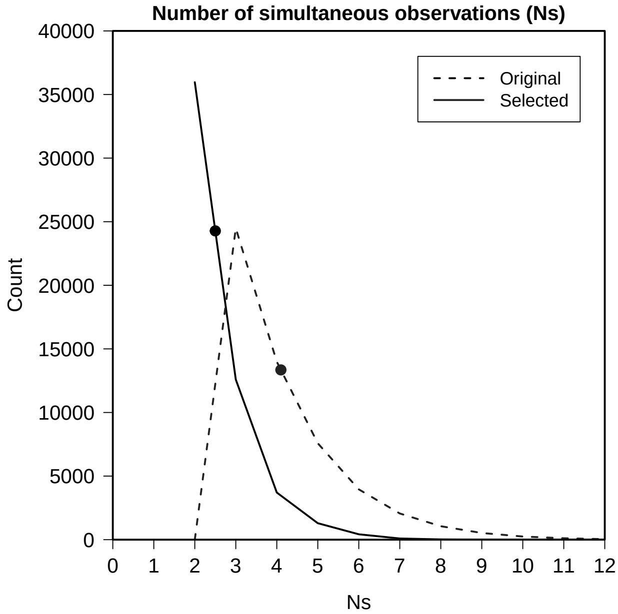

Figure 4 – Distribution change of the number of simultaneous observations on the 73 636 meteors that originally has 3 or more observations. The average (see circles) changed from 4.1 to 2.5 by the selection. The maximal Ns was 20 and only data up to $Ns = 12$ are plotted because the number of meteors with $Ns > 12$ is small.

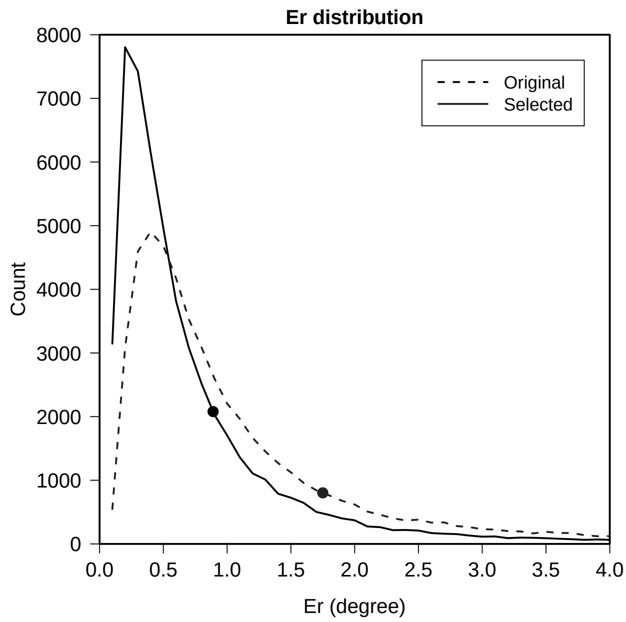

Figure 5 – *Er* distribution of 73 636 meteors. The average *Er* becomes 0.°89 from 1.°75 (see circles).