# On the possible effect of signal processing in meteor-head radar reflections from Jicamarca

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## Abstract

We report the analysis of a peculiar signature present in Signal to Noise Ratio (SNR) plots from meteor-head radar returns. These radar reflections were collected with the High-Power Large-Aperture (HPLA) radar at Jicamarca in Lima, Peru. The signature appears to be systematic, being caused by the combined effect of meteor-head echoes properties and signal processing in the radar receiver. We describe a first order model to support this hypothesis. Our studies reveal that at least 15% of the meteor population exhibit this signature. Therefore, the understanding of this feature is critical to differentiate them from actual physical processes present in meteor returns. Failing to do so could lead to misinterpretation of meteor data.

## 1 Introduction

Since mid 1990s High Power-Large Aperture (HPLA) radars such as Jicamarca have demonstrated to be excellent tools for conducting meteor research. These types of radars can detect signals scattered back from the plasma surrounding a size-grain meteoroid. These radar returns are called meteor-head echoes. In recent years, there have been substantial progress in this field using HPLA radars to understand meteor source distributions, differential ablation and fragmentation [1-3]. But there has been limited studies to understand the possible systematic effects being introduced by the radar system's characteristics and meteor-head echoes properties. We report, for the first time, an unusual signature observed in Signal to Noise Ratio (SNR) plots from meteor-head echoes collected with the large VHF radar at Jicamarca. We describe a software model of the digital receiver section of Jicamarca radar that can successfully reproduce the main features of this signature observed in SNR plots. We call this signature $S$ (from Systematic). Our analysis indicates that this feature appears to be a systematic effect due to both meteor-head echoes characteristics and signal processing in the digital receivers of the radar. We also discuss the impact of this signature on meteor-head echo analysis.

## 2 Description of Signature $S$

The presence of signature $S$ is evident in SNR plots of meteor-head echoes with low radial velocity ($\sim$15 Km/s). An example of signature $S$ is depicted in Figure 1. Notice from this figure the following features: 1) strong correlation among fluctuations in SNR values and change in range of a meteor echo, and 2) the fluctuations exhibit periodic ripples with amplitude of $\sim$3 dB. These characteristics are quite different from meteor fragmentation observations reported by [2][4], that showed SNR fluctuations larger than 10 dB and non-constant oscillation periods.

We examined a total of three nights of meteor observations from three different seasons: 27th February 2006, 5th May 2007 and 14th December 2008. The observations were counted and analyzed to identify the presence (blue curve) or absence (green curve) of signature $S$ as indicated in Figure 2. These plots also show normalized statistics of meteor-head parameters detected during 5th May 2007. The other two days show similar trends and are not the focus of this report. Notice from Figure 2 the following characteristics: 1) initial range, radial velocity, elevation, speed, and acceleration show similar trends for both blue and

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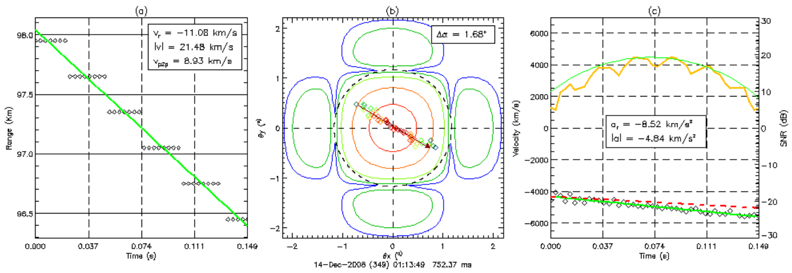


Figure 1: (a) Range vs. time, (b) Trajectory of the meteor-head with respect to the radar coordinate system, and (c) Pulse-to-Pulse radial velocity and SNR plot along the meteor trajectory (in orange). Notice the correlation in SNR fluctuations with change in range of the meteor-head echo.

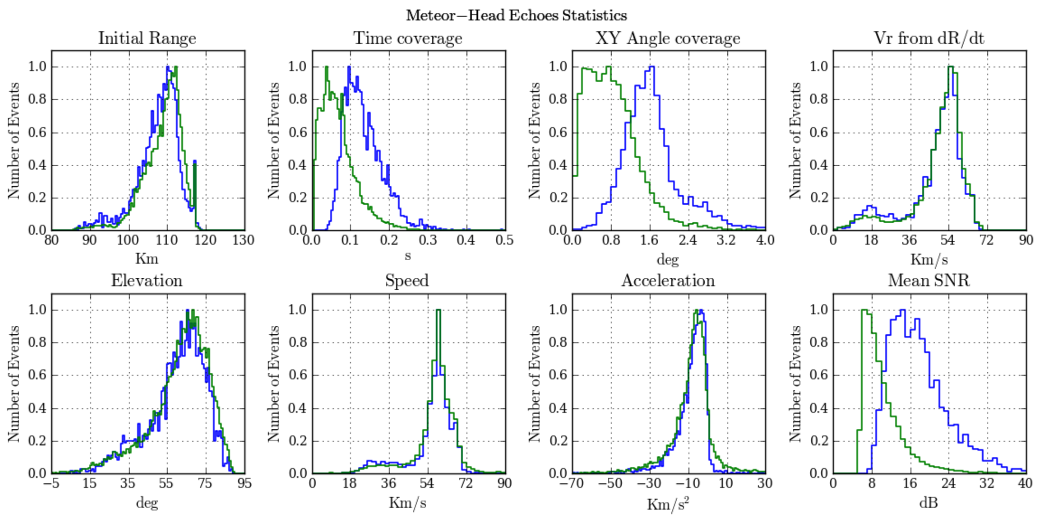


Figure 2: Statistical comparison of the meteor-head parameters of those events that include the presence (blue line) and absence (green line) of signature $S$.

green curves, 2) time and angle coverage are wider for meteors with signature $S$ than those without it, and 3) SNR values are high for meter-head echo reflections containing signature $S$. Upon examination of these statistics, we infer that at least 15% of the total meteor-head population exhibit signature $S$. Furthermore, these events are observed in more inter-pulse periods and with stronger SNRs than those events that do not include signature $S$. These statistics demonstrate that the occurrence of meteor events with signature $S$ are a subset of the well-known sporadic population.

## 2.1 First order software model

Following our experimental analysis, we constructed a model of the digital receiver system of Jicamarca's radar to better assess the role of signature $S$ observed in SNR plots of meteor returns. The model is a first order approach that assumes meteor-head echoes as hard targets and mimics the main schemes of the digital receiver. It also assumes ideal antenna characteristics of the radar and ideal sampling in the digital receiver system. The model does not consider multiple targets or differential ablation of meteors. The simulation produces amplitude and phase information of a back scatter signal from a meteor-head echo. These values are used to generate the corresponding SNR plot of the echo, as it can be seen in Figure 3. Notice that despite the simplifications, the model can replicate the presence of signature $S$ in SNR plots (blue color),

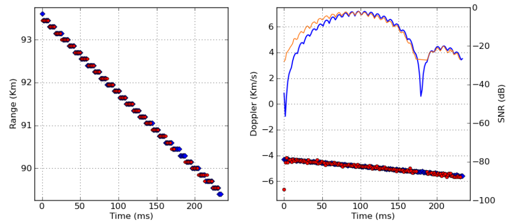


Figure 3: Similar to the Figure 1, but showing the Range vs. time; and Pulse-to-Pulse radial velocity and SNR along the meteor trajectory. The model is represented by the blue color, and the red and orange colors represent the experimental data.

and is in excellent agreement with the experimental data (red and orange colors), as pointed out in Figure 3. The differences between the two data sets might be caused by the assumptions made in constructing the model.

## 3 Results and discussions

Some of the outcomes of the analysis are summarized and discussed below.

- If we envision that signature $S$ as a result of the fragmentation of the meteoroid, the feature of this signature could hardly be explained. For example, considering two particles with relative movement and different size (one much more larger than the other). The SNR plot produced by the interference effect of the two particles would generally follow the SNR plot of the larger particle with small fluctuations due to the smaller particle. Although this situation is a possibility, it is incompatible with the periodicity in the SNR fluctuations because the two particles would be affected by different decelerations. Additionally, the strong correlation between the fluctuations and the change in range could not be explained due to any physical process.

- The statistics results presented in Section 2 were obtained analyzing three days of meteor observations (a total of $\sim$55000 meteor events were detected). A revealing aspect of these statistical results is not the similarities to previous reports[1], but rather on the unique characteristics of these plots showing events with and without signature $S$. In Section 2, we indicated that there was a proportional trend in these six distributions of parameters: initial time, initial range, radial velocity, elevation, speed, and acceleration between these two sets of meteor events. If we assume that the population showing signature $S$ was caused by fragmentation, then one should expect different distributions of these six parameters between those events with and without signature $S$. Additionally, the differences in the distributions of the duration, angle coverage, and SNR clearly show that a higher SNR is related to meteor events that last longer in time. Ideally, if the noise did not distort the receiver signal we would be able to see the signature $S$ in most of the events.

- The model can reproduce signature $S$ in SNR plots. This outcome is evident in Figure 3 that depicts excellent agreement between experimental and modeled data. Notice that we have considered the meteoroid to be a single point target and thus we should expect to observe a smooth SNR plot displaying the beam pattern of the antenna of Jicamarca. Additionally, we have not taken into account extra physical process as the meteoroid enters the Earth's atmosphere. It is therefore reasonable to conclude that signature $S$ is an artifact produced by the radar. This effect seems to be associated with the meteor-head echo features because the presence of signature $S$ has not been reported in previous meteor studies.

## 4 Conclusion

We reported a unique feature present in SNR plots of meteor-head echoes. The characteristics, analysis, and modeling of the signature indicates a systematic problem in meteor data. The situation can be summarized as follows: when performing digital down-sampling and convolving it with the linear filters, the output data is one single point within one inter-pulse period. When repeating the process for the next inter-pulse period, the meteor-head echo has moved rapidly, and consequently a new value of convolution function is sampled.This effect would result in the periodic rippled observed in SNR plots. A possible solution is to sample at a higher rate (e.g. 60MHz), otherwise the effect will always be observed, with varying degrees of magnitude (depending to the configuration). The understanding of these signatures is critical to differentiate them from actual physical processes present in meteor returns. This is the most direct and critical problem related to meteor fragmentation [2][4].

## 5 Acknowledgments

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