Meteor Candidate Identification Algorithm for the GWAC System (Postprint)

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Abstract

GWAC' s ultra-wide field of view can observe hundreds of meteoroids daily, and identifying these meteoroids provides important scientific data for meteor research. This article addresses the challenge faced by GWAC-like ultra-wide-field photometric survey systems in effectively distinguishing meteors from other moving objects during meteor identification, and designs and implements a meteor candidate identification algorithm. This algorithm primarily comprises two components: meteor trajectory identification and light curve morphology analysis. The identification algorithm processed approximately two months of images from Mini-GWAC, extracting 109,000 moving object trajectories, of which over 90% were non-meteor targets. By analyzing the parameters of Gaussian fitting curves for meteor targets during midnight time periods, it was discovered that for most single-peak meteor targets, the peaks of their light curves exhibit a slow variation trend with respect to image pixel positions. Through comprehensive filtering based on the single-frame characteristics of meteors, the single-peak structural features of light curves, and the slow variation characteristics of light curves, we ultimately obtained 4.1% high-precision meteor candidates. After manual inspection and verification, 85%–87.3% of the targets within the 4.1% meteor candidates conform to the morphological and brightness characteristics of meteors.

Full Text

Preamble

An Algorithm for Meteor Candidate Identification in the GWAC System

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Abstract

With its ultra-wide field of view, the Ground-based Wide-Angle Camera Array (GWAC) can observe hundreds of meteors daily. Identifying these meteors provides crucial scientific data for meteor research. This paper addresses the challenge of effectively distinguishing meteors from other moving objects in GWAC-like ultra-wide field photometric survey systems by designing and implementing a meteor candidate identification algorithm. The algorithm comprises two main components: meteor trajectory recognition and light curve morphology analysis. When applied to approximately two months of Mini-GWAC images, the algorithm extracted 109,000 moving object trajectories, over 90% of which were non-meteor objects. By analyzing the parameter of Gaussian fitting curves for meteor targets during midnight hours, we discovered that the peak of the light curve for most single-peak meteor targets varies slowly with pixel position. By combining filters based on the single-frame appearance characteristic, the single-peak structure of light curves, and the slow variation of light curves, we ultimately obtained 4.1% high-precision meteor candidates. Manual verification confirmed that 85%–87.3% of these candidates exhibited morphological and brightness characteristics consistent with meteors.

Keywords: meteor; elongated track recognition; light curve; morphology analysis; GWAC

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1. Introduction

The Ground-based Wide-Angle Camera Array (GWAC, detailed in Section 2) is the ground-based follow-up observation facility for the Sino-French astronomical satellite SVOM [**?**], with the primary scientific objective of detecting electromagnetic counterparts to gamma-ray bursts and gravitational wave events. In addition to detecting transients such as gamma-ray bursts, GWAC' s ultra-wide field of view of approximately 5,000 square degrees can simultaneously detect numerous moving objects, including meteors, near-Earth objects, asteroids, comets, aircraft, space debris, and satellites. These moving objects affect the detection efficiency of gamma-ray bursts and other transients, making their identification and filtering crucial for the GWAC system. Meanwhile, many international organizations conduct research on various moving objects; for example, the International Astronomical Union' s Meteor Data Center is dedicated to collecting meteor data and studying meteor characteristics [**?**], and the GWAC system will contribute a substantial amount of meteor data. This paper focuses on designing an identification algorithm specifically for meteor targets in GWAC.

Numerous meteor research projects exist internationally: NASA' s Cameras for Allsky Meteor Surveillance (CAMS) project [?] comprises three stations with 60 video cameras, aiming to systematically study meteor shower characteristics and origins; Japan' s SonotaCo [?] includes 25 stations with 100 video cameras and has contributed substantial meteor shower data to the International Astronomical Union' s Meteor Data Center; the European viDeo Meteor Observation Network (Edmond) meteor database [?] aggregates data from multiple European meteor observation networks; Croatia' s Croatian Meteor Network (CMN) [?] builds meteor observation systems for science education based on inexpensive surveillance cameras and ordinary desktop computers; the University of Western Ontario' s Southern Ontario Meteor Network (SOMN) [?] focuses on detecting centimeter-scale meteoroids; and Russia' s Mini-MegaTORTORA (MMT) astronomical telescope array [?] shares similar scientific goals with GWAC, namely detecting short-timescale optical transients. MMT includes a shallow field of 900 square degrees and a deep field of 100 square degrees, with a white-light 0.1-second exposure limiting magnitude of approximately 11V, and has observed about 90,000 meteors over 1.5 years [?].

Existing meteor identification software used in these projects, such as MeteorScan [?], MetRec [?], UFO Capture [?], AIM-IT [?], Gural [?], and Vida [?], is primarily designed for meteor survey projects with images characterized by: (1) low limiting magnitude (approximately 5V), resulting in fewer background stars and fewer interference sources for meteor identification; (2) high frame rate (tens to hundreds of frames per second), where meteor trajectories appear across multiple frames, with each frame containing a trajectory segment that enables calculation of the meteor' s angular velocity; and (3) multi-station observations, with meteor survey projects typically comprising at least two and up to several dozen observation stations, allowing calculation of the meteor' s position, altitude, and linear velocity from combined data. The meteor identification process in these survey projects involves: (1) extracting trajectory segments from multiple frames and associating them into a single target; (2) calculating the target' s position from multi-station data; (3) computing the target' s velocity from multiple trajectory segments; and (4) filtering meteor candidates based on altitude and velocity information. Wang [?] applied an improved frame difference method to detect space moving objects with short elongated trajectories in images.

GWAC images exhibit distinct characteristics: (1) high limiting magnitude (16V for GWAC, 12.5V for Mini-GWAC), resulting in numerous background stars and moving objects; (2) slow frame rate (10-second exposure, 5-second readout), where meteors appear in a single frame, typically as a complete elongated trajectory (see Section 2.2), making velocity calculation impossible; and (3) currently only a single observation station, preventing calculation of position and altitude. Due to these fundamental differences in image characteristics and meteor trajectory morphology compared to existing meteor survey projects, current meteor identification software and algorithms cannot be directly applied to GWAC meteor detection.

International wide-field photometric survey projects with similar scientific goals to GWAC, such as MMT [?] and Pi of the Sky [?], offer no applicable experience: (1) MMT' s exposure time is 0.1 seconds, and its meteor identification algorithm is similar to those used in meteor survey projects; (2) Pi of the Sky has not published research results on meteor identification.

[Figure 1: see original paper] shows various types of objects in Mini-GWAC images, with the upper portion displaying original images and the lower portion showing residual images from adjacent frame subtraction. (1) represents meteor candidates; (2-6) represent different categories of moving objects; (7) represents false targets generated by obstructions at the telescope' s field edge; (8) represents meteor wake flames; and (9) represents hot columns. [Figure 2: see original paper] illustrates a typical meteor example that is morphologically wider and brighter in the center than at both ends.

GWAC' s ultra-wide field of view observes not only hundreds of meteors daily but also thousands of other moving objects such as aircraft and satellites. As shown in [Figure 1: see original paper], Mini-GWAC (see Section 2.1) images contain various moving object categories, with all but (1) being interference sources. Compared to other moving objects, meteor trajectories exhibit typical features: (1) short duration, generally appearing in a single frame; and (2) morphologically wider and brighter in the center than at both ends (except for fireballs), as shown in [Figure 2: see original paper].

The challenge for meteor identification in the GWAC system is locating meteors among numerous moving objects without reliable velocity and altitude information for accurate discrimination. This paper designs a meteor identification algorithm tailored to GWAC' s system characteristics and meteor trajectory features: (1) a meteor trajectory recognition algorithm addressing the elongated trajectory and single-frame appearance characteristics; and (2) morphology analysis of meteor candidates based on brightness and shape features to further improve accuracy. Section 2 briefly introduces the GWAC system and analyzes moving object trajectory characteristics, Section 3 details the meteor trajectory recognition and morphology analysis algorithms, Section 4 describes implementation details, Section 5 presents statistical analysis of moving object trajectory morphology, and the final section summarizes the algorithm' s advantages and disadvantages and outlines future work.

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2.1 GWAC Observation System

[Figure 3: see original paper] shows the GWAC system, with Mini-GWAC on the left and GWAC on the right. The GWAC system construction comprises two phases: the first-phase Mini-GWAC experimental system and the second-phase GWAC system. (1) Mini-GWAC consists of 12 wide-field telescopes with 6-cm apertures, each equipped with a 3K×3K CCD camera, providing a combined field of view of approximately 5,000 square degrees and a stellar detection limiting magnitude of approximately 12.5V (10 seconds, 5 , moonless night). It was constructed in October 2014 and began formal observations in October 2015. (2) GWAC consists of 40 wide-field telescopes with effective apertures of 18 cm, each equipped with a 4k×4k high-performance CCD camera, providing a combined field of view of approximately 5,000 square degrees and a stellar detection limiting magnitude of approximately 16.0V (10 seconds, 5 , moonless night). Partial telescope commissioning has been completed, and trial observations are underway.

Mini-GWAC has accumulated substantial observational data, which this paper uses to develop the meteor identification algorithm for subsequent application to GWAC.

2.2 Analysis of Moving Object Trajectory Characteristics in Mini-GWAC

Moving objects in Mini-GWAC images primarily fall into three categories: aircraft, meteors, and satellites (space debris). We briefly analyze the characteristics of these three target types below.

1) **Altitude and Velocity Characteristics**: As shown in , the altitude and velocity ranges of aircraft, meteors, and satellites differ significantly, enabling category discrimination if either parameter can be calculated. However, the current single-station GWAC system cannot compute target altitude or velocity, precluding the use of these characteristics for classification.

2) **Temporal Characteristics**: MMT uses the same lens model as Mini-GWAC and observed approximately 90,000 meteors over 1.5 years, with durations of 0.1 to 2.5 seconds [?]. Based on this estimate, meteors can only appear in a single frame of Mini-GWAC images (10-second exposure, 5-second readout). Aircraft, satellites, and other moving objects persist until exiting the image edge and can therefore appear continuously across multiple frames.

3) **Trajectory Length Characteristics**: [Figure 4: see original paper] presents estimated trajectory lengths for the three typical moving object categories from in a single 10-second exposure Mini-GWAC image. The trajectory lengths of these categories overlap at different velocities and altitudes, preventing direct classification by trajectory length alone. [Figure

4: see original paper] Estimation of meteor, aircraft, and satellite trajectory lengths in a 10-second Mini-GWAC exposure image. Meteor lengths are estimated based on a 0.5-second duration, while aircraft and satellite lengths are estimated based on a 10-second duration. The left panel compares meteor and aircraft trajectory lengths, while the right panel compares meteor and satellite trajectory lengths.

4) **Trajectory Morphology Characteristics**: Subasinghe [**?**] analyzed light curves and shapes of 891 meteors from CAMS dual-station observations: (1) Light curve analysis revealed that 67% of meteors had single-peak light curves, including 14% early-peak, 42% symmetric, and 11% late-peak types; (2) Shape analysis showed that meteors in single-frame images (110 frames/second) appeared comet-like. Meteors appear in single Mini-GWAC frames, and their trajectories contain both light curve and shape information: (1) Light curves: Mini-GWAC images can provide light curves varying with pixel position, which will be detailed later; (2) Shape features: Meteor trajectories in Mini-GWAC images are thicker in the middle and taper toward both ends, with widths of only a few to a dozen pixels, resulting in insufficient sampling and susceptibility to noise. Therefore, this paper does not analyze meteor shape.

3.1 Meteor Trajectory Recognition

The algorithm processes spatiotemporally consecutive FITS images I(k), with the overall workflow shown in [Figure 5: see original paper]. Key steps are detailed below.

1) **Image Preprocessing**: Consecutive frames are separated by 15 seconds, with minimal changes in seeing and other environmental factors between images, enabling direct subtraction of adjacent frames:

$$S(k) = I(k) - I(k-1) \quad (k = 2, \ldots, N)$$

where k is the image sequence number. Subtracting adjacent frames eliminates the need for dark frame and bias operations in astronomical data processing pipelines, as well as background removal. Since adjacent pixels in original images are correlated and subtle local noise fluctuations exist between adjacent images (e.g., thermal noise, atmospheric turbulence), whitening can be applied to subtracted images S(k) to reduce environmental impacts on critical information. With covariance matrix R(k), whitening is expressed as:

$$W(k) = R(k)^{-1/2} S(k)$$

The subtracted image S(k) primarily contains three components: background (pixel values near zero), residual signals (local fluctuations), and real signals (stars brightening, moving objects, etc.). Image binarization involves: (1) applying the 3 principle to W(k) to remove background information and computing mean E and standard deviation D; (2) initializing threshold T = E + 2D and binarizing S(k) to obtain binary image B(k):

$$B_k = \begin{cases} 255, & W_k \geq T \\ 0, & W_k < T \end{cases}$$

(3) if the Hough transform operation in Equation (5) obtains no line segment set and T > 100, dynamically adjusting threshold T:

$$T = E + 2D - N \times 5 \quad (N \in \mathbb{Z}^+)$$

The loop decrements T by 5 each iteration before performing binarization and line extraction. The loop terminates if T < 100 or if Equation (5) finds a line segment set.

2) **Moving Object Trajectory Identification**: This paper employs the progressive probabilistic Hough transform (PPHT) [**?**] for line detection in binary images. Compared to the standard Hough transform, PPHT offers faster computation and directly yields endpoint coordinates. After PPHT, candidate line segments are obtained:

$$L(k) = \text{PPHT}(B(k))$$

Meteor trajectories in Mini-GWAC images have widths of only a few to a dozen pixels. Consequently, a single meteor trajectory may be detected as multiple line segments after Hough transform. To remove redundant segments, the algorithm fuses candidate line segment sets L(k) by merging adjacent multiple segments into one. Similarity is determined using three parameters: segment center distance, segment slope, and distance from image center to segment. Segments with all three parameters below specified thresholds are merged into a single segment L0, representing a moving object candidate O0. After fusing segment set L(k), the moving object candidate set O(k) is obtained.

3) **Multi-Frame Filtering**: Mini-GWAC images contain not only meteors but also other moving objects (e.g., aircraft, satellites). The key distinction is that meteors appear only in single frames (meteor duration: 0.1–2.5 seconds; Mini-GWAC single-frame exposure: 10 seconds; readout time: 5 seconds), while other moving objects may appear across multiple frames. Therefore, associating moving object candidate sets O(k) across consecutive frames can filter some non-meteor targets.

3.2 Meteor Light Curve Morphology Analysis

Moving object light curves can be morphologically classified into three categories: no-peak, single-peak, and multi-peak objects, as shown in [Figure 6: see original paper]. Subasinghe [**?**] found that 67% of meteors in their sample were single-peak targets, and their morphology analysis focused primarily on these single-peak objects. Therefore, this paper attempts to analyze single-peak object morphology to further filter non-meteor targets. Since meteors in Mini-GWAC images appear primarily in single frames, temporal light curves cannot be obtained. However, light curves varying with pixel position along the elongated trajectory can be derived, hereafter referred to simply as light curves. Key steps for light curve extraction and single-peak object morphology analysis are described below.

[Figure 6: see original paper] Three types of moving objects: left, no-peak object; center, single-peak object; right, multi-peak object.

1) **Light Curve Extraction**: With 0 representing the angle between segment L0 and the original image’ s X-axis, S(k) is rotated clockwise by 0 to align the target’ s major axis horizontally. A rectangular region is cropped to obtain the window image Sub0 shown in [Figure 6: see original paper]. Summing flux intensities along the Y-axis direction for each X-axis position yields the brightness variation curve with x:

$$\mathrm{Flux}_x = \sum_y \mathrm{Sub}_0(x, y)$$

2) **Peak Calculation and Multi-Peak Filtering**: The peak calculation process follows SExtractor’ s [**?**] method for deblending adjacent stellar objects. For light curve Flux_x, a horizontal line y = Y0 is drawn, with Y0 decrementing from the maximum value of Flux0 by Stepy until reaching the minimum. After each decrement, intersections between the line and light curve are counted, with the number of intersections representing the peak count peakNum. If peakNum = 0, the target is a no-peak object; if peakNum = 1, it is a single-peak object; if peakNum > 1, it is a multi-peak object.

3) **Light Curve Morphology Analysis**: The paper employs Gaussian function fitting to quantify light curve shape. Multiple Gaussian functions can more accurately describe the light curve, with up to two Gaussian functions used for fitting. The light curve fitting function is:

$$\mathrm{Flux}_k = \sum_{i=1}^{N} A_i \times e^{-\frac{(x-x_{0i})^2}{2\alpha_i^2}}, \quad N \in [1, 2]$$

where fitted Gaussian parameters (A_i, x_{0i}, and _i representing the height, center, and peak sharpness of the ith component, respectively) serve as quantitative descriptors of target light curve morphology. Section 5 provides detailed analysis and discussion of target light curve morphology.

4. Program Implementation

The algorithm is implemented using Python and OpenCV. Tested on an i7-4770k CPU, processing time per image does not exceed 1 second, meeting GWAC’ s real-time detection requirements. Key implementation details are as follows:

1) **Abnormal Image Filtering**: Mini-GWAC' s single-image field covers a large sky area and is susceptible to environmental factors. The paper filters images using two parameters: variance of residuals after adjacent image subtraction and percentage of valid pixels.

2) **Hough Transform Parameter Selection**: After binarization, moving object trajectories may form multiple line segments. Based on analysis of meteor characteristics in Mini-GWAC images, PPHT parameters are selected as: = 1 pixel, = 1 degree, minimum sub-segment length = 10 pixels, maximum gap between sub-segments = 5 pixels, and minimum trajectory length = 50 pixels.

3) **Line Segment Fusion Parameter Selection**: Multiple line segments in an image are merged into one if their center distance is less than 50 pixels, slope difference is less than 5 degrees, and distance difference from the image center is less than 150 pixels.

4) **Adjacent Frame Segment Stack Construction**: Line segment sets L(k) from consecutive frames are cached in a stack to filter multi-frame moving objects. For adjacent segment sets, all segments in one set are compared with those in the other. If the absolute slope difference between two segments is less than 5 degrees, they are considered segments of the same target, indicating a multi-frame moving object.

5) **Peak Number peakNum Calculation**: The flux curve is first median-filtered with kernelSize set to 10% of target length. The peak calculation uses Stepy = Flux_max/10. To filter noise-induced spikes, the difference between adjacent peak maxima must exceed Stepy.

6) **Light Curve Normalization**: Both length and height (brightness) of light curves are normalized to [0, 1]. For all light curves, maximum length L_max and maximum height H_max are recorded. All light curves are scaled to length L_max, then lengths are divided by L_max and heights by H_max to complete normalization.

7) **Fitting Parameter Fusion**: For single-peak object fitting, some targets O1 can be effectively fitted with one Gaussian function, while others O2 require two. For O1, the algorithm directly uses the three fitted parameters (A, x0, and) to describe morphology. For O2, parameters from the two Gaussian functions are fused for more accurate meteor curve description: the maximum of the two A values, the mean of the two x0 values, and the minimum of the two values.

5.1 Data Statistics

The paper analyzed and processed 1.31 million Mini-GWAC images (approximately two months of data). Statistics for various target categories are presented in .

1) **Sample Selection**: Moving objects with single-pixel (mean) signal-to-noise ratio 5 were selected, totaling approximately 109,000 objects.
2) **Statistics by Multi-Frame Appearance**: The sample includes 12,000 single-frame objects and 97,000 multi-frame objects.
3) **Statistics by Light Curve Peak Count**: The sample includes approximately 25,000 single-peak objects, 13,000 multi-peak objects, and 71,000 no-peak objects.
4) **Meteor Candidates**: Based on the single-frame appearance characteristic of meteors in Mini-GWAC, meteor candidates account for approximately 10.7% of all moving objects. Further filtering by the single-peak light curve characteristic reduces meteor candidates to 5.8%.

Statistics of different moving object categories in Mini-GWAC

Category	Count	Percentage
Total moving objects	109,000	100%
Single-frame objects	12,000	11.0%
Multi-frame objects	97,000	89.0%
Single-peak objects	25,000	22.9%
Multi-peak objects	13,000	11.9%
No-peak objects	71,000	65.1%
Single-frame single-peak objects	6,275	5.8%
Single-frame single-peak with > 0.2	5,583	5.1%
Single-frame single-peak with > 0.2 and $R^2 > 0.7$	4,453	4.1%

To quantify light curve fitting accuracy, the paper employs R-Square (R^2) evaluation. [Figure 7: see original paper] shows the R^2 histogram for Gaussian fitting results of 6,275 single-frame single-peak objects. Among these, 41.2% have $R^2 > 0.9$, and 81.8% have $R^2 > 0.7$. Due to noise interference during data processing, a lower R^2 threshold of 0.7 is selected for filtering fitting results.

5.2 Light Curve Morphology Analysis

[Figure 7: see original paper] Histogram of R^2 for Gaussian fitting of 6,275 single-frame single-peak objects.

The Gaussian fitting parameter represents the peak width of a moving object' s light curve: smaller values indicate narrower peaks, while larger values indicate wider peaks. This paper conducts statistical analysis of light curves for single-frame single-peak objects based on . To identify parameters that can distinguish different moving objects by light curve morphology, three sample sets are selected for histogram analysis of peak width :

1) **Sample Set 1 -All Single-Frame Single-Peak Objects**: Primarily composed of meteors with a small fraction of long-duration moving objects such as space debris, satellites, and aircraft that failed multi-frame matching. The distribution is shown in [Figure 8: see original paper].

2) **Sample Set 2 -Evening/Dawn Single-Frame Single-Peak Objects**: Targets from Set 1 appearing before 9 PM or after 4 AM, with similar object categories. The distribution is shown in [Figure 9: see original paper].

3) **Sample Set 3 -Midnight Single-Frame Single-Peak Objects**: Targets from Set 1 appearing between 10 PM and 2 AM. During this period, the sky is in Earth' s shadow, making it difficult to observe sun-reflecting objects (space debris, satellites) except self-luminous objects (meteors, aircraft). Self-luminous aircraft are typically multi-frame due to speed limitations, making single-frame appearance unlikely. Therefore, this set consists mainly of meteors, with distribution shown in [Figure 10: see original paper].

[Figure 8: see original paper] Histogram of parameter for 6,275 single-frame single-peak objects.
[Figure 9: see original paper] Histogram of parameter for 2,962 single-frame single-peak objects appearing before 9 PM or after 4 AM.
[Figure 10: see original paper] Histogram of parameter for 1,306 single-frame single-peak objects appearing between 10 PM and 2 AM.

Analysis of the three sample sets' histogram distributions reveals:

1) **Analysis of [Figure 8: see original paper]**: Sample Set 1's distribution curve has two peaks, representing two target categories: brightness rapid-change objects (< 0.2, 10% of the sample) where brightness varies quickly with pixel position, and brightness slow-change objects (> 0.2, 90% of the sample) where brightness varies slowly.

2) **Analysis of [Figure 9: see original paper]**: Sample Set 2's distribution curve is generally consistent with Set 1 but shows a higher proportion of rapid-change objects.

3) **Analysis of [Figure 10: see original paper]**: Compared to Sets 1 and 2, Set 3' s distribution curve has lower proportions at both ends, with only a small peak in the rapid-change region, indicating very few rapid-change objects. Since Set 3 consists mainly of meteors, rapid-change individuals are rare among meteors.

Comprehensive analysis of [Figure 8: see original paper], [Figure 9: see original paper], and [Figure 10: see original paper] shows that most single-peak meteors are brightness slow-change objects. Filtering Sample Set 1 by this criterion yields 5,583 meteor candidates (5.1% of all moving objects). Applying the additional $R^2 > 0.7$ filter produces 4,453 targets (4.1%), as shown in . Manual inspection of these 4,453 targets confirms that 3,785 (85%) exhibit meteor morphology and brightness characteristics; 104 (2.3%) are edge targets with only partial trajectories visible, which also show meteor characteristics; and the remaining 564 (12.7%) are low signal-to-noise ratio targets, weather-induced false objects, or celestial objects with meteor-like morphology. The algorithm' s overall identification accuracy is therefore 85%-87.3%.

6. Summary and Outlook

GWAC' s ultra-wide field of view detects numerous meteors daily, and effective identification provides valuable data for global meteor research. The greatest challenge in meteor identification within GWAC-like ultra-wide field photometric survey systems is the lack of sufficient information to effectively distinguish meteors from other moving objects. To identify meteors as accurately as possible, this paper designed and implemented a meteor trajectory recognition algorithm for such systems, complemented by light curve morphology analysis of meteor candidates. Results are summarized as follows:

1) The recognition algorithm processed approximately two months of Mini-GWAC historical images, selecting about 109,000 moving objects with single-pixel signal-to-noise ratio > 5 .
2) Using the single-frame appearance characteristic of meteors in Mini-GWAC images, 89.3% of moving objects were filtered, leaving 10.7% candidate targets.
3) Most meteors exhibit single-peak light curve structures (see Section 3.2), which further filters candidates to 5.8%.
4) Analysis of parameter histograms from three sample sets revealed that most meteors are brightness slow-change objects. Using this characteristic combined with light curve fitting R^2 further 筛选 ed candidates, yielding 4.1% meteor candidates.
5) Manual inspection of these 4.1% candidates confirmed that 85%-87.3% exhibited morphological and brightness characteristics consistent with meteors.

This paper employed two characteristics—single-peak light curve structure and brightness slow-change—to filter meteors. These features capture most meteors but miss some (e.g., meteors with multi-peak light curves). However, filtering by these features yields the final 4.1% meteor candidates with higher accuracy.

Analysis of actual single-peak target images reveals that some moving objects (satellites, aircraft, etc.) have shapes and light curve morphologies very similar to meteors. If these targets appear at image edges, they likely appear in only a single frame, making them difficult to filter with the current algorithm. Future improvements will focus on three aspects: (1) Adding morphology analysis methods for moving objects, such as shape analysis to identify multiple quantifiable morphological descriptors, to further improve meteor identification quantity and accuracy; (2) GWAC is planning a second station; dual-station observations will enable calculation of moving object altitude, allowing filtration of aircraft and satellites; (3) GWAC is developing fast-frame-rate CMOS cameras with 0.1-second exposure times, which will greatly increase temporal resolution and enable velocity calculation. Incorporating altitude and velocity information will enable more accurate discrimination between meteors and other moving objects.

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Note: Figure translations are in progress. See original paper for figures.