DEFINITION OF POLES OF THE LARGE CIRCLES OF METEORIC TRAJECTORIES

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ABSTRACT. We present the method and software Meteor Pole for calculation of the spherical equatorial coordinates of the meteor points within the images obtained by TV observations. This software is a part of computer package Odessa Meteor which was elaborated for processing of the TV meteor patrol observational material. The results of such processing are the equatorial coordinates of the large circles poles of meteor trajectories on celestial sphere. These data are necessary for determination of the equatorial coordinates of radiants.

We give the description of the method which enables one to estimate accuracy of the equatorial coordinates deternination taking into account specific chatcter of the operation of TV camera WATEC LCL-902 and its modifications.

An analysis of the distribution of the large circles poles based on observations that were carried out in Astronomical Observatory of Odessa National University is given.

We made a conclusion that there is no selected global direction in meteor movement on celestial sphere.

Key words: Meteors: radiant, meteor trajectory, telescopic meteors; meteor observations: TV observations, CCD observations, WATEC, LCL-902K, LCL-902H, meteor patrol

1. Introduction

In the beginning of the XXI century the main principle of the astronomical images recording was cardinally changed. Instead of photoplates and electronic tubes the CCD cameras are widely used now. In particular, the meteor astronomy uses CCD detectors which are working in TV mode.

TV meteor patrol was created in Astronomical observatory of Odessa National University in 2003, and it is in operation until now. There is also expedition of the meteor patrol that was tested several times at the Zmeijny island in Black Sea. As a detector we used TV camera WATEC LCL-902H2, LCL-902H and LCL-902K. Meteor events are recorded with a time resolution of 0.02 second. Such an observing mode was chosen after many years of exploration, while the main aim of this investigation is the possibility of observations in the visual spectral range with a high time and space resolution of the meteor events that are registered only in the radio and visual telescopic modes ($> +6^m$).

Taking above mentioned into account we decided to create new software which is necessary for processing of the observational material. After digitalization of the image we get coordinates of each pixel (X,Y) and its brightness (I). Their exact values give us possibility of using strict mathematical approach, and thus to increase the quality of observational material processing.

The main goal is to obtain accurate photometric and positional characteristics of meteors. In particular, the positional characteristics are the equatorial coordinates of the large circle pole of the meteor trajectory on celestial sphere. If we deal with basis meteor, then we can obtain exact element of its orbit. As a result all these data allow one to identify to which meteor stream a certain meteor belongs, as well as to investigate the fine structure of the meteor stream.

Table 1: Comparative statistics of photographic and TV meteors on major observational projects

Observational project	Period of observations	Number of meteors
Harvard Meteor Project (U.S.)	1936–1959	1245
Prairie Network (U.S.)	1963–1975	2700
MORP (Meteorite Observation and Recovery Project, Canada)	1971–1984	218
Dushanbe, Odessa, Kiev (USSR)	1940–1983	1111
Odessa (Ukraine)	2003–2010	> 3500

In Table 1 we show selective statistics of the photographic and TV meteors registered in the second part of XX century within the different projects. From our experience we can conclude that the number of meteors

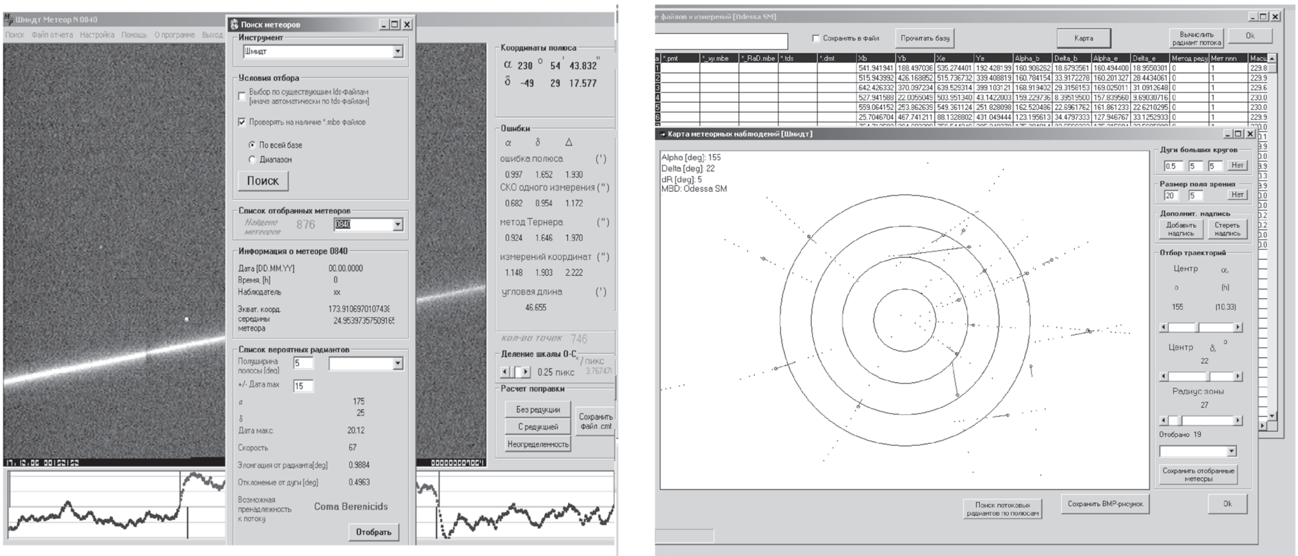


Figure 1: ***Meteor Pole*** interface.

detected by the modern devices increased tenfoldly.

For the sake of comparison, we note that Odessa meteor data-base was supplemented during 2003-2010 by about 3500 registered events (meteors of $+12^m$ and brighter). The number of individual frames for each meteor image often exceeded ten. This statistics testifies about the huge amount of the measuring and calculating work.

The distinguishing feature of the observed material which is collected with the help of CCDs, CMOS-sensor is the numerical representation of the data forming an image, while the further processing of an image is quite similar both for CCD and photographic images. There, of course, exist some factors which are connected to the detector characteristics. We think that the correct account for such factors is very important for precise positional reduction of the observational material, and this point will gain a specific attention in this paper.

2. Software Meteor Pole

In order to understand at which stage and for what one needs to calculate equatorial coordinates of the meteor trajectory large circle poles we give below the short clescription of the scheme of a preliminary processing of the observational material.

Preliminary positional measurements and calculations of the meteor images are carried out as follows:

1. Observational material in the form of video-films recorded in an interlaced mode with 50 video fields (or 25 complete video frames) per sec is cut by AVICutter software into separated images that contain the meteor trace.

2. Using software based on the methods described in (Gorbanev et al., 2006; Gorbanev et al., 2008) the position of the reference stars are found. Equatorial coordinates of these stars are listed in the stellar catalogue (software PSF). The same method is used to find position of the meteor trajectory points in the rectangular system (software PicScan).

3. All measurements are controlled in order to find possible errors. For this the special method and software Meteor Control Data, Meteor Manager were created.

As a result of a preliminary processing, we get the files with rectangular coordinates of each point of the meteor trajectory, rectangular and equatorial coordinates of the reference stars, and calculated coefficients of the Turner method, as well as measurement errors. In addition, the file containing the date and time of the meteor event is created. For the facilities, the software subroutine creates at each stage the corresponding file with calculation results. The Meteor Pole software (Fig. 1) helps to gather all the files containing results of measurements and calculations, and to make the final positional calculations and their analysis.

The practical use of the Meteor Pole software is the following:

1. In "Search" select the observational database that corresponds to a given telescope and detector, and observational place.

2. Push the button "Search" to find the database of the meteor events for which a preliminary processing of the image star field and meteor image was performed.

3. After selection of a given meteor event (certain number), one gets the table with complete positional characteristics: coordinates of the large circle the pole of the meteor trajectory, errors of calculations of this pole position and trajectory. Software also informs about errors of calculations based on the Turner method, angular length of the meteor trajectory that

was adopted for calculation of the pole coordinates and angular scale of the image.

4. Special attention requires an accuracy of calculations of the large circle pole coordinates which is connected to so-called effect of the TV Interlace. Software Meteor Pole affords a possibility to take into account this effect (this is described in details below).

5. Software uses list of radiants of the most known meteor streams, as well as the list of supposed and theoretical radiants. Thus, knowing coordinates of the large circle of a meteor trajectory, coordinates of the observed region and radiant coordinates one can obtain elongation of the meteor from the catalogued radiant value. Then, combining the time of observation of a meteor event with the time of meteor stream operation (catalogue data), one can select the minimum calculated elongation value. Therefore, one can plilimnary estimate to which catalogued meteor stream a certain meteor event belongs. In case the meteor event was registered with a basis method, one can get an individual radiant by calculating equatorial coordinates of the poles of the large circles of meteor trajectories for each observational station.

This is a general description of the positional measurements and calculations based on Meteor Pole software. Below we consider the calculation method enabling one to find equatorial coordinates of the pole of the meteor trajectory large circle.

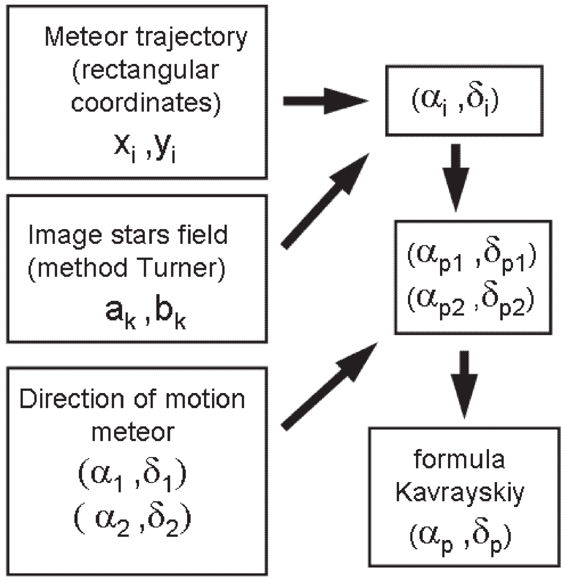


Figure 2: Block-scheme of the meteor trajectory large circle pole coordinates determination.

3. Calculation of the equatorial coordinates of the meteor trajectory large circle pole

For registered meteor trajectory the characteristics are the equatorial coordinates of the large circle pole. These equatorial coordinates can be calculated using Kavrayskiy (Kavrayskiy, 1926) formula:

$$\begin{aligned} \cot\alpha_p &= \frac{\cot\delta_1\sin\alpha_1 - \cot\delta_2\sin\alpha_2}{\cot\delta_1\cos\alpha_1 - \cot\delta_2\cos\alpha_2} \\ \tan\delta_p &= -\cot\delta_1\cos(\alpha_p - \alpha_1) = \\ &= -\cot\delta_2\cos(\alpha_p-\alpha_2) \end{aligned} \quad (1)$$

Here α_p and δ_p – the equatorial coordinates of the pole of the large circle, α_k and δ_k – equatorial coordinates of the two points on the meteor trajectory ($k = 1, 2$).

After the use of the PicScan software (the meteor image processing) we get more than two points of the meteor trajectory. It should be noted that coordinates of the points are delivered in rectangular system. They should be transformed into spherical equatorial coordinates (Turner method, using the measurement results based on PSF software).

Since the number of points is larger than 2 ($n > 2$), the pole coordinates calculation can be performed using the least square method. According to the second equation of the system (1):

$$\begin{aligned} \tan\delta_p &= -\cot\delta_1\cos(\alpha_p-\alpha_1) \\ \tan\delta_p &= -\cot\delta_2\cos(\alpha_p-\alpha_2) \\ &\ldots\ldots\ldots\ldots\ldots\ldots \\ \tan\delta_p &= -\cot\delta_n\cos(\alpha_p-\alpha_n) \end{aligned} \quad (2)$$

Performing a simple transformation and introducing designations:

$$\begin{aligned} \cot\delta_i\cos\alpha_i &= A_i \\ \cot\delta_i\cos\alpha_i &= A_i \\ (i = 1, 2, 3, &\ldots n) \end{aligned} \quad (3)$$

we get

$$\begin{aligned} \sec\alpha_1\tan\delta_1 + B_1\tan\alpha_1 &= A_1 \\ \sec\alpha_2\tan\delta_2 + B_2\tan\alpha_2 &= A_2 \\ &\ldots\ldots\ldots\ldots\ldots\ldots \\ \sec\alpha_n\tan\delta_n + B_n\tan\alpha_n &= A_n \end{aligned} \quad (4)$$

This system can be solved by the least square method. In the Gauss we have

$$\begin{aligned} \sec\alpha_1 n\tan\delta_1 + [B]\tan\alpha_1 &= [A] \\ \sec\alpha_1[B]\tan\delta_1 + [B^2]\tan\alpha_1 &= [BA] \end{aligned} \quad (5)$$

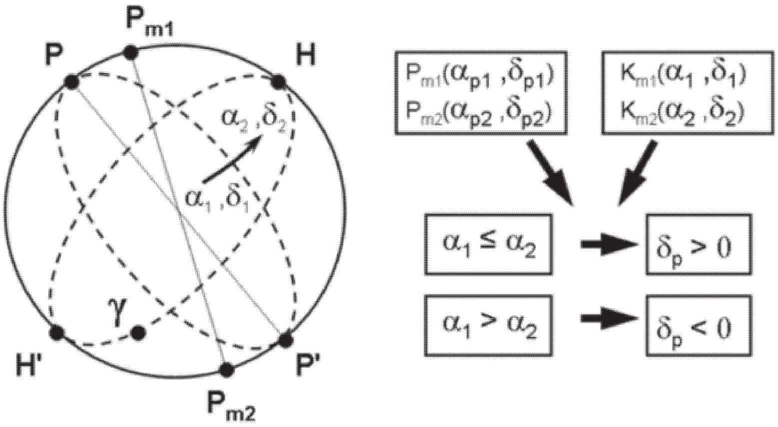


Figure 3: Scheme explaining the selection of one from two solutions for the pole coordinates determination.

where

$$\begin{aligned} [A] &= \sum A_i \\ [B^2] &= \sum {B_i}^2 \\ [B] &= \sum B_i \\ [BA] &= \sum B_i A_i \end{aligned} \quad (6)$$

Using the substitution in (5) we get

$$\begin{aligned} \tan \alpha_p &= \frac{[A][B] - [BA]n}{[B][B] - [B^2]n} \\ \sec \alpha_p \tan \delta_p &= \frac{[A][B^2] - [BA][B]}{n[B^2] - [B][B]} \end{aligned} \quad (7)$$

General block-scheme of the Meteor Pole software is given in Fig. 2.

Solution of (7) gives two sets of the pole coordinates, uniquely defining the arc of a great circle of the meteor trajectory. In order to select one of them, one can use the law which is based on the direction of meteor motion along the arc of the large circle. Fig. 3 represents the scheme which gives an explanation of this procedure. Here P_{m1} and P_{m2} are two pairs of the pole coordinates, K_{m1} and K_{m2} – coordinates of the meteor image ending points. They defines the starting and ending points of the meteor trace on celestial sphere (software Card File). Depending on the right ascension K_{m1} and K_{m2} could be positive or negative.

4. Accuracy of the coordinates determination of the meteor trajectory large circle poles

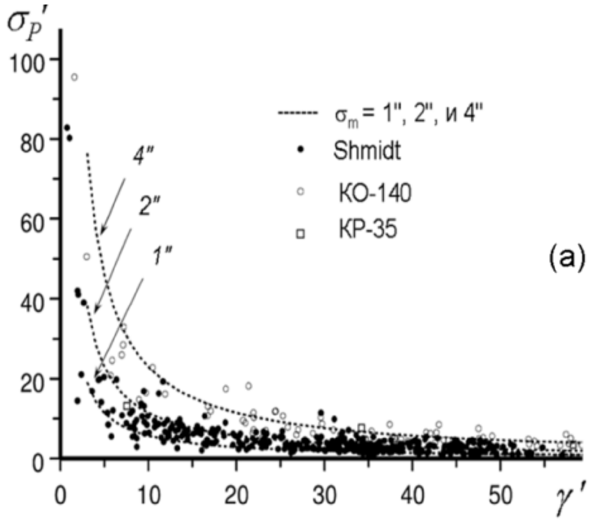
It is easy to show (Katasev, 1957; Gorbanev et. al., 2008), that accuracy of determination of the coordinates of the meteor trajectory large circle poles depends on accuracy of the trajectory determination and angular length of the meteor. Theoretically such a dependence can be expressed as

$$\sigma_p = \frac{1}{\sqrt{2}} \frac{\sigma_m}{\sin \gamma} \quad (8)$$

were γ – angular length of the meteor image, $\sigma_m = \sqrt{\sigma_T^2 + \sigma_t^2}$ – error of the coordinate determination.

In our case this error is conditioned, first of all, by the accuracy of the Turner method used for the measurements of the stellar images σ_T, secondly, by the accuracy of the measurements of the meteor trajectory image σ_t. Fig. 4a presents dependences of the error value that characterizes determination of the coordinates of the meteor trajectory large circle pole on the angular length of the observed part of the meteor trajectory (both are given in arcmin). Each dependency is calculated for a certain σ_m value (it is showed in arcsec near the corresponding curve). For the short trajectories (shorter than $10'$ the determination accuracy is larger than $20'$, while the trajectory is measured with accuracy of about 4 arsec). Those meteor images that were registered near the TV frame boundaries, and thus they have low angular sizes, are of little avail for the pole coordinates determination.

Each component of error (σ_T and σ_t) can vary within some range forming therefore the error of the of measurement of each meteor image. Fig. 4a shows not only theoretical curves with fixed σ_m values, but also gives the data calculated for the real meteor images based on the random sample of 338 meteors observed with the Schmidt telescope, and 177 meteors observed with astrocamera equipped with objective lens KO-140. With the aim of comparison we also show the small sample of meteors having different angular lengths registered with astrocamera equipped with objective lens KP-35. In this case an accuracy of determination of the meteor trajectory large circle pole is the same as for astrocamera with KO-140 objective lens. It is quite expectable



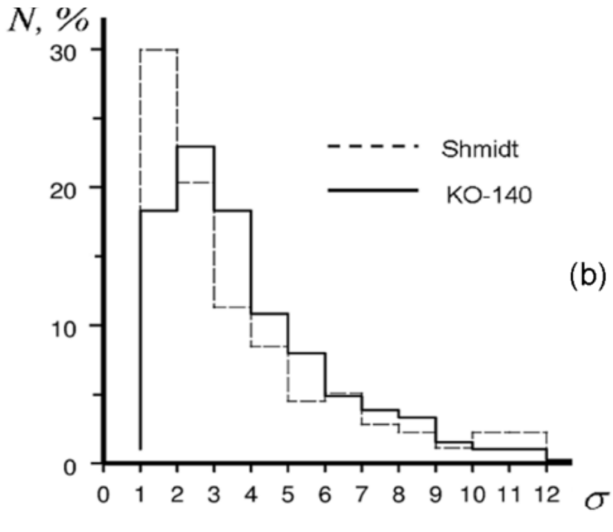


Figure 4: (a) Dependence of the accuracy of the pole coordinates determination on the length of the meteor trajectory for Schmidt telescope and astrocameras with KO-140 and KP-35 objective lenses. (b) Distribution of the accuracy of the pole coordinates determination for our meteor database.

since the optical parameters of both devices do not differ.

Fig. 4b presents the histograms of the error distribution of the large circle pole position determination based on observations with Schmidt telescope and astrocamera equipped with objective lens KO-140. For the firmly measured images the error value of the pole coordinates determination is of about 1′ and 2′ respectively, which is limiting value for our meteor patrol.

5. An influence of the Interlace TV effect on the determined coordinates of the meteor trajectory large circle pole.

After the determination of the equatorial coordinates of the meteor trajectory points it is necessary to take into account all the factors connected with detectors work.

The frame scanning of the videomaterials could be progressive scanning (interlinear) or interlaced. In case of progressive scanning, all horizontal lines of image are represented successively. In case of interlace, either all odd, or all even lines are alternately uploaded (together they form the field of frames or semi-frame). At present we carry out the meteor observations in the interlaced mode. This enables one to improve the time resolution of the meteor event registration almost twice. Thus, if the complete frame is combined during 0.04 sec, then each semi-frame (either consisting only of the odd frames, or even frames) will be combined during 0.02 sec. The losses of the permeability for telescope will be insufficient when the interlaced mode is used. The obvious shortcoming of the interlaced mode is some deterioration of resolving power (this is because of the lack in each frame the lines of the opposite parity, and as a consequence the lack of the information about the meteor that might have been obtained from those lines).

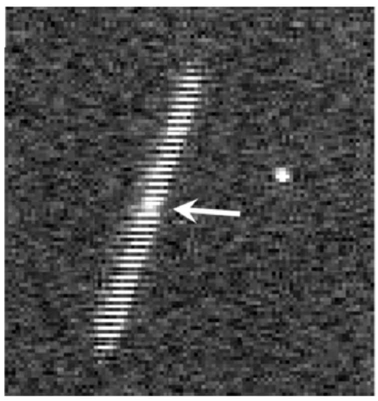


Figure 5: The Interlace effect. The frame composed during 0.04 sec is showed. Effect of the bright dot (discussed in the text) is indicated by the arrow.

The splitting of the vertical boundaries of the horizontally moving objects causes an effect which is called "Interlace" (Fig. 5). When the videofilm with meteor image (or image of the Earth's artificial satellite) is visually examined, then one can note some oscillations of

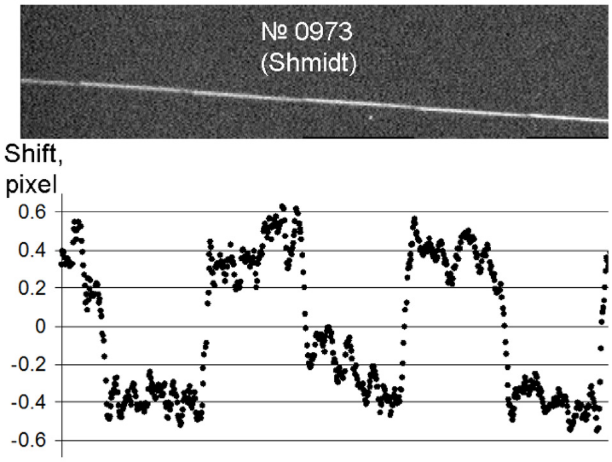


Figure 6: An influence of the Interlace effect on accuracy of the meteor trajectory measurement.

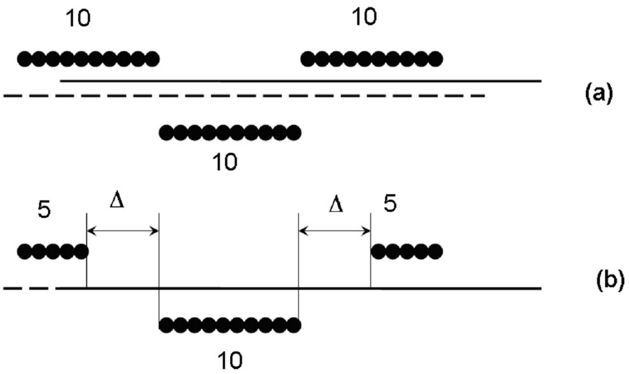


Figure 7: Scheme explaining the correct means of taking into account the equal number of the dots of the meteor image strokes.

the recorded picture of the object relatively the mean line of its motion. Small shifts are seen in case of meteor motion along the frame lines, while for the motion which is transversal to the frame lines such an effect is absent. In positional measurements this effect is developed as periodic shifts of each meteor stroke of the semi-frame relatively the arc of the large circle which is drawn on the combined image based on all the frames of a meteor image (Fig. 6). Since the registered object has its own characteristic size depending on its brightnes, the bright spot is produced in the frame in that region where the odd and even images overlap (Fig. 6, indicated by arrow). The brighter the object, the larger the size of this spot. For the faint objects this effect is weak or absent. This effect can be used for instance for the determination of the length of meteor strokes within each of the semi-frames.

Fig. 6 shows combined image of a meteor composed of the odd and even semi-frames of the videofilm. Below (the same figure) the shown is a plot demonstrating the positions of the measured strokes of a meteor at the semi-frames in pixel (1 pixel in this case corresponds to about 3.85″) relatively to the motion trajectory. The shift of each stroke is about 0.3 - 0.4 pixel (1.2″ - 1.5″).

Thus, when determining the coordinates of the large circle pole it is necessary to take into account correction caused by the effect connected with above described specific character of the meteor image formation by the TV camera.

The size of shift depends upon the object size in the frame and its brightness. As a rule, these parameters change during the meteor event existence. Therefore, in a certain case, an analytic estimate of the correction can be complicated. Nevertheless, for each observational device there is a possibility to determine an averaged dependence of the correction value upon an angle of the meteor trajectory relatively the frame lines basing on the whole observational material. In order to find correction value for a given meteor it is necessary to use this dependence found for a given instruments. For Odessa meteor patrol (Schmidt telescope) in some cases correction can achieve 2″ - 3″.

After the determination of the equatorial coordinates of the meteor trajectory large circle pole, the correction value (in angular measure) should be included in the error of the determination of this pole coordinates.

6. The determination of the large circle pole coordinates with an account of the Interlace effect.

As it was stated above, in the interlace regime the meteor image is separated into two sets of strokes of the odd and even semi-frames. Therefore the second important thing in the determination of the large circle pole coordinates is correct account of the symmetrical number of those strokes of the meteor image relatively an axis of its trajectory.

Let us suppose in the simple case that all strokes have the same length. Let also the number of the strokes from one side of the trajectory axis exceed the same number from another side by one, and consequently the number of the dots that can be used for determination of the large circle arc will be larger (Fig. 7a). It is quite understandable that these dots will shift to their side the large circle arc (the smooth line in Fig. 7a). It will be correct in this case to select equal numbers of the dots from both sides of the trajectory axis. It is important to note that selected dots should be situated at the same distance (Δ, Fig. 7b) relatively to the dots of that stroke which is not used for the length determination. Otherwise, the calculated trajectory will be biased.

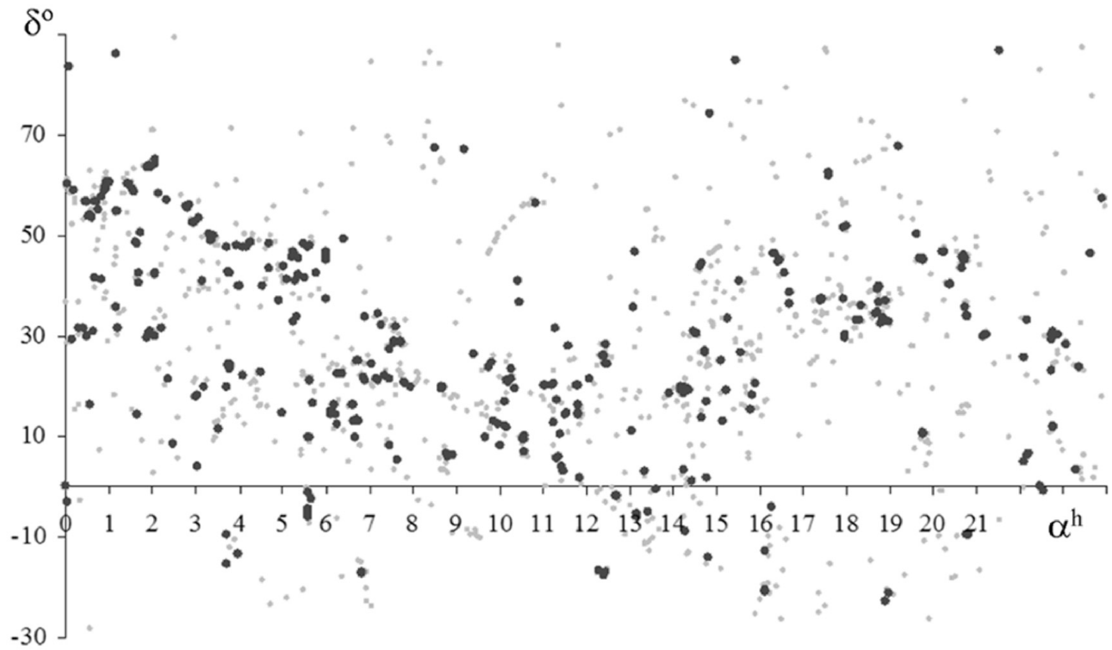


Figure 8: The map of the regions of the meteor patrolling (Schmidt telescope, August 2003 - August 2004)

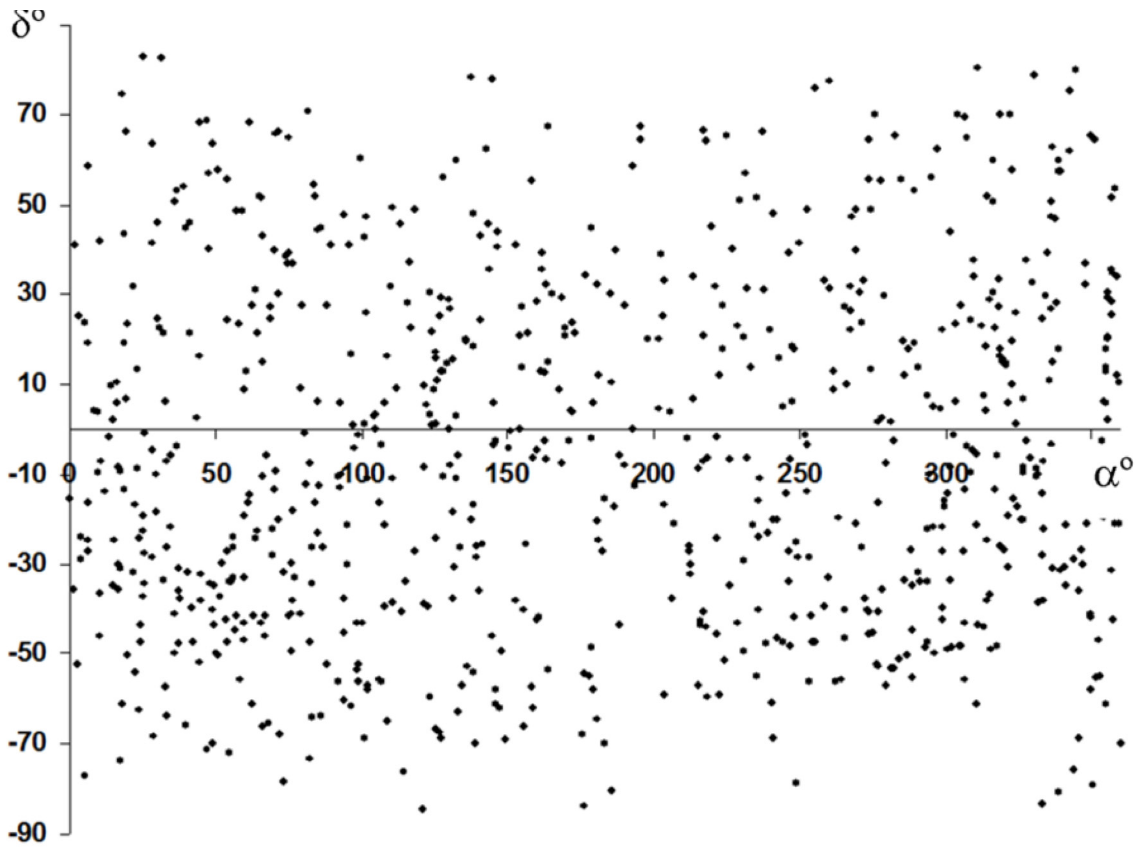


Figure 9: The map showing the distribution of the meteor trajectory large circle poles (Odessa, Schmidt telescope, 2003-2004).

a) In the upper part the total number of the dots which are used for calculation of the large circle arc is 20, while in the lower part this number is 10. Calculated trajectory (smooth line) is shifted towards that side where the number of the dots is larger.

b) The number of the dots on both sides is equal. All selected dots which belong to the upper stroke are at the same distance as the dots of the lower stroke. No trajectory shift is presented.

While determining the arc of the large circle meteor trajectory (software Meteor Pole) the length of the stroke is controlled by user. After that, using the sample of selected dots one can determine equatorial coordinates of the meteor trajectory large circle pole using the approximation method and formulae of the spherical astronomy.

7. Results and analysis.

Software Meteor Pole enables one to integratedly work with astrometric characteristics of meteors.

Fig. 8 shows the map of the region of the meteor observations which are carried out with Schmidt telescope at the Kryzhanovka station. In order to avoid the crowding of the data in Fig. 8, we present here only those observations that were performed during August 2003 - August 2004. Equatorial system is used for presentation. The grey dots represents all observational regions, while black dots show those region where at least one meteor event was registered. As one can see there is a tendency of the meteor activity distribution along a certain line. To some extent it is connected with a concentration of the meteor radiants toward the ecliptic plane (it is a well known fact in meteor astronomy). From the other side, there exist an observational selection, an observer more often carries out observations in those region where the meteor activity is higher.

For the same sample of meteors Fig. 9 displays the distribution of the poles on the celestial sphere. This distribution shows that the large circle poles are distributed uniformly. Since the large circle pole position is determined taking into account the direction of meteor motion, one can make a conclusion that such an uniformity also characterize the meteor motion directions.

Conclusions.

1. Software enabling one to work with meteor images that are registered by means of the TV methods, to calculate equatorial coordinates of the large circle poles of the meteor trajectories, and to estimate an accuracy of these coordinates determination was elaborated in the Department of the Solar system small bodies of Astronomical Observatory of Odessa National University.

2. The precision of the pole coordinates determination for meteor trajectory registered with Scmidt telescope is the same as for astrocamera equipped with KO-140 objective lens (about $1' - 2'$ for the length of the meteor image not less than $10'$).

3. All distortions caused by the TV detector working in the interlace regime are taking into account while calculating coordinates of the meteor trajectory large circle poles.

4. Our analysis of the data shows that there is no preferred direction in the meteor motions on celestial sphere.

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