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Determination of astronomical co-ordinates of geodetic point at Bunger Oasis in Antarctic*)

ABSTRACT: During a Polish Antarctic Expedition to Dobrowolski Station the astronomic co-ordinates of a main geodetic point have been determined. The observations were performed by Kavrajski's method. In result 26 pairs of bright stars were observed. Longitude and latitude were defined with an estimated accuracy about $\pm 1''$.

Key words: Antarctic, geodetical astronomy

1. Introduction

The research programme of the expedition included an establishement of geodetic network for Bunger Oasis. During a short stay at the station the geodetic works were concetrated on the fragments of planned net designed for the photogrammetric study of the dinamic of ice cap along the marginal zone of the Oasis as well as on the area close to station where some photogrammetric and gravimetric surveys have been performed. A connection of the net to the system of astronomical co-ordinates was done by determination of the astronomic co-ordinates of a main geodetic point at the Dobrowolski Station. In the paper there is a short description of the method of determination of the co-ordinates, preparation of ephemeris, observations and calculations.

2. Description of a method of simultaneous determination of astronomical co-ordinates

Among many methods used for determination of the astronomical co-ordinates, the Kavrajski's method was chosen. It is the method of simultaneous determination of both co-ordinates — latitude and longitude based on observa-

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tions of the pairs of bright stars at equal altitudes above the horizon. For a choice of a suitable method for observations in subpolar areas an experiance of Jasnorzewski was also taken into account; the latter found by means of this method the co-ordinates of a point at Hornsund Station, Spitsbergen, over 20 years ago (Jasnorzewski 1964). The method enabled to select the bright stars seen in a theodolite telescope during a long polar day, even at a full sunshine. A theoretic base of the method comes from basic equations of parallactic triangles for western — W and estern — E stars (Kavrajski 1936)

$$\left.\begin{aligned} \cos z_W &= \sin\varphi \sin\delta_W + \cos\varphi \cos\delta_W \cos t_W \\ \cos z_E &= \sin\varphi \sin\delta_E + \cos\varphi \cos\delta_E \cos t_E \end{aligned}\right\} \tag{1}$$

Due to unsatisfactory knowledge of a geographic longitude the hour angles t_W and t_E are to be defined by approximate sidereal times θ and corrections to assumed longitude λ.

$$t = \theta + \Delta\lambda - \alpha$$

With an assumption of $z_W = z_E$ the following equation is received:

$$\sin\varphi \sin\delta_W + \cos\varphi \cos\delta_W \cos(\theta_W + \Delta\lambda_n - \alpha_W) = \\ = \sin\varphi \sin\delta_E + \cos\varphi \cos\delta_E \cos(\theta_E + \Delta\lambda_n - \alpha_E) \tag{2}$$

In the Kavrajski's method the lattitude of the observational place is also unknown precisely and composes of an approximate value $\bar{\varphi}$ and correction $\overline{\Delta\varphi}$. Both corrections $\overline{\Delta\varphi}$ and $\overline{\Delta\lambda}$ are defined together on the ground of adjustment by a least squares method of observations of many pairs of stars.

After expansion of the equations (1) into Taylor's sequence and transformations the following equation is received for every pair:

$$\lambda - \bar{\lambda} + \Delta\lambda_n = \frac{1}{15\cos\varphi}(\varphi - \bar{\varphi}) \operatorname{tg} \frac{a_W + a_E}{2} \tag{3}$$

These equations have different weights and to make them possible to be solved simultaneously by a least squares method they are reduced to the same weight by multiplying them by factors accordingly to every pair:

$$\frac{15}{\sqrt{2}}(\sin a_W - \sin a_E)\cos\varphi$$

The factor is defined by an analysis of mean errors. After this operation the conditional equations change into:

$$A(\varphi - \bar{\varphi}) + B(\lambda - \bar{\lambda}) + L\,\Delta\lambda_n + V_n = 0 \tag{4}$$

In this equation:

$$A = \frac{1}{\sqrt{2}} \operatorname{tg} a\,(\sin a_W - \sin a_E)$$

$$B = \frac{1}{\sqrt{2}}(\sin a_W - \sin a_E)$$

$$L = \frac{15}{\sqrt{2}} \cos \varphi \, (\sin a_W - \sin a_E)$$

For every pair $\Delta\lambda_n$ is calculated from the formula coming from transformation of equations (2):

$$\sin \Delta\lambda_n = \frac{(\cos \delta_W \cos t_W - \cos \delta_E \cos t_E) + \operatorname{tg} \varphi \, (\sin \delta_W - \sin \delta_E)}{\cos \delta_W \sin t_W - \cos \delta_E \sin t_E}$$

Solving a system of conditional equations one obtain the final values $\overline{\Delta\lambda}$ and $\overline{\Delta\varphi}$ as well as mean errors of values $\varepsilon_{\overline{\Delta\varphi}}$ and $\varepsilon_{\overline{\Delta\lambda}}$.

3. Calculation of ephemeris of pairs of stars for Kavrajski's method

Preparation of ephemeris was based on the selection of pairs of bright stars possible to be observed at the same almucantarat with a time difference of about 6 minutes at both sides of the local meridian. While choosing the stars it should be taken into account that common zenithal distances should not be biger than 60°. Also distribution of pairs at the horizon should be uniform what makes a considerable practical difficulty for small number of bright stars. To find the stars in the vision range of an instrument a knowledge of horizontal co-ordinates z and a is necessary as well as a moment in which the star appeared in a local sidereal time. The calculations of these data were prepared before the expedition started, in an analytic--graphic way.

Using a star catalogue (Astronomičeskij Ežegodnik 1979) 24 bright stars with a star magnitude less than $m = 3$ were selected. For each chosen star a diagram was drawn showing the changes of $\cos z$ according to the hour angle t and therefore, to the sidereal time θ

$$\cos z = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos t$$

Putting the curves one on another in many different combinations and reading the moments of the same altitude of stars a list of suitable pairs was proposed. Then, with the formula:

$$\frac{dz}{dt} = \cos \varphi \cos \delta \frac{\sin t}{\sin z}$$

a zenithal distances, azimuths and local sidereal times were calculated for any hour angle found at the diagrams and assuming 6 minutes interval between observations of stars of a single pair. That permitted to lay down the working programme composing of 27 pairs.

4. Observations of Kavrajski's pairs

The main point at Dobrowolski Station is stabilized by metal bolt fixed in a rock, over which the theodolite Wild T2 on tripod has been erected. To find the local meridian an astronomic azimuth was determined from the

observations of an hour angle of the sun with a Roelof's cap. During observations of Kavrajski's pairs the following values were defined: passing moments of the stars across every of five horizontal hairs of a telescope and differences in zenithal distances of western and eastern stars ($\Delta z = z_W - z_E$). To be sure of needed accuracy of time registration a systematic time service was carried through during the whole research period; it was based on comparison of indications of working chronometers (sideral and mean ones) with time signals received at chronograph through a radio receiver at frequencies of 7.5 and 10 MHz. A passing time of the stars across the hairs was noted with a stop watch and a working sidereal clock with an accuracy of about ± 0.2 s. An attempt of chronograph application was negative in result due to freezing of chronograph grease. The theodolite Wild *T*2, borrowed from a Swiss firm — Wild Heerbrugg, was equipped with an automatic index of the vertical circle that enabled to measure easily and quickly the differences of Δz with an accuracy of about $\pm 1''$. According to the mentioned method 26 pairs of stars have been observed from 27th January to 13th February, availing of every period of good weather.

5. Reductions of collected data

A preliminary calculating phase including the calculations of observations with clock corrections of sidereal times was finished already at the Dobrowolski Station. The following phase of calculating: the apparent co-ordinates of stars, the corrections ΔT_W and ΔT_E according to the formulae:

$$\Delta T_W = \frac{\Delta z}{30 \cos \varphi \sin a_W}$$

$$\Delta T_E = \frac{\Delta z}{30 \cos \varphi \sin a_E}$$

the corrections $\Delta \lambda_n$ as well as of composing and resolving a system of conditional equations, was completed at Institute of Geodesy and Cartography. A solution of the equation system gave the following:

$$\varphi = -66^\circ\ 16'\ 34.4'' \pm 1.6''$$
$$\lambda = -100^\circ\ 45'\ 00.7'' \pm 0.3''.$$

6. Analysis of results

The astronomic observations carried out at Bunger Oasis enabled to find that the microclimate of Oasis, specific for its many fine days and nights (about 60%) and for a great transparency of atmosphere (about 2.5 time as much as in Poland) makes possible to observe the stars with greater magnitude; therefore another methods could be used especially more detailed and more simple ones during preparation and calculations. The mentioned

difficulties, with a suitable selection of pairs according to its uniform distribution in the horizon caused that weights of observations for determination of $\Delta\lambda$ was considerably greater than weights of observations for determination φ. It was reflected in the errors of estimated co-ordinates $\varepsilon_\varphi = \pm 1.6''$, $\varepsilon_\lambda = \pm 0.3''$. Respectively it should be noted that these are the mean errors describing an inner accuracy of the found value. An imporent part is played in astronomic observations by systematic errors of time registration that can influence considerably the time of passing of the star across the hairs. An experience allows to estimate the influence of systematic errors on defined longitude and latitude for about 1″. Coming to the end it should be added that during a stay of the expedition at Dobrowolski Station Mr Vincent Morgan, an Australian, came invited to the Bunger Oasis for a short visit; at that time he was carrying through the investigations at Mirnyj Station. He determined the co-ordinates at the our astronomic point by Doppler's method on the basic of three passages of a satellite only. He received the following results:

$$\varphi = -66^\circ\ 16'\ 30''$$
$$\lambda = -100^\circ\ 45'\ 03''.$$

An accuracy of these values is estimated (not calculated) for over $\pm 1''$.

7. Summary

In the paper there is a description of the Kavrajski's method of determination of the astronomic co-ordinates for finding them at a geodetic point in Bunger Oasis at the Dobrowolski Station. The calculations were based on observations of 26 pairs of bright stars at the same altitude at different azimuths.

The values of calculated co-ordinates are:

$$\varphi = -66^\circ\ 16'\ 34.4'' \pm 1.6''$$
$$\lambda = -100^\circ\ 45'\ 00.7'' \pm 0.3''$$

The mean errors calculated from the adjustment describe the inner accuracy. The errors of the co-ordinates are estimated to be about $\pm 1''$ for latitude as well as for longitude.

8. Резюме

Описано метод Каврайского, совместного установления астрономических координат на геодезийном пункте в Оазисе Бунгера на Станции им. Добровольского. Вычисления основано на наблюдениях 26 пар ярких звёзд на равных высотах в разных азымутах.

Вычисленно следующие величины координат:

$\varphi = -66^\circ 16' 34{,}4'' \pm 1{,}6''$

$\lambda = -100^\circ 45' 00{,}7'' \pm 0{,}3''$

Представленные точности, полученные на основании выравнивания характеризуют внутренную точность. Оценивается, что ошибка определения больше и она перевышает так для ширины как и для длины $\pm 1''$.

9. Streszczenie

W pracy zamieszczono opis metody Kawrajskiego łącznego wyznaczenia współrzędnych astronomicznych zastosowanej do wyznaczenia tych współrzędnych na punkcie geodezyjnym w Oazie Bungera na Stacji im. Dobrowolskiego. Obliczenia oparto na obserwacji 26 par jasnych gwiazd na równych wysokościach w różnych azymutach. Obliczone wartości współrzędnych są następujące:

$$\varphi = -66^\circ\ 16'\ 34{,}4'' \pm 1{,}6''$$
$$\lambda = -100^\circ\ 45'\ 00{,}7'' \pm 0{,}3''$$

Podane dokładności, obliczone na podstawie wyrównania, charakteryzują dokładność wewnętrzną. Szacuje się, że błąd wyznaczenia jest większy przekraczając zarówno dla szerokości jak i długości $\pm 1''$.

10. References

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