ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

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ΓΕΩΔΑΙΤΙΚΗ ΑΣΤΡΟΝΟΜΙΑ.— **Astronomical determination of the deviation of the vertical in various areas of Greece. I: Measurements in Central Macedonia during the year 1980,** *by L. N. Mavridis - P. Savaidis - A. C. Tsioumis - I. N. Tziavos**. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἰωάν. Ξανθάκη.

1. INTRODUCTION

The astronomical determination of the deviation of the vertical in as many stations of a region as possible could be of considerable importance among others from the following points of view:

1) For the astrogeodetic geoid determination in the region concerned.

2) For the reduction of the horizontal angle measurements to the reference ellipsoid.

3) For the adjustment of trigonometric levelling networks with simultaneous determination of the value of the coefficient of terrestrial refraction (Ramsayer, 1979).

The main work in the field of astronomical determination of latitude, longitude and azimuth in the area of Greece has been carried out so far by the Hellenic Army Geographical Service. Thus, until 1969 the Hellenic

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Army Geographical Service had carried out astronomical determinations of the deviation of the vertical in a total of 46 stations all over Greece (Hellenic National Committee for Geodesy and Geophysics 1963, 1967, 1971). In 1970 the Hellenic National Committee for Geodesy and Geophysics initiated a special program for the astronomical determination of the deviation of the vertical in 14 additional stations along the road from Athens to Kavala. This determination was completed by 1972 and the results obtained together with the already existing values of the deviation of the vertical for the 46 stations observed by the Hellenic Army Geographical Service were used by Balodimos (1972) for the computation of the first detailed astrogeodetic geoid in the area of Greece.

In 1976 the Department of Geodetic Astronomy, University of Thessaloniki initiated a program for the astronomical determination of the deviation of the vertical in Northern Greece. In the framework of this program 3 stations in Central Macedonia were measured, using a level Zeiss Ni-2 equipped with an astrolabe, and the results were published by Kaltsikis et al. (1978).

Finally, during the period 1970 - 79 the Hellenic Army Geographical Service carried out astronomical determinations of the deviation of the vertical in 10 additional stations and established 20 new Laplace stations (Hellenic National Committee for Geodesy and Geophysics 1975, 1979). The complete list of the stations with astronomical determination of latitude and longitude in Greece was published recently by the Hellenic Army Geographical Service (1983). According to this list the total number of stations with astronomical determination of the deviation of the vertical (including the Laplace stations) in Greece in the year 1982 was equal to 90 stations (27 stations of the first order network and 63 stations of the second, third and fourth order networks).

In order to increase the number of the stations with astronomical determination of the deviation of the vertical in Greece, and especially to achieve a more uniform distribution of these stations all over the country, a new program for the astronomical determination of the deviation of the vertical in various areas of Greece has been initiated by the Department of Geodetic Astronomy, University of Thessaloniki in 1980. Two were the main improvements adopted during this new program, as compared with the previous (1976) program of the same Department :

1) The astronomical observations were carried out with the help of a universal theodolite KERN DKM 3-A, which gives higher accuracy, especially in the determination of the longitude, than the level Zeiss Ni-2 with astrolabe used during the 1976 observations.

2) A base-station was established in the area of Thessaloniki (station KRANOS), which was observed before the beginning and after the end of each annual campaign, for the determination of an eventual personal equation of the observers.

In the present paper, a general description of this program, together with the results obtained during the year 1980 for 5 stations in Central Macedonia are given. Thus, part 2, refers to the instrumentation used. In parts 3 and 4 the methods used for the determination of latitude and longitude and the selection of the stars observed are outlined. Parts 5 and 6 deal with the computation of the apparent coordinates of the stars used and the reduction of the observations, while in part 7 the results obtained for the 5 stations in Central Macedonia measured during the 1980 campaign are given. The results of the measurements carried out in the framework of the same program during the following years will be given in forthcoming papers.

2. INSTRUMENTATION

2.1. Transit Instrument KERN DKM 3-A

As mentioned already the astronomical observations were made using the universal theodolite KERN DKM 3-A No. 85582 equipped with the striding level KERN No. 65870.

The determination of the lost motion (m) and the mean width of the contact strips (s) of the impersonal micrometer of the theodolite was made in the laboratory by the method described by Mueller (1969) before and after each annual period of measurements, and the weighted mean was used for the computations. The values of m and s thus found for the year 1980 were equal to —0.010 and 0.406 correspondingly, expressed in units of measuring drum division.

The calibration of the impersonal micrometer for equatorial value of one drum revolution (r) in seconds of time was made by the method described by Mueller (1969), i.e. by actually tracking stars with the micrometer in the field, before and after each annual period of measurements, and the weighted mean was used for the computations. The value of r thus found for the year 1980 was equal to $0^{s}.063$.

The final correction derived from the above values was computed with the help of the equation

$$l = \frac{1}{2} r (m + s) \sec \delta. \tag{2.1}$$

2. 2. Striding Level

The determination of the sensitivity of the striding level was made on a level trier. The sensitivity p in seconds of arc per division is given by the equation :

$$p = \frac{[xx] - \frac{[x]^2}{n}}{[xy] - \frac{[x][y]}{n}}, \tag{2.2}$$

where x is the reading of the micrometer on the level trier, y is the mean reading of the ends of the bubble and n is the number of settings. The brackets denote summation of the enclosed values.

In our case four least squares determinations of the level sensitivity were made before and after each annual period of measurements, and the weighted mean was used for the computations. The value of the level sensitivity thus found for the year 1980 was equal to 1.″85/division, with a r.m.s. error equal to ±0.″048/division.

2.3. Time Determination

A standard frequency and time system Rohde und Schwarz CAC was used as the basic unit for time determination. The time correction of this system was determined with the help of RWM (10 MHz) time signals. In this way an accuracy of the order of 1 ms could be achieved. For the registration of the times of transit during field work two chronometers, one Chronocord 681, constructed by Littlemore Scientific Engineering Co., and one Tele-Longines 2202, both of which register the time in units of 1 ms, were used. During the 1980 campaign, the observers could return every day in Thessaloniki. In this way the determination of the time correction and rate of the two chronometers used in the field could be made through comparisons with the Rohde und Schwarz CAC-system. As the rate of both chronometers was found constant with time, one should expect that the accuracy of time registration obtained with these chronometers was the same with that of the Rohde und Schwarz CAC-system, i.e. of the order of 1 ms.

3. DETERMINATION OF LATITUDE

3.1. Method

The determination of latitude was made using the refined version of the meridian zenith distances method known as Sterneck method, i.e. by observing pairs of stars culminating the one north of the zenith and the other south, at about the same zenith distance. This method has been described in detail in many textbooks and special publications (Mueller, 1969; Jordan et al., 1970; Müller, 1973; Sigl, 1975; Sevilla and Nuñez, 1979a; Tsioumis and Savaidis, 1983).

3.2. Selection of Stars

All stars observed were taken from FK 4. Since the maximum zenith distance at the time of observation was taken 30°, the declination range of the stars used was determined with the help of the condition :

$$\varphi - 30° < \delta < \varphi + 30°.$$

For a single latitude determination a minimum of four star pairs were observed. In order to increase the accuracy and minimize the influence of the systematic errors due to refraction anomalies, each final latitude value was based on observations of at least 32 star pairs distributed over a period of at least two nights.

A star program was prepared for each observing night. In this program stars were listed in order they should be observed, including : 1) name and number of the star in FK 4, 2) magnitude, 3) approximate values of the apparent coordinates α, δ of the star, 4) approximate value of the zenith distance of the star at upper culmination (with the subscripts N or S depending on whether the upper culmination takes place to the north or south of zenith), 5) approximate time of transit (UT + 2^h in winter, or UT + 3^h in summer). More details about the preparation of this program will be given elsewhere.

4. DETERMINATION OF LONGITUDE

4.1. Method

For the determination of longitude a refined version of the meridian transit times method, known as Mayer method, was used i.e.:

1) we determine the local apparent sidereal time by observing the transit times of stars over the local meridian, and

2) we receive time signals for the determination of the Greenwich apparent sidereal time and the rate of the chronometer.

This method has been described in detail in several textbooks and special publications (Mueller, 1969; Jordan et al., 1970; Müller, 1973; Sigl, 1975; Ollikainen, 1977, 1982; Sevilla and Nuñez, 1979 b; Tsioumis and Savaidis, 1983).

As mentioned already the universal theodolite KERN DKM 3-A No. 85582 used for the astronomical observations is equipped with an impersonal micrometer, which makes this instrument specially suited for the observation of meridian transits of stars.

4.2. Selection of Stars

All stars observed were taken from FK 4. For a single longitude determination a group with a minimum of six stars was observed. The final longitude value of each station was based on observations of at least six star groups distributed over a period of two or more nights.

Following conditions were used for the selection of the stars observed :

1) The zenith distance at the time of observation should not exceed 30°, which yields

$$\varphi - 30^\circ < \delta < \varphi + 30^\circ.$$

2) Only stars brighter than seventh magnitude were used.

3) For each star the azimuth factor

$$A = \sin(\varphi - \delta) \sec \delta$$

should be smaller than 0.6.

4) For each group of stars ΣA should be as near to zero as possible, and in any case

$$0 < \Sigma A < 1.$$

5) A time interval of 5^m - 10^m should be allowed between consecutive star transits.

A star program was prepared for each observing night. Besides the data included in the program for the latitude observations mentioned in § 3.2, the program for longitude included also the azimuth factor of each star, as well as the time interval needed for the star to cross the optical field of the theodolite.

5. STAR COORDINATES

All coordinates of the stars used in this paper are in the FK 4-system.

The computation of the apparent places of the stars observed was made through interpolation of the values given in the volume Apparent Places of Fundamental Stars using the electronic computer UNIVAC 1106 of the University of Thessaloniki and a program in FORTRAN V specially written for this purpose. More details about this program will be given elsewhere.

6. REDUCTION OF THE OBSERVATIONS

6.1. Reduction of Latitude Observations

The latitude φ can be computed from the measured zenith distance z at meridian transit, corrected for refraction, and the apparent declination δ of a star with the help of the formulae :

$$\varphi_N = \delta_N - z_N = \delta_N + \upsilon_N - 90^\circ \text{ (upper transit north of the zenith)}, \quad (6.1)$$

$$\varphi_S = \delta_S + z_S = \delta_S + 90^\circ - \upsilon_S \text{ (» » south » »)}, \quad (6.2)$$

where $\upsilon = 90^\circ - z$.

As we have seen in § 3 in order to avoid systematic errors due to refraction and the error of setting the instrument in the meridian (diurnal aberration has no effect on the declination, when the star is on the meridian), the stars have been observed in north-south pairs at about the same altitude. Therefore, the value of latitude corresponding to the observation of such a pair will be

$$\varphi = \frac{1}{2}(\varphi_N + \varphi_S) = \frac{1}{2}(\delta_S + \delta_N) + \frac{1}{2}(z_S - z_N) = \frac{1}{2}(\delta_S + \delta_N) + \frac{1}{2}(\upsilon_N - \upsilon_S). \quad (6.3)$$

The value of φ corresponding to a single latitude determination was taken equal to the average of the values of φ corresponding to all the star pairs used for this determination. The final value of φ for each station was taken equal to the weighted mean of the values of φ corresponding to all single latitude determinations carried out in this station.

6.2. Reduction of Longitude Observations

The chronograph time (U.T.C.) of each observation was the mean of approximately 20 - 25 pairs of contact times. This time was corrected with the help of the chronometer correction and transformed into UT1 by applying the correction UT1 - UTC given in Circular D of the Bureau International de l'Heure. UT1 was further transformed into Greenwich Apparent Sidereal Time (GAST) in the usual manner.

The longitude correction $\Delta\Lambda$ has been computed from the transit observations using Mayer's formula properly modified :

$$\Delta\Lambda = \alpha - (\text{GAST} + \lambda_0 + Aa + Bb + Cc + l + \Delta h_D)\,, \qquad (6.4)$$

where

α is the apparent right ascension of the star observed,

λ_0 is an assumed value of the longitude of the station,

$A = \sin(\varphi - \delta)\sec\delta$ is the azimuth factor,

a is the azimuth setting error (unknown quantity),

$B = \cos(\varphi - \delta)\sec\delta$ is the level factor,

$b = \frac{1}{4}(\Sigma W - \Sigma E)\,p$ is the inclination of the horizontal axis, where ΣW and ΣE are the sums of the readings of the bubble in east and west telescope position correspondingly and p is the level's sensitivity,

$C = \sec\delta$ is the collimation factor,

c is the collimation error,

$l = \frac{1}{2}\,r\,(m+s)\sec\delta$ is the correction derived from the calibration of the impersonal micrometer given by relation (2.1),

$\Delta h_D = -0^s.0213\cos\varphi\sec\delta$ is the diurnal aberration.

Equation (6.4) can be written in the form

$$\Delta\Lambda + Aa - (\alpha - t) = 0, \tag{6.5}$$

where

$$t = GAST + \lambda_0 + Bb + l + \Delta h_D$$

and C_C is eliminated.

Each observed transit yields an observation equation of the form

$$\Delta\Lambda + A_i a - (\alpha_i - t_i) = \upsilon_i, \quad (i = 1, 2, \ldots, n). \tag{6.6}$$

Therefore, the system of normal equations has the form

$$\begin{aligned} n\,\Delta\Lambda + [A]\,a - [\alpha - t] &= 0, \\ [A]\Delta\Lambda + [AA]\,a - [A(\alpha - t)] &= 0. \end{aligned} \tag{6.7}$$

Two solutions were made: one with equal weights and a second one by giving to each observation equation a weight equal to $G = \cos^2\delta$ (Müller, 1973). Both solutions gave the same results. This should have been anticipated as our observations were made in moderate latitudes. The solution with equal weights was finally adopted.

The least squares solution (6.7) was performed for each star group observed. In this way the value of $\Delta\Lambda$ and the corresponding r.m.s. error based on this star group was found. The corresponding value of the astronomical longitude was then derived with the help of the equation :

$$\lambda = \lambda_0 + \Delta\Lambda. \tag{6.8}$$

The final value of the astronomical longitude for each station was taken equal to the weighted mean of the values of λ corresponding to all star groups observed at this station.

6.3. Corrections

6.3.1. Correction for Polar Motion.

The values of latitude and longitude thus found for each single determination refer to the instantaneous pole. These values were reduced to the mean pole with the help of the formulae :

$$\Delta\varphi = -(x\cos\lambda - y\sin\lambda), \tag{6.9}$$

$$\Delta\lambda = -\frac{1}{15}(x\sin\lambda + y\cos\lambda)\tan\varphi, \tag{6.10}$$

where the coordinates x, y of the instantaneous pole were taken from the Circulaire B/C of the Bureau International de l'Heure.

6.3.2. Correction for the Curvature of the Plumb Line.

The value of φ computed in § 6.3.1. refers to the actual observing station. In order to reduce this value to the geoid, following correction for the curvature of the plumb line was applied (Mueller, 1969) :

$$\Delta\varphi_{pc} = -0.''00017 \, H \sin 2\varphi \,, \qquad (6.11)$$

where H is the orthometric height of the station and φ denotes either the geodetic or the observed astronomical latitude.

7. RESULTS

The results for the 5 stations in Central Macedonia measured during the year 1980 are given in Table 1. In this table the first and second columns give the name and the altitude of each station. The third and fourth columns give the final values of the astronomical latitude and longitude found in this paper for each station. These values have been rounded off to the nearest 1′, because of the security regulations valid in the country. The actual values of these quantities were computed in units of 0.″001. The fifth and sixth columns give the r.m.s. error of the final values of the astronomical latitude and longitude found in this paper. The geodetic latitude and longitude for the stations observed, referred to ED 1950 (Hayford ellipsoid), were kindly put at our disposal by the Hellenic Army Geographical Service, also in units of 0.″001. In this way the values of the components ξ and η of the deviation of the vertical corresponding to each station could be computed and the results are given in the seventh and eighth columns. The ninth and tenth columns give the number of stars observed for the determination of the values of φ and λ given in columns 3 and 4, and the eleventh column gives the corresponding period of measurements.

As mentioned already in § 1 the base-station KRANOS was measured twice every year, i.e. once before the beginning and once after the end of the field campaign. The final values of the astronomical latitude and lon-

TABLE 1

Components of the deviation of the vertical for the 5 stations in Central Macedonia measured during the year 1980

Station	Altitude (m)	Astronomical		r. m. s. error		Components of the deviation of the vertical		Number of stars observed		Period of measurements
		Latitude	Longitude	Latitude	Longitude	ξ	η	Latitude	Longitude	
KRANOS (a)	423	40° 38′	22° 59′	±0.″126	±0.″195	—11.″888	—9.″774	68	60	23.6 - 2.7.80
KRANOS (b)	423	40° 38′	22° 59′	±0.″316	±0.″285	—11.″902	—9.″973	64	42	15.10 - 30.10.80
ANGELOCHORI	43	40° 40′	22° 12′	±0.″299	±0.″315	—12.″493	+3.″932	64	38	16.7 - 25.7.80
TSIMENTENIA GEFYRA	10	40° 41′	22° 26′	±0.″071	±0.″285	—12.″158	—1.″900	64	44	15.7 - 24.7.80
YDRAGOGION	245	40° 51′	22° 23′	±0.″158	±0.″225	—18.″550	—2.″087	66	42	28.7 - 21.8.80
TOUMBA MESIAS	135	40° 53′	22° 34′	±0.″198	±0.″315	—13.″144	—0.″857	66	44	8.7 - 14.7.80

gitude corresponding to these two periods of measurements are given separately in Table 1 under the indications KRANOS (a) and KRANOS (b).

From Table 1 following conclusions could be drawn :

1) The r.m.s. errors of the final values of astronomical latitude and longitude for all the stations measured are contained between $\pm 0.''1$ and $\pm 0.''3$.

2) The values of ξ and η for the base-station KRANOS found during the two periods of measurements in the year 1980 are in fairly good agreement.

3) The values of the components ξ and η corresponding to all the stations of Central Macedonia measured during the year 1980 are contained correspondingly in the intervals $-19''$ to $-12''$ for ξ and $-10''$ to $+4''$ for η.

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ΠΕΡΙΛΗΨΗ

Ὁ ἀριθμὸς τῶν σταθμῶν γιὰ τοὺς ὁποίους ἔχει γίνει ἀστρονομικὸς προσδιορισμὸς τῆς ἀποκλίσεως τῆς κατακορύφου στὴ χώρα μας εἶναι πολὺ περιορισμένος. Γιὰ νὰ αὐξηθεῖ ὁ ἀριθμὸς αὐτὸς καὶ παράλληλα νὰ ἐπιτευχθεῖ περισσότερο ὁμοιόμορφη κατανομὴ τῶν σταθμῶν σὲ ὅλη τὴν ἔκταση τῆς ἠπειρωτικῆς Ἑλλάδος, τὸ Ἐργαστήριο Γεωδαιτικῆς Ἀστρονομίας τοῦ Πανεπιστημίου Θεσσαλονίκης ἐγκαινίασε τὸ 1980 ἕνα ἐρευνητικὸ πρόγραμμα μὲ στόχο τὸν ἀστρονομικὸ προσδιορισμὸ τῆς ἀποκλίσεως τῆς κατακορύφου σὲ ἕνα κατὰ τὸ δυνατὸ μεγαλύτερο ἀριθμὸ σταθμῶν σὲ κατάλληλα ἐπιλεγόμενες περιοχὲς τῆς χώρας. Στὸ πρόγραμμα αὐτὸ οἱ ἀστρονομικὲς παρατηρήσεις ἐκτελοῦνται μὲ ἕνα θεοδόλιχο τύπου KERN DKM 3-A ἐφοδιασμένο μὲ ἀπρόσωπο μικρόμετρο καὶ ἐπιβατικὴ ἀεροστάθμη, ὁ δὲ προσδιορισμὸς τοῦ ἀστρονομικοῦ γεωγραφικοῦ πλάτους καὶ μήκους γίνεται ἀντίστοιχα μὲ τὶς μεθόδους Sterneck καὶ Mayer. Στὴν παροῦσα ἐργασία δίνεται πρῶτα μιὰ γενικὴ περιγραφὴ τοῦ προγράμματος. Στὴ συνέχεια δίνονται

τὰ ἐξαγόμενα γιὰ τοὺς 5 σταθμοὺς τῆς Κεντρικῆς Μακεδονίας (ἀπὸ τοὺς σταθμοὺς αὐτοὺς ὁ σταθμὸς ΚΡΑΝΟΣ χρησιμεύει σὰν σταθμὸς ἀναφορᾶς) ποὺ μετρήθηκαν κατὰ τὸ ἔτος 1980. Τὸ μ.τ.σ. τοῦ προσδιορισμοῦ τόσο τοῦ ἀστρονομικοῦ γεωγραφικοῦ πλάτους, ὅσο καὶ τοῦ ἀστρονομικοῦ γεωγραφικοῦ μήκους περιλαμβάνεται γιὰ ὅλους τοὺς σταθμοὺς στὸ διάστημα ±0.″1 μέχρι ±0.″3, οἱ δὲ τιμὲς τῶν συνιστωσῶν τῆς ἀποκλίσεως τῆς κατακορύφου περιλαμβάνονται γιὰ μὲν τὸ ξ στὸ διάστημα —19″ μέχρι —12″, γιὰ δὲ τὸ η στὸ διάστημα —10″ μέχρι +4″.

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