ΓΕΩΔΑΙΤΙΚΗ ΑΣΤΡΟΝΟΜΙΑ.— **Astronomical determination of the deviation of the vertical in various areas of Greece. II: Measurements in Western Macedonia and Peloponnese during the year 1981,** *by L. N. Mavridis - 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 was carried out by the Hellenic Army Geographical Service. Thus, until 1979 a total of 90 stations with astronomical determination of the deviation of the vertical (including 20 Laplace stations) were established by this Service. The complete list of these stations was published recently by the Hellenic Army Geographical Service (1983).

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 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. A detailed description of this program together with the results obtained during the year

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1980 for 5 stations in Central Macedonia have been given in a previous paper (Mavridis et al., 1983), which will be referred to in the following as Paper I.

In the present paper a brief description of the instrumentation (part 2), and the methods used for the determination of latitude and longitude (parts 3 and 4), as well as for the reduction of the observations (part 5), together with the results obtained during the year 1981 for the base-station KRANOS and 3 additional stations in Western Macedonia and Peloponnese (part 6) are given.

2. INSTRUMENTATION

The astronomical observations were carried out using the universal theodolite KERN DKM 3-A No. 85582 equipped with the striding level KERN No. 65870. Details about the calibration of the impersonal micrometer of the theodolite and the striding level have been given in Paper I. The results of the calibration for the year 1981 were as follows :

Impersonal micrometer :

Lost motion: $m = -0.010$ units of measuring drum division.

Mean width of the contact strips: $s = 0.406$ units of the measuring drum division.

Equatorial value of one drum revolution : $r = 0^s\!.063$.

Striding level :

Sensitivity: $p = 1.''85 \pm 0.''048$ per division.

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 one chronometer Chronocord 681, constructed by Littlemore Scientific Engineering Co., which registers the time in units of 1 ms, was used. The determination of the time correction and rate of this chronometer was made through comparisons with the Rohde und Schwarz CAC-system before the beginning and after the end of each field operation. In order to check the constancy of the rate of Chronocord 681 during each field operation, time signals RWM (10 MHz) were also received in the field, with the help of two standard time and frequency receivers Kinemetrics, type WWVT. As the rate of Chronocord 681 was found constant with time, one should expect that the accuracy of time registration with this chronometer was the same with that of the Rohde und Schwarz CAC-system, i.e. of the order of 1 ms.

3. DETERMINATION OF LATITUDE

The determination of latitude was made using the 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 several textbooks and special publications (Mueller, 1969; Jordan et al., 1970; Müller, 1973; Sigl, 1975; Sevilla and Nuńez, 1979 a; Tsioumis and Savaidis, 1983).

All stars observed were taken from FK 4. For a single latitude determination a minimum of four star pairs were observed, while the final latitude value for each station 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. More details about this program are given in Paper I.

4. DETERMINATION OF LONGITUDE

The determination of longitude was made using a refined version of the meridian transit times method known as Mayer method, 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 Nuńez, 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 observations of meridian transits 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 for each station was based on the observation of at least six star groups distributed over a period of two or more nights.

A star program was prepared for each observing night. More details about this program are given in Paper I.

5. REDUCTION OF THE OBSERVATIONS

5.1. 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.

5.2. 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 :

$$\varphi_N = \delta_N - z_N = \delta_N + \upsilon_N - 90^\circ \quad \text{(upper transit north of the zenith)}, \quad (5.1)$$

$$\varphi_S = \delta_S + z_S = \delta_S + 90^\circ - \upsilon_S \quad (\text{» » south » »}), \quad (5.2)$$

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

$$\varphi = \frac{1}{2}(\varphi_N + \varphi_S) = \frac{1}{2}(\delta_S + \delta_N) + \frac{1}{2}(z_S - z_N) = \frac{1}{2}(\delta_S + \delta_N) + \frac{1}{2}(\upsilon_N - \upsilon_S). \quad (5.3)$$

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.

5.3. Reduction of Longitude Observation

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 UT 1 by applying the correction UT 1-UTC given in Circular D of the Bureau International de l'Heure. UT 1 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 :

$$\Delta\Lambda = \alpha - (\mathrm{GAST} + \lambda_0 + \mathrm{Aa} + \mathrm{Bb} + \mathrm{Cc} + l + \Delta h_D)\,, \qquad (5.4)$$

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,
$\Delta h_D = -0^s0213\,\cos\varphi\,\sec\delta$	is the diurnal aberration.

Equation (5.4) can be written in the form

$$\Delta\Lambda + Aa - (\alpha - t) = 0, \qquad (5.5)$$

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

$$\Delta\Lambda + A_i a - (\alpha_i - t_i) = \upsilon_i\,, \quad (i = 1, 2, \ldots, n)\,. \qquad (5.6)$$

Therefore, the system of normal equations has the form

$$\begin{aligned} n\,\Delta\Lambda + [A]\,a - [\alpha - t] &= 0, \\ [A]\Delta\Lambda + [AA]\,a - [A\,(\alpha - t)] &= 0. \end{aligned} \qquad (5.7)$$

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 (5.7) 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 :

$$\lambda = \lambda_0 + \Delta\Lambda. \qquad (5.8)$$

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.

5.4. Corrections

5.4.1. 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 :

$$\Delta\varphi = -(x\cos\lambda - y\sin\lambda)\,, \qquad (5.9)$$

$$\Delta\lambda = -\frac{1}{15}(x\sin\lambda + y\cos\lambda)\tan\varphi\,, \qquad (5.10)$$

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

5.4.2. Correction for the Curvature of the Plumb Line.

The value of φ computed in § 5.4.1 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) :

$$\Delta\varphi_{pc} = -0.''00017\,\mathrm{H}\sin 2\varphi\,, \tag{5.11}$$

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

6. RESULTS

The results for the 4 stations measured during the year 1981 are given in Table 1. These stations include the base-station KRANOS in Central Macedonia, two stations (Makrovouni and Vathylakos) in Western Macedonia and one station (Agios Nikolaos) in Peloponnese.

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.

TABLE 1

Components of the deviation of the vertical for the 3 stations in Western Macedonia and Peloponnese as well as the base-station KRANOS measured during the year 1981

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.″118	±0.″155	—12.″255	— 9.″334	64	72	23.6 - 29.6.81
KRANOS (b)	423	40° 38′	22° 59′	±0.″172	±0.″345	—12.″320	— 9.″479	64	51	16.10 - 30.10.81
3 - AGIOS NIKOLAOS	673	37° 30′	22° 24′	±0.″227	±0.″320	—14.″951	—17.″643	64	58	28.9 - 1.10.81
7 - 99 MAKROVOUNI	942	39° 57′	21° 32′	±0.″310	±0.″270	—20.″653	— 7.″358	68	54	31.8 - 4.9.81
8 - 18 VATHYLAKOS	532	40° 15′	21° 54′	±0.″206	±0.″250	—20.″665	— 7.″280	64	57	6.7 - 10.7.81

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 longitude 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 the stations measured during the year 1981 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 1981 are in fairly good agreement.

3) The values of the components ξ and η corresponding to all the stations measured during the year 1981 are contained correspondingly in the intervals —21″ and —12″ for ξ and —18″ and —7″ 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 τῶν σταθμῶν αὐτῶν 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 ἐπιλεγμένες περιοχὲς τῆς χώρας. Στὸ πρόγραμμα αὐτὸ οἱ ἀστρονομικὲς παρατηρήσεις ἐκτελοῦνται μὲ ἕνα Θεοδόλιχο KERN DKM 3-A ἐφοδιασμένο μὲ ἀπρόσωπο μικρόμετρο καὶ ἐπι-

βατική ἀεροστάθμη, ὁ δὲ προσδιορισμὸς τοῦ ἀστρονομικοῦ γεωγραφικοῦ μήκους καὶ πλάτους γίνεται ἀντίστοιχα μὲ τὶς μεθόδους Sterneck καὶ Mayer. Στὴν παροῦσα ἐργασία δίδεται πρῶτα μία σύντομη περιγραφὴ τοῦ ὅλου προγράμματος καὶ στὴ συνέχεια δίδονται τὰ ἐξαγόμενα γιὰ 1 σταθμὸ στὴν Κεντρικὴ Μακεδονία (σταθμὸς KRANOS), ποὺ χρησιμεύει σὰν σταθμὸς ἀναφορᾶς, 2 σταθμοὺς στὴ Δυτικὴ Μακεδονία καὶ 1 σταθμὸ στὴν Πελοπόννησο ποὺ μετρήθηκαν κατὰ τὸ ἔτος 1981. Τὸ μ.τ.σ. τοῦ προσδιορισμοῦ τόσο τοῦ ἀστρονομικοῦ γεωγραφικοῦ πλάτους ὅσο καὶ τοῦ ἀστρονομικοῦ γεωγραφικοῦ μήκους περιλαμβάνεται γιὰ ὅλους τοὺς σταθμοὺς στὸ διάστημα $\pm 0.''1$ μέχρι $\pm 0.''3$, οἱ δὲ τιμὲς τῶν συνιστωσῶν τῆς ἀποκλίσεως τῆς κατακορύφου περιλαμβάνονται γιὰ μὲν τὸ ξ στὸ διάστημα $-21''$ μέχρι $-12''$, γιὰ δὲ τὸ η στὸ διάστημα $-18''$ μέχρι $-7''$.

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