MAREES TERRESTRES

BULLETIN D'INFORMATIONS

N° 87

15 MAI 1982

Association Internationale de Geodesie

Commission Permanente des Marees Terrestres

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Observatoire royal de Belgique

Avenue Circulaire 3

1180 Bruxelles

TABLE DES MATIERES N°87

DISCUSSION OF A LONG SERIES OF GRAVITY TIDE MEASUREMENTS AT ALICE SPRINGS IN THE CENTRE AUSTRALIA (*)

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SUMMARY

This paper describes the installation of a tidal gravimeter at Alice Springs in the frame of the Trans World Tidal Gravity Profiles, the instrumental characteristics and the calibration problem.

Barometric pressure influences and oceanic loading estimations are considered. The results of analysis of the data which cover totalize 14736 hourly readings over an interval of 1060 days of observations allow to give new conclusions about ocean loading and liquid core effects.

1 - the installation at Alice Springs
2 - the instrument and its calibration
3 - the results of analysis
4 - the effect of atmospheric pressure
5 - oceanic loading
6 - liquid core effects.

This gravimeter Geodynamics 84 was installed at Alice Springs in early february 1976 by J. Van Son and was expected to continuously register during three years. Unfortunately as a result of the practical difficulties encountered in the maintenance at such an isolated place, many recording gaps happened in 1976 and 1977.

By the end of 1977, B. Barlow revisited the station and carefully redetermined the instrumental constants (minimum of sensitivity to tilt and calibration voltages). Then, a new, more homogeneous, series of registrations started in january 1978 which allowed us to obtain one year of data with only a very few short gap (348 days of complete normal registration out of a total of 358). The observations were terminated on january 6, 1979.

(*) This paper was presented at the IUGG General Assembly, Canberra, December 1979, Symposium n°20 "Tidal Interactions".

1 - THE INSTALLATION AT ALICE SPRINGS.

Alice Springs is the real center of the Australian continent with coordinates

$$\phi = 23°42'36" \text{ South}$$
$$\lambda = 133°50' 6" \text{ East,}$$

the nearest sea coast being at 1000 km in the south (Great Australian Bight) or north-east (Gulf of Carpentaria) but west or east, it is at 2000 km from the Indian Ocean or the Pacific Ocean. It is situated in a very hot desert in the MacDonnell Ranges, at a height of 590 m above sea level and practically upon the Tropic of Capricorn. Summer temperatures in the high 30°C are no exceptions while in the winter time the night temperature sometimes drops to a few degrees below zero.

Our choice of Alice Springs was evidently dictated by the hope to obtain there a nearly pure direct earth tide, the indirect effects being minimized by the geographical situation.

We were extremely fortunate to obtain the use of the only underground gallery existing, which had been drilled horizontally in a small hill some time ago, and which is 20 m long. The extremity has been isolated to install Geodynamics gravimeter GEO 84 of the Royal Observatory of Belgium with a quartz clock and a recorder. (This is a cooperative project between that Institution and the Bureau of Mineral Resources at Canberra).

During the first Trans-World tidal gravity profile, this equipment had previously been installed at :

	Bruxelles (Belgium)	from 1971/06/29 till 1973/11/08 - 782 days registration available
	Bangkok (Thailand)	from 1973/11/17 till 1974/03/13 - 96 days registration available
	Chiang Mai (Thailand)	from 1974/04/09 till 1974/09/08 - 132 days registration available
	Kathmandu (Nepal)	from 1974/09/30 till 1975/03/14 - 80 days registration available
	Canberra (Australia)	from 1975/04/04 till 1975/07/03 - 86 days registration available
and	Armidale (Australia)	from 1975/07/17 till 1976/01/24 - 160 days registration available.

It has been installed at Wuhan, China, on october 5, 1979 and then at Urumqi (Sinkiang, China) for a period of 6 months.

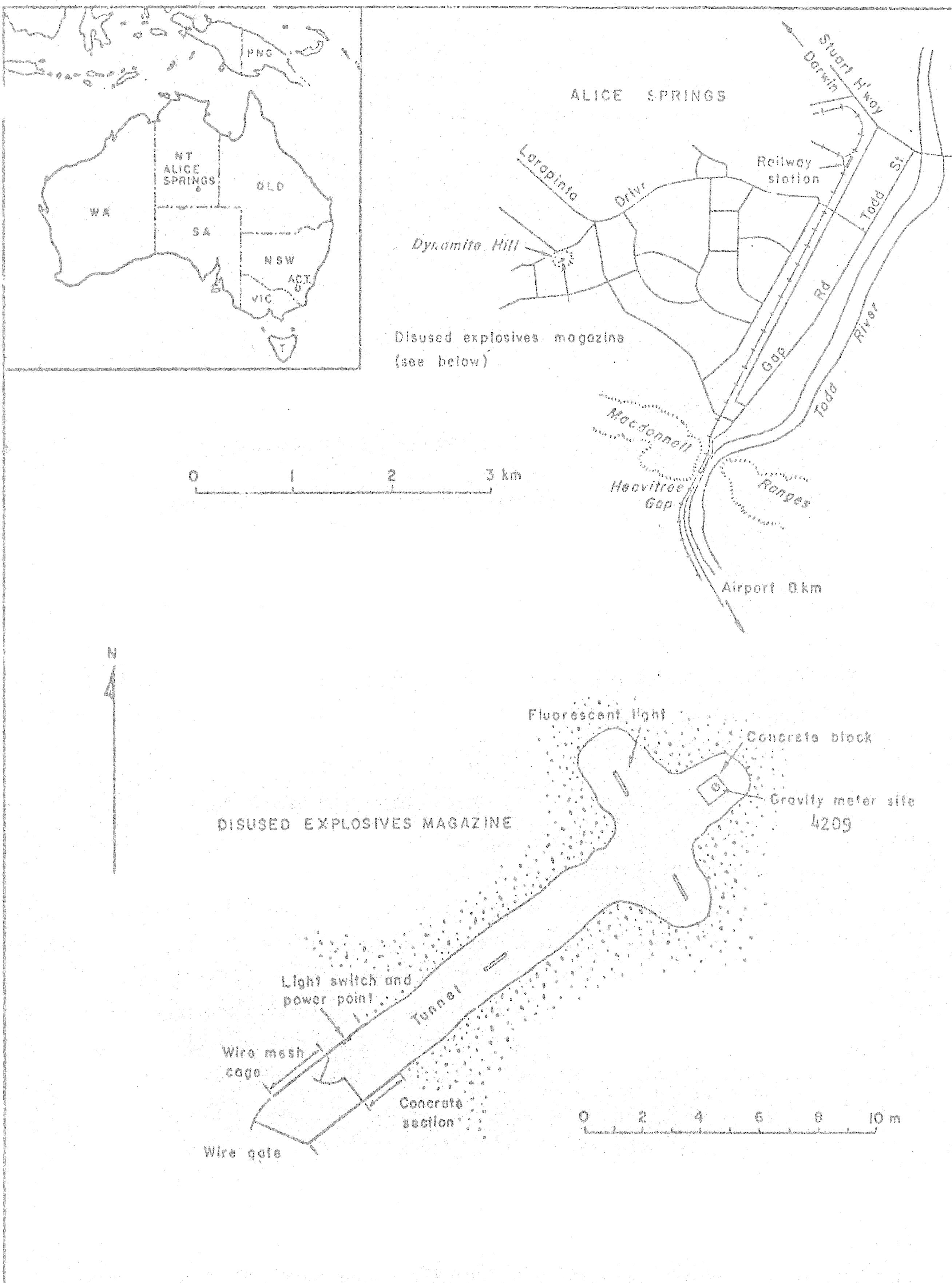

FIG. 1 EARTH TIDE GRAVITY METER SITE
ALICE SPRINGS (DISUSED EXPLOSIVES MAGAZINE)

F53/B2-76A

We have therefore made global analyses

a - for the total amount of data available (12528 hourly readings)

b - for the year 1978 alone (8352 readings)

Table II allows us to compare the results of these analyses for the main tidal waves (amplitude ≥ 9 microgals) and shows that, at this level, there is no significant difference between the two sets.

2 - THE INSTRUMENT AND ITS CALIBRATION.

In this instrument , the displacements of the mass are detected by a double capacitive transducer, the signal amplitude being about 15 mV μm^{-1}.

The equipment is completed with a potentiometric recorder and a quartz clock (specially built for this purpose by the Time Section, Department I, Royal Observatory, Brussels) to provide the time scale. The time marks are superimposed on the tidal curve itself to avoid parallax effects. The chart speed is about 5 cm h^{-1} resulting in a timing accuracy of about 10 s in the digitisation process. The microseismic noise is attenuated by low-pass filter of 30 s for the Geodynamics instruments. The tidal curves are digitised by a semi-automatic reading device having a resolution of 0.1 mm.

The modified Geodynamics instrument is no longer calibrated by a micrometer. Its sensitivity is checked by means of an electrostatic calibration device. A fixed voltage is applied between the beam and the condenser plate, producing a constant force proportional to the square of the voltage (Melchior, 1971) which is equivalent to about 100 µGal. A digital voltmeter is used to check the calibration voltages which are activated twice a week for a 50-min period. The procedure only allows the sensitivity changes to be checked and the instruments must be externally calibrated. The instrument was calibrated by the manufacturer against the vertical gradient of gravity. A more accurate calibration factor deduced from long recording periods at the Bruxelles fundamental station {780 days} (Ducarme, 1975a), has been adopted for this profile.

Two differently regulated voltage supplies are used. The first is a simple Zener diode which shows some variation in behaviour with temperature. As a consequence, a thermally-compensated electronic circuit designed at the Geodeettinen Laitos (Helsinki) was subsequently installed. The stability exhibited by this supply is better than one part in two thousand. The voltage was measured at each calibration. Table I gives the mean value of this voltage.

It must be pointed out that at some places a small permanent residual voltage appeared between the two plates of the condenser because of earthing problems. This reduces the effective calibration voltage and correspondingly increases the instrument scale factor. Table I gives also the amplitude in microgals of the resulting calibration pulse.

TABLE 1 - G E O D Y N A M I C S 8 4

		"Old Calibration"(OC)			"New Calibration"(NC)		
Station	Epoch	Zener Diode Voltage (V)	Residual Voltage (V)	Calibration pulse Δg (μgal)	Stabilised Supply Voltage (V)	Residual Voltage (V)	Calibration pulse Δg (μgal)
0201 Bruxelles	1973	48.1	0.0	118.26			
2501 Bangkok	1973-74	48.0	0.9	113.4			
2502 Chiang Mai	1974	48.1	1.1	112.9			
2450 Kathmandu	1974-75	48.1	1.3	112.0	46.9	1.3	106.29
4206 Canberra	1975	48.0-47.8	0.0	117.8-116.8	46.9	0.0	112.43
4205 Armidale	1975-76	48.1-48.0	0.0	118.3-117.8	46.8	0.0	111.93
4209 Alice Springs	1976-78	48.2	0.0	118.75	46.8	0.0	111.93
0201 Bruxelles	1979	48.0	0.0		46.8	0.0	111.15
0201 Bruxelles	1979				49.91 ✱	0.0	128.11 ✱

V_o = 48.1 volts Δg_o = 100.00 μgal

✱ LWA Reference after transformation of the gravimeter's electronics

$$R_1^2 = \frac{A(OC)}{A(NC)} = \left(\frac{48.2}{46.8}\right)^2 = \frac{118.75}{111.93} = 1.061$$

After the transformation of the electronics the ratio of the square of the voltages became such as

$$\left(\frac{49.91}{46.8}\right)^2 = 1.137$$

which no more corresponds to the ratio of the calibration pulses: $R_2^2 = \frac{128.11}{111.15} = 1.153$

As a control, comparisons of the amplitudes of the calibration pulses has been made by the Nakai procedure and gave

$$R_1^2 = 1.054$$

$$R_2^2 = 1.146$$

The discrepancy with respect to the direct measurements is only 0.8%.

A great deal of work has been made to derive a sensitivity table w ch is as correct as possible. When using an electrostatic attraction device the sensitivity is given by the formula

$$S = f \times \frac{\Delta g_o \times V^2}{\ell \times V_o^2} \text{ microgals mm}^{-1} \qquad (1)$$

where

- V_o is the standard voltage (48.1 volts for G 84)
- V is the measured voltage corresponding to each individual calibration
- ℓ is the displacement of the pen on the recording paper, measured in millimeters
- Δg_o is the equivalent acceleration corresponding to the application of the voltage V_o (for G 84 Δg_o = 100 µgals).
- f is the normalisation factor which has been determined in order that the measurements made at Bruxelles give $\delta(O_1) = 1.161$ (Ducarme 1975a). It was found to be, in 1971-1973 :

$$f = 1.18255 \qquad (2)$$

From january till september 1979 the gravimeter was reinstalled at the fundamental station Bruxelles. From the seven months new registration obtained, the coefficient (2) was reconfirmed to 0.1 % which means that the many long transportations have not affected the calibration constant. The complete revision accordingly made, including the 1971-73 data and the 1979 data altogether gave indeed $f = 1.18073$.

The coefficient (2) has been used here.

A similar comparison was made indeed at Canberra in 1975 with two LaCoste Romberg gravimeters which reconfirmed this factor with a precision of respectively 0.06 % (LCR 8) and 0.13 % (LCR 336).

The calibration pulses have been correlated with the environment temperature which gaves

- for the maker device $r = 0.52$
- for the new device $r = 0.47$

A smoothing of the calibration determinations was made in function of time by the Vondrak method and was compared with a similar smoothing of the output of a Nakai analysis of the data.

The concluded calibration table is obtained from the adjustment of these two procedures. It gives a calibration value every two days.

Instrumental stability

Among the parameters influencing instrumental stability, the levelling is considered the most important in the case of astaticized gravimeters. Two spirit levels are located on top of the instrument. The first, parallel to the beam, is called the longitudinal level while the second, perpendicular to it, is called the transverse level. When installing the instrument, it is extremely important to set the levels in the position corresponding to that of minimum sensitivity to tilting because the instrument output exhibits a parabolic dependence on the extent of tilting. Moreover, any tilt along the longitudinal direction directly affects the sensitivity of the instrument. The levelling stability is therefore a basic factor affecting the quality of the results. Any diurnal tilt at the site can be expected to directly affect the results of the tidal analysis if the instrument were not operating at its minimum sensitivity to tilting.

From our experience, it is observed that the levelling stability of the Geodynamics instruments is better than that of the La Coste-Romberg meters. This is probably due to the size and the weight of the former.

As a consequence the sensitivity of the Geodynamics instruments is more stable.

At Alice Springs this instrument has experienced a regular drift of about 0.5 milligal per year.

Phase correction

The Gravimeter Geodynamics 84 was represented by a rheological model where the phase lags for the basic tidal frequencies of O_1 and M_2 were corrected by the addition of

$$+ 0°73 \text{ at } O_1 \text{ frequency}$$
$$+ 0°76 \text{ at } M_2 \text{ frequency}$$

(Ducarme 1975) which results in a relative correction of the amplitudes by a factor 1.0097 to be applied to the semi-diurnal waves.

3 - THE RESULTS OF ANALYSIS

The analysis of the data has been performed according to three methods

I. The now classical procedure of Venedikov (1966) which is a least squares analysis applied to the band pass filtered data, separately for diurnal, semi-diurnal and ter-diurnal components.

II. The new procedure introduced by Venedikov (1979) which is also a least squares procedure but here applied after application of new band pass filters the results of which are automatically weighed according to the internal errors.
The results obtained from the whole set of data are given on Table II which reproduces the computer output.

III. A spectral analysis of the one year uninterrupted set of data obtained in 1978.

IV. Spectral analysis has also been applied to the residuals obtained by subtracting from the observed curve a curve reconstructed by using the tidal parameters given in the Table II.
Besides expected peaks around 24 hours, the power spectrum exhibits small peaks around 4 hours period but nothing at 6, 8 or 12 hours.

The power spectrum represented on Fig.4 still exhibits small peaks at K_1 and S_2 periods.

The Table II allows to compare the results for the whole set of data (17172 hourly readings) and for an uninterrupted 352 days interval covering the year 1978 alone (8448 hourly readings) which we trust more because of maintenance problems.

4 - THE EFFECT OF ATMOSPHERIC PRESSURE.

Measurements of the atmospheric pressure were obtained from the Australian Meteorological Service, Melbourne for every three hours.

To analyse these data in the same way as the gravity tide, we firstly interpolated by a polynomial fitting to obtain a value at every hour. From this, evidently, results the impossibility to extract components of a frequency higher than the Nyquist frequency i.e. 6 hours.

The atmospheric pressure curve is extremely regular at Alice Springs and exhibits a clear semi-diurnal tidal component. It was treated by spectral analysis as well as by the Venedikov method (Table VI). Peaks are clearly visible at 24h (S_1), 12h (S_2) and 8h (S_3).

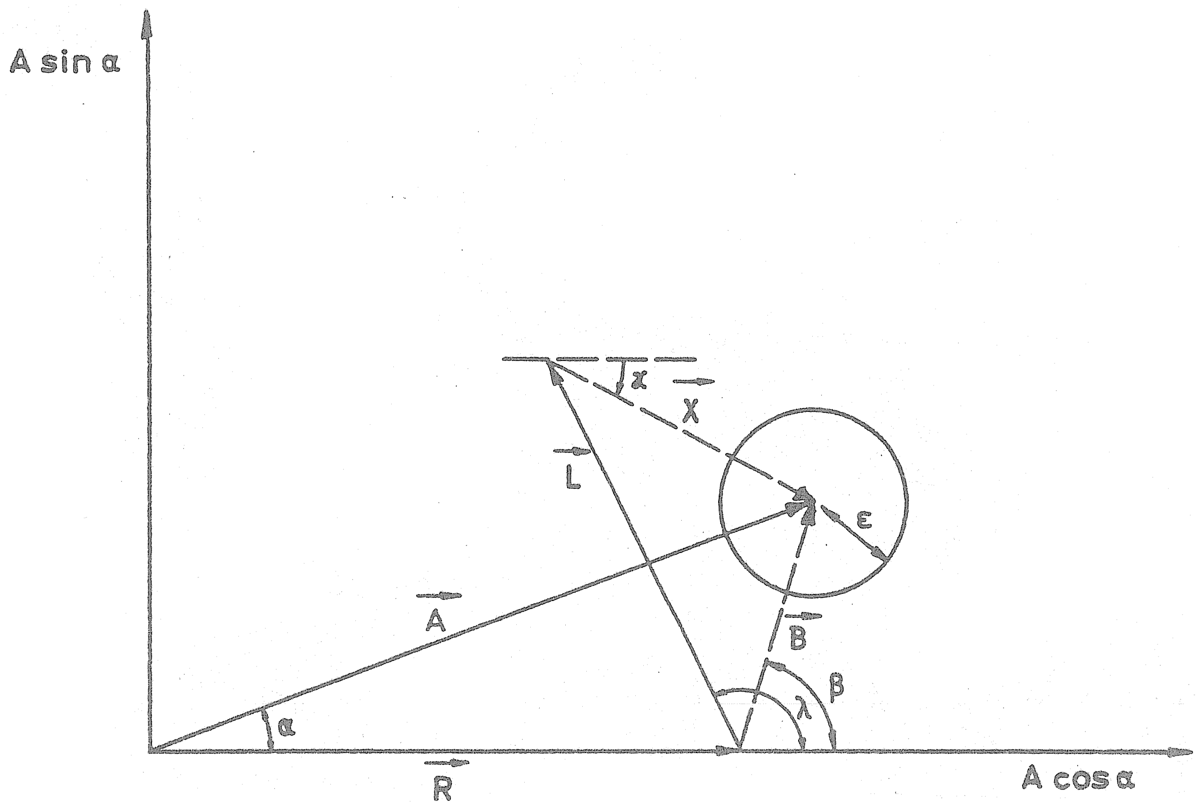

Figure 2 - Errors Vector $\vec{X}$

For the semi-diurnal wave M_2, the correct scale of this figure should be on the order of

$R \sim A \sim 40$ (Europe) to 90 (Equator) μgals,

$\alpha \sim 0°$ to $\pm 5°$

$L \sim B \sim 2$ (Europe) to 10 (South Pacific) μgals,

$X \sim 0.5$ to 5 μgal

$\varepsilon \sim 0.5$ μgal, (Europe) to 1 μgal (Equatorial zone)

$\vec{B} = \vec{A} - \vec{R}$; $\quad \vec{B} - \vec{L} = \vec{X}$

TABLE II

COMPARISON OF ANALYSIS PERFORMED ON DIFFERENT SETS OF DATA

Analysis	made on	D.	NR	O_1 δ	O_1 α	O_1 B	O_1 β	M_2 δ	M_2 α	M_2 B	M_2 β
78 01 13 - 79 01 04	79/7/26	358	8352	1.1722	0.97°	0.54	-123°	1.1686	-0.38°	0.72	-43°
76 09 03 - 79 01 04	79/7/26	855	12528	1.1715	0.82°	0.47	-126°	1.1684	-0.40°	0.73	-45°
76 09 03 - 77 05 27	79/7/26	268	4176	1.1727	0.45°	0.37	-146°	1.1668	-0.43°	0.69	-52°
76 02 21 - 79 01 04	79/2/7	1060	14688	1.1747	1.01°	0.59	-126°	1.1746	-0.36°	1.02	-27°
78 01 13 - 78 12 29	80/9/9	352	8448	1.1716	1.06°	0.57	-119°	1.1693	-0.40°	0.77	-42°
corrected for atmospheric pressure				1.1719	1.08°	0.58	-119°	1.1688	-0.40°	0.75	-43°
Oceanic Attraction and Loading Effect according to Schwiderski maps						0.54	-122°			0.54	-79°

D : number of days.

NR : number of hourly readings.

TABLE III

TRANS WORLD PROFILE AUSTRALIA STATION ALICE SPRINGS
STATION 4209 ALICE SPRINGS VERTICAL COMPONENT NORTH.TERR.-AUSTRALIA

23 42 36 S 133 50 06 E H 590 M P 10 M D 1000 KM
IGSN71 978640.
SHALLOW TUNNEL INTO HILL, PRECAMBRIAN SCHISTS AND GNEISSES
BUREAU OF MINERAL RESOURCES, CANBERRA
GRAVIMETER GEODYNAMICS 084 P.MELCHIOR TRANS WORLD PROFILES
CALIBRATION BRUXELLES - FUNDAMENTAL STATION
INSTALLATION J.VAN SON
MAINTENANCE P.TAYLOR
GRANT AFOSR-73-2557 A PROJECT-TASK 8607-02

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
COMPUTER UNIVAC 1100/40 PROCESSED ON 80/11/17

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR 1.18255
PHASE LAG O1 .73 M2 .76 O1/M2 .96
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00976 /MODEL 2/

G 84 78 113/781229

TIME INTERVAL 352.0 DAYS 8448 READINGS 1 BLOKS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
115.-11X.	11	SIGMQ1	.23	.05	1.3680	.3147	-10.43	13.15	.05	126.9
124.-126.	10	2Q1	.72	.05	1.2367	.0875	1.72	4.05	.05	-154.1
127.-129.	11	SIGMA1	.77	.05	1.0972	.0723	-.76	3.77	.04	13.2
133.-136.	20	Q1	5.16	.05	1.1787	.0111	2.19	.54	.21	-112.1
137.-139.	10	RO1	1.00	.05	1.2079	.0546	5.99	2.59	.11	-108.3
143.-145.	16	O1	26.78	.05	1.1716	.0021	1.06	.10	.57	-119.0
146.-149.	10	TAU1	.36	.03	1.2192	.1047	-.51	4.92	.02	169.8
152.-155.	15	NO1	2.07	.05	1.1522	.0301	1.04	1.50	.04	-72.3
156.-158.	7	KI1	.33	.05	.9594	.1372	3.10	8.19	.07	-14.5
161.-162.	3	PI1	.74	.04	1.1809	.0599	-3.99	2.90	.05	105.4
163.-163.	7	P1	12.36	.04	1.1619	.0035	1.32	.17	.30	-106.5
164.-164.	3	S1	.72	.05	2.8385	.2061	36.57	4.18	.51	-123.7
165.-165.	11	K1	37.06	.04	1.1528	.0013	1.00	.07	.80	-126.8
166.-166.	2	PSI1	.31	.04	1.2217	.1497	-.27	7.02	.01	16.7
167.-168.	7	PHI1	.50	.04	1.0971	.0830	.35	4.33	.04	-5.0
172.-174.	8	TETA1	.40	.04	1.1718	.1300	-.58	6.36	.01	130.9
175.-177.	14	J1	2.05	.05	1.1407	.0258	1.26	1.30	.06	-50.1
181.-183.	7	SO1	.39	.05	1.3187	.1679	-1.24	7.30	.05	169.7
184.-186.	11	OO1	1.02	.09	1.0377	.0958	3.71	5.29	.14	-28.2
191.-195.	14	NU1	.23	.08	1.1964	.4501	-11.29	21.58	.04	93.2
215.-22X.	19	EPS2	.57	.04	1.2370	.0887	-2.11	4.14	.04	-31.0
233.-236.	10	2N2	1.94	.04	1.2194	.0245	-.63	1.16	.10	-12.8
237.-23X.	10	MU2	2.31	.04	1.2028	.0218	-1.01	1.04	.09	-26.4
243.-245.	13	N2	14.15	.04	1.1751	.0033	-.32	.16	.20	-24.0
246.-248.	11	NU2	2.66	.04	1.1614	.0179	.80	.89	.04	85.8
252.-258.	26	M2	73.55	.04	1.1693	.0006	-.40	.03	.77	-41.9
262.-264.	5	LAMB2	.56	.04	1.1959	.0839	3.14	4.05	.03	62.6
265.-265.	9	L2	2.19	.04	1.2312	.0249	.72	1.17	.13	12.3
267.-272.	5	T2	1.90	.04	1.1050	.0234	-2.78	1.22	.13	-136.5
273.-273.	4	S2	33.96	.04	1.1603	.0014	.70	.07	.41	89.6
274.-277.	12	K2	9.10	.05	1.1423	.0068	.08	.34	.14	174.8
282.-285.	15	ETA2	.60	.06	1.3566	.1337	3.19	5.69	.09	21.2
292.-295.	11	2K2	.13	.09	1.0928	.7969	-71.13	42.06	.15	-128.0
335.-347.	5	MO3	.33	.01	1.0564	.0402	-1.28	2.20	.01	-115.3
353.-375.	11	M3	1.24	.01	1.0988	.0107	-.85	.56	.04	-27.4

STANDARD DEVIATION D 2.20 SD 2.35 TD .70 MICROGAL
O1/K1 1.0163 1-O1/1-K1 1.1231 M2/O1 .9980
CENTRAL EPOCH TJJ= 2443696.0

TABLE IV

TRANS WORLD PROFILE   AUSTRALIA   STATION ALICE SPRINGS
STATION 4209 ALICE SPRINGS   VERTICAL COMPONENT   NORTH.TERR.-AUSTRALIA

23 42 36 S   133 50 06 E   H 590 M   P 10 M   D 1000 KM
IGSN71   978640.
SHALLOW TUNNEL INTO HILL, PRECAMBRIAN SCHISTS AND GNEISSES
BUREAU OF MINERAL RESOURCES, CANBERRA
GRAVIMETER GEODYNAMICS 084   P.MELCHIOR   TRANS WORLD PROFILES
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COMPUTER   UNIVAC 1100/40   PROCESSED ON 80/11/17

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR   1.18255
PHASE LAG   O1   .73   M2   .76   O1/M2   .96
CORRECTION FOR DIFFERENTIAL ATTENUATION   M2/O1 1.00976   /MODEL 2/
CORRECTED FOR ATMOSPHERIC PRESSURE   ADMITTANCE -0.29 MICROGAL / MILLIBAR

G 84 78 113/781229

TIME INTERVAL   352.0 DAYS   8448 READINGS   1 BLOKS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
115.-11X.	11	SIGMQ1	.23	.05	1.3603	.3041	-12.15	12.78	.06	120.7
124.-126.	10	2Q1	.71	.05	1.2261	.0845	-1.01	3.94	.04	162.0
127.-129.	11	SIGMA1	.76	.05	1.0877	.0699	-1.03	3.68	.05	15.1
133.-136.	20	Q1	5.16	.05	1.1801	.0108	2.36	.52	.23	-112.0
137.-139.	10	RO1	1.01	.04	1.2144	.0528	6.43	2.49	.12	-109.2
143.-145.	16	O1	26.79	.05	1.1719	.0020	1.08	.10	.58	-119.3
146.-149.	10	TAU1	.36	.03	1.2166	.1012	-2.67	4.76	.02	134.7
152.-155.	15	NO1	2.06	.05	1.1469	.0291	1.40	1.45	.05	-66.5
156.-158.	7	KI1	.34	.05	.9975	.1326	4.44	7.61	.06	-25.2
161.-162.	3	PI1	.74	.04	1.1877	.0579	-2.96	2.79	.04	116.7
163.-163.	7	P1	12.37	.04	1.1627	.0034	1.15	.17	.27	-110.7
164.-164.	3	S1	.39	.05	1.5391	.1986	-13.97	7.46	.13	132.8
165.-165.	11	K1	37.00	.04	1.1511	.0013	.85	.06	.70	-128.0
166.-166.	2	PSI1	.31	.04	1.2082	.1447	9.36	6.86	.05	-76.0
167.-168.	7	PHI1	.51	.04	1.1076	.0802	.41	4.14	.03	-6.8
172.-174.	8	TETA1	.41	.04	1.1921	.1256	1.10	6.04	.01	-143.1
175.-177.	14	J1	2.05	.04	1.1421	.0249	.71	1.25	.04	-36.4
181.-183.	7	SO1	.37	.05	1.2260	.1622	-.07	7.59	.02	178.7
184.-186.	11	OO1	1.04	.09	1.0577	.0926	3.84	5.02	.12	-33.9
191.-195.	14	NU1	.21	.08	1.1341	.4350	-12.09	22.00	.05	77.8
215.-22X.	19	EPS2	.58	.04	1.2419	.0871	-1.72	4.05	.04	-24.6
233.-236.	10	2N2	1.95	.04	1.2204	.0241	-.59	1.14	.10	-11.7
237.-23X.	10	MU2	2.31	.04	1.1992	.0214	-.92	1.03	.08	-26.3
243.-245.	13	N2	14.14	.04	1.1744	.0032	-.29	.16	.19	-23.3
246.-248.	11	NU2	2.67	.04	1.1675	.0176	.69	.87	.04	62.6
252.-258.	26	M2	73.53	.04	1.1688	.0006	-.40	.03	.75	-43.1
262.-264.	5	LAMB2	.55	.04	1.1819	.0824	2.57	4.02	.03	68.7
265.-265.	9	L2	2.19	.04	1.2310	.0244	.41	1.15	.13	7.1
267.-272.	5	T2	1.88	.04	1.0945	.0230	-2.12	1.21	.13	-148.6
273.-273.	4	S2	33.86	.04	1.1568	.0014	.15	.07	.13	136.8
274.-277.	12	K2	9.08	.05	1.1401	.0066	-.13	.34	.16	-172.6
282.-285.	15	ETA2	.61	.06	1.3675	.1313	3.89	5.54	.10	24.5
292.-295.	11	2K2	.12	.09	1.0493	.7828	-63.53	43.02	.14	-126.4
335.-347.	5	MO3	.33	.01	1.0613	.0401	-1.31	2.18	.01	-104.5
353.-375.	11	M3	1.24	.01	1.0980	.0107	-.73	.56	.04	-24.7

STANDARD DEVIATION   D   2.13   SD   2.31   TD   .70 MICROGAL
O1/K1 1.0181   1-O1/1-K1 1.1379   M2/O1   .9973
CENTRAL EPOCH TJJ= 2443696.0

The amplitudes and phases at the frequencies corresponding to the main tides are given in the Table V.

An analysis of other pressure data of Alice Springs had been made by Haurwitz (1969) who obtained for the M2 frequency :

$$\Delta P\ (M2) = 38.2\ \mu bar \quad \omega = -25.9°$$

while our result is

$$\Delta P\ (M2) = 37.7\ \mu bar \quad \omega = -36.8°$$

After several tentative corrections of the gravity tide from this effect, an admittance factor of 0.00029 microgal per microbar was adopted. The result of this correction on the solar waves is given in the Tables V and VI.

We observe that the spurious S_1 component in the gravity tide is reduced by 45 % while its phase changes from 36° to -14°.

The S_2 wave has its phase reduced from 0.70° to 0.15° (± 0.07°) that is non significantly different from zero.

Finally the ψ_1 wave amplitude factor slightly decreases from 1.22 to 1.21 which may be considered as satisfactory (nothwithstanding it must be taken with caution).

The effect upon lunar waves, if any, is well below the level of precision of our measurements as no lunar wave has an amplitude of more than 40 ubars in the barometric pressure variations, that is the noise level.

The atmospheric pressure has a considerable effect upon the drift of the instrument as may be seen on the figure 3 where the curve (1) represents the observed drift as obtained by subtracting the tidal components of the Table III from the rough data while the curve (2) has been obtained by subtracting the same tidal components from the data corrected for barometric effects.

The purely instrumental drift thus looks almost linear. Its value was -1.851 µgal per day, the total amount reaching some 0.55 milligal over the whole 1978 year.

5. OCEANIC ATTRACTION AND LOADING EFFECTS.

The oceanic effects obviously do not vanish at Alice Springs as may be seen from the results of our harmonic analysis as well as from the attraction and load calculated on the basis of the different available cotidal maps.

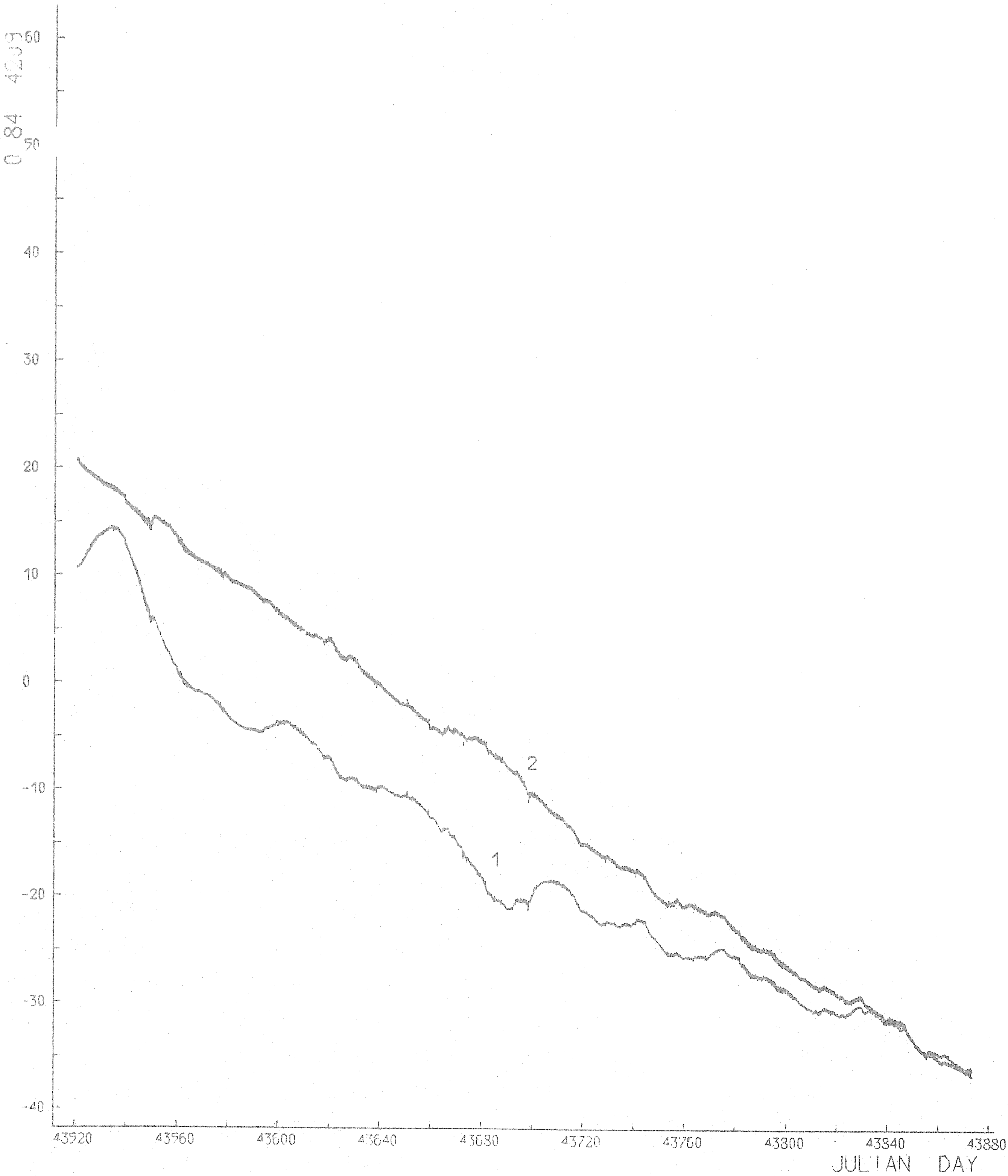

Figure 3 - <u>Drift</u>
Curve (1) Observed gravity tide minus calculated tide (Table III)
Curve (2) The same after elimination of atmospheric pressure effect from initial hourly readings with an admittance of -0.29 µgal/millibar

initial epoch: 1978.01.12   final epoch: 1978.12.30

scale : 1 unit in ordinates is 10 microgals

TABLE V - EFFECT OF ATMOSPHERIC PRESSURE CORRECTION

Wave	Gravity Tide				Barometric pressure		Corrected gravity tide			
	Δg	α	δ	|R|	Δg	$\overline{\omega}$	Δg	α	δ	|R|
P_1	12.36	1.32°	1.1619	0.30	132	250.46°	12.37	1.15°	1.1627	0.27
K_1	37.06	1.00°	1.1528	0.80	150	259.70°	37.00	0.85°	1.1511	0.70
ψ_1	0.31	-0.27°	1.2217	0.01	66	119.65°	0.31	9.36°	1.2082	0.05
S_1	0.72	36.57°	2.8385	0.51	1750	250.78°	0.39	-13.97°	1.5391	0.13
T_2	1.90	-2.78°	1.1050	0.13	67	135.79°	1.88	-2.12°	1.0945	0.13
S_2	33.96	0.70°	1.1603	0.41	913	253.96°	33.86	0.15°	1.1568	0.13

Δg in microgals, ΔP in microbars. admittance : 1 microbar → 0.00029 microgal
α and ω in degrees (positive for a phase advance).

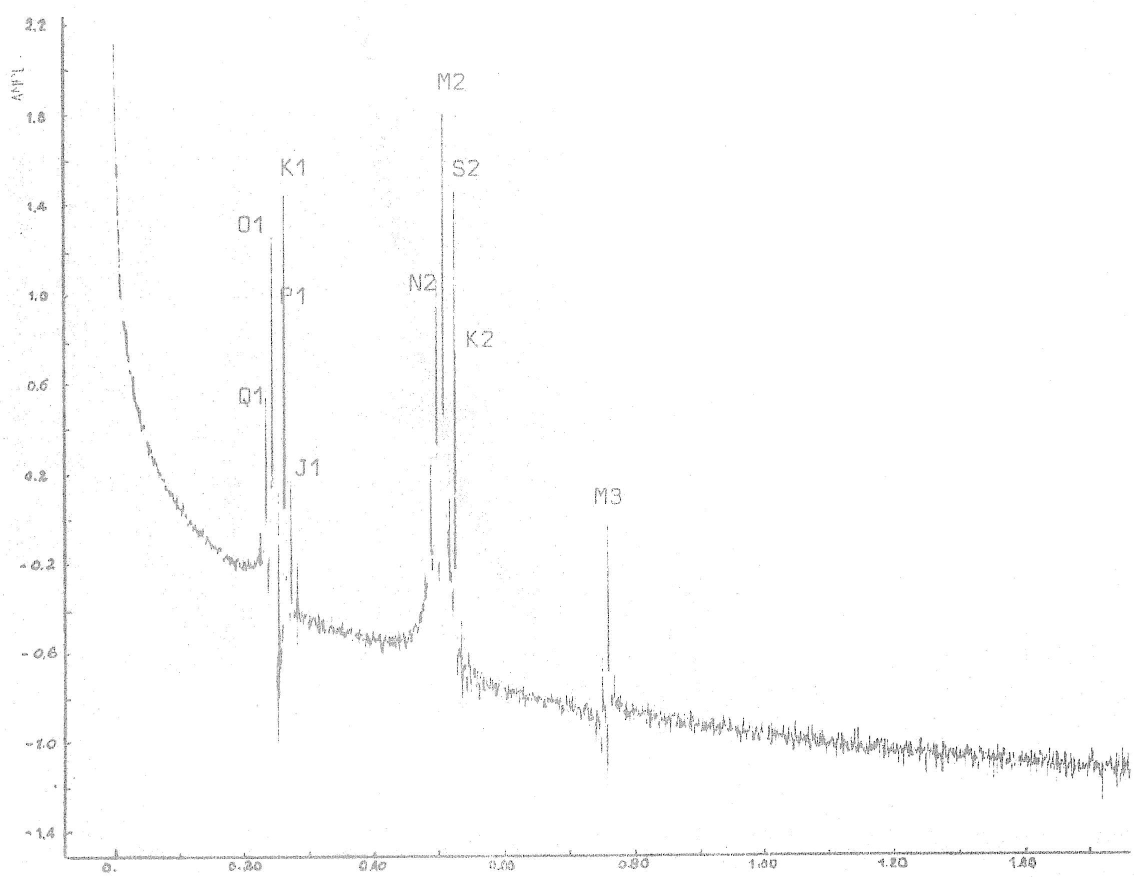

Figure 4 - Power spectrum of 1978 continuous series.

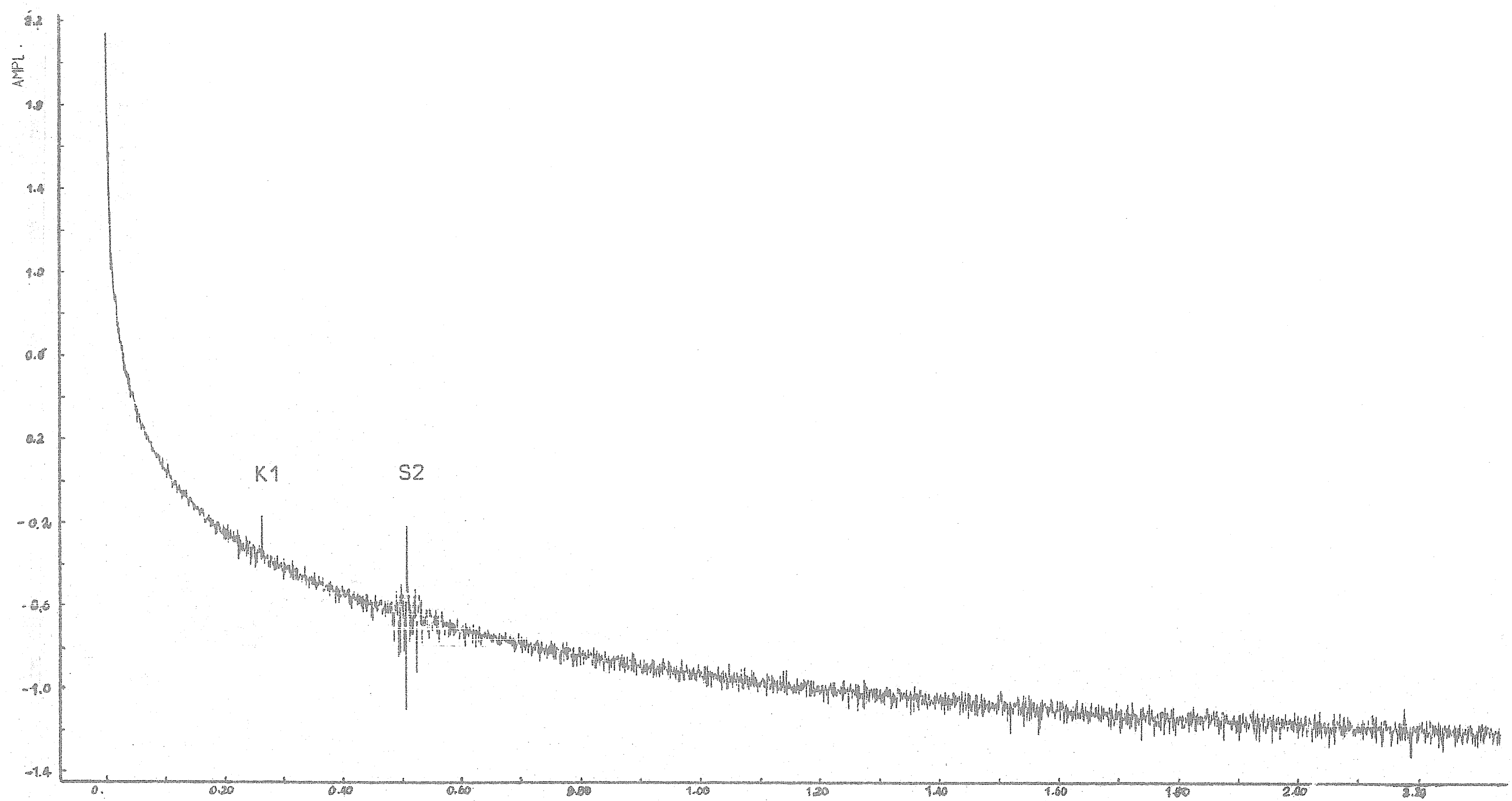

Figure 5 - Power spectrum of the residuals (observed - calculated - atmospheric pressure effect) for the 1978 continuous series.

TABLE VI

TIDAL WAVE M_2

Observed residue :			*0.75*	*-43°*
calculated residue :				
Map :	Schwiderski	1° x 1°	*0.54*	*-79°*
	Bogdanov	5° x 5°	1.47	87°
	Hendershott	6° x 6°	2.75	4°
	Parke	6° x 6°	0.14	-99°
	Parke (1979)	6° x 6°	*0.56*	*-55°*
	Zahel	1° x 1°	1.65	- 2°
	Zahel	4° x 4°	2.98	85°

	132	133	134	135	136	137	138	139	140	141	142	143	144
22	0.25	0.18	0.14	0.14	0.19	0.25	0.33	0.41	0.49	0.57	0.66	0.75	0.85
23	0.25	0.18	0.13	0.12	0.17	0.23	0.31	0.39	0.47	0.56	0.66	0.76	0.86
24	0.25	0.18	0.12	[illegible]	0.14	0.21	0.29	0.37	0.46	0.55	0.66	0.76	0.88
25	0.26	0.19	0.12	0.09	0.11	0.18	0.26	0.35	0.44	0.54	0.65	0.78	0.91
26	0.28	0.21	0.14	0.08	0.08	0.14	0.23	0.32	0.42	0.53	0.65	0.79	0.94
27	0.31	0.24	0.17	0.10	0.05	0.09	0.18	[illegible]	0.39	0.51	0.64	0.80	0.98
28	0.36	0.30	0.23	0.15	0.07	0.03	0.11	0.22	0.34	0.47	0.62	0.80	1.00
29	0.46	0.40	[illegible]	[illegible]	0.17	0.08	0.03	0.14	0.27	0.42	0.59	0.78	1.01
30	0.61	0.55	0.48	0.40	0.32	0.24	0.15	0.06	0.16	0.33	0.53	0.75	1.00
31	0.88	0.81	0.71	0.62	0.56	0.52	0.44	[illegible]	0.10	0.21	0.45	0.70	0.97
32	1.48	1.32	1.07	0.93	0.94	1.08	1.11	0.82	0.39	0.28	0.33	0.63	0.93

	λ	φ	L	β
AS: ALICE SPRINGS	133 51	-23 43	0.72	-43°
BH: BROKEN HILL	141 28	-31 56	0.17	-116°

Figure 6: M2 Ocean Loading amphidromic area in Australia according to the Parke cotidal map.

TABLE VII

COMPARISON OF OBSERVED AND
CALCULATED RESIDUES FOR THE SIX MAIN WAVES

Tidal wave	Observed		Calculated with: Schwiderski maps		Calculated with: Others		
M_2	0.75	- 43°	0.54	- 79°	see Table VII		
N_2	0.19	- 23°	0.09	0°			
S_2	0.13	137°	0.27	159°	0.80	143°	(Parke)
O_1	0.58	-119°	0.53	-122°	0.45	162°	(Bogdanov)
P_1	0.27	-111°	0.18	-133°			
K_1	0.70	-128°	0.55	-121°	0.41	-109°	(Parke)

The geographical position of Alice Springs makes the effects of the coastal sea tides totally negligeable. This station consequently can be considered as a strategic test station for the validity of the proposed world cotidal maps.

From the Tables VI and VII there is no doubt that the six Schwiderski maps are of high quality although a problem remains for M_2, the vectorial difference (O-C) leaving indeed an end residue of 0.45 μgal with a 2° phase which is surely larger than the instrumental error.

However the 1979 M_2 Parke map gives a better result as the (O-C) difference reaches only 0.23 μgal (phase -13°). One will also observes that the S_2 and K_1 Parke maps give a fair agreement in the phases but not as good in the amplitudes.

All other maps obviously fail to correctly represent the observed phenomena.

A similar conclusion was reached by Melchior et al (1980) for a large number of european and east african stations (particularly Antananarivo, Madagascar) as well as Kerguelen.

The question may be raised if there is an amphidromic point for oceanic attraction and loading somewhere in Australia, other than Alice Springs. A comparison with the results obtained at other places on this continent, Perth, Darwin, Charters Towers, Broken Hill, Armidale and Canberra (see Melchior et al. 1980) suggests that such a point could exist between Alice Springs and Broken Hill a station where the observed residue amplitude is indeed below the instrumental error.

The Parke map indicates that such a point could exist indeed with the coordinates $\phi = -28°30'$, $\lambda = 137°30'$ (fig. 3) but the Schwiderski map do not how anything but a uniform residue of 0.5 μgal over a broad area covering Alice Springs as well as Broken Hill.

6. Liquid core effects.

Considering that the results of the 1978 series when corrected for atmospheric pressure are the most attendible, we have applied to them the oceanic attraction and load corrections calculated with the three diurnal Schwiderski cotidal maps. This gives the following results:

O_1	$\delta = 1.1597$	$\alpha = 0.01°$	$X = 0.01$	$(\chi = -165°)$
P_1	$\delta = 1.1491$	$\alpha = 0.71°$	$X = 0.16$	$(\chi = -72°)$
K_1	$\delta = 1.1445$	$\alpha = 0.44°$	$X = 0.36$	$(\chi = -128°)$

The vector $\vec{X}(X,\chi)$ being the final unexplained residual. Considering its very small amplitude, its phase is obviously meaningless except perhaps in the case of K_1 which still may be taken as significative and may be suspected to be from thermic origin.

The Table VIII offers a comparison of our results with other experimental data and with six theoretical models, including the recent one of Wahr (elliptic rotating earth) (1979).

It must be clear that the standard deviation of the individual readings being of 3 μgals in the diurnal band, there is not much hope to obtain a significative determination for diurnal waves having an amplitude less than one microgal.

Despite this, the result obtained for the ψ_1 wave is in agreement with expected effects from the liquid core. It is evident that to make progress on this very important aspect of tidal research, other instruments must be used now. The only one having a decisively much lower noise level is presently the supraconducting gravity meter.

TABLE VIII

	Theoretical Models					W	Experimental results Melchior		Alice Springs results			
	MI β 0.0	MII β 0.0	PYS-M β -0.2	PYS-M β 0.0	PYS-M β +0.2		1977	1979 (10 séries (*))	1976-78	1978(X)	m.s.e.	corrected with Schwiderski maps
Q1	1.160	1.165	1.161	1.160	1.160	1.152	1.160 ± 0.018	1.153 ± 0.011	1.195	1.180	0.011	-
O1	1.160	1.164	1.161	1.160	1.159	1.152	1.161 ± 0.009	1.157 ± 0.006	1.172	1.1719	0.0020	1.1597
P1	1.153	1.158	1.155	1.154	1.153	1.147	1.150 ± 0.021	1.160 ± 0.009	1.161	1.1627	0.0034	1.1491
K1	1.137	1.151	1.138	1.138	1.137	1.132	1.144 ± 0.015	1.147 ± 0.009	1.151	1.1511	0.0013	1.1437
ψ1	1.242	1.246	1.243	1.244	1.246	1.235	———	1.261 ± 0.157	1.153	1.208	0.145	-
φ1	1.174	1.178	1.176	1.175	1.174	1.167	1.175 ± 0.092	1.189 ± 0.119	1.273	1.108	0.080	-
J1	1.161	1.166	1.163	1.162	1.161	1.155			1.172	1.142	0.025	-
OO1	1.161	1.165	1.162	1.161	1.159	1.154	1.162 ± 0.024	1.159 ± 0.047	1.268	1.058	0.093	-
							external errors				internal errors	

(*) includes Alice Springs

(X) corrected for atmospheric pressure effects

MI Molodensky, model I

MII Molodensky, model II

PYS-M Po Yu Shen - Mansinha (1976)

W Wahr (1979) (result accurate to better than one percent)

$$\beta = \frac{\lambda \rho_o'}{\rho_o^2 W_o} - 1,$$ $\beta < 0$: unstable core, $\beta > 0$ stable core

$\beta = 0$: neutral core (Adams Williamson core).

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Traduction

INFLUENCE DES HETEROGENEITES LOCALES DE L'ECORCE ET DU MANTEAU SUPERIEUR SUR LES INCLINAISONS DE MAREES DE LA SURFACE DE LA TERRE

S.M. Molodenskii

Rotation et déformation de marées de la Terre - vol.13, pp 10 - 13, 1981.

Une théorie générale des marées de la pesanteur et des inclinaisons à la surface d'une Terre faiblement aplatie, non symétrique, est proposée dans les travaux [1-2]. En [3] est donné le calcul numérique qui permet d'estimer l'influence d'hétérogénéités horizontales arbitraires du manteau, représentées par une décomposition en fonctions sphériques jusqu'au 47ème ordre, sur les marées radiales, du potentiel de gravitation, de l'accélération de la pesanteur et des inclinaisons de la surface de la Terre.

On y a montré aussi que les corrections dues à l'influence des hétérogénéités horizontales à grande échelle du manteau sur les valeurs des facteurs gravimétrique δ et clinométrique γ sont du premier ordre. Comme la précision actuelle de la mesure du facteur clinométrique est à peu près 5 fois plus faible que la précision de la mesure du facteur δ, les observations clinométriques ne permettent pas jusqu'à présent d'obtenir une information sur les hétérogénéités à grande échelle du manteau.

Mais en même temps, les valeurs de γ renferment évidemment des traces sensiblement plus importantes des hétérogénéités locales du manteau supérieur que les valeurs de δ. Pour s'en assurer il suffit de tenir compte de ce que les variations de marée de la pesanteur sont proportionnelles aux déplacements verticaux de la surface (la variation du potentiel de gravitation joue un rôle peu important [4]) et les variations des inclinaisons au gradient du déplacement vertical. Pour cette raison l'influence des hétérogénéités de faible étendue du manteau sur les valeurs de δ est négligeable alors que leur influence sur γ peut être importante.

Les hétérogénéités à petite échelle du manteau inférieur ne peuvent exercer une influence importante sur les valeurs de γ puisque les coefficients de la décomposition des mouvements verticaux de la surface en fonctions sphériques suivant la profondeur ont en facteur exp $(-n\ell/a)$ [1] où n est l'ordre de la fonction sphérique; a le rayon de la Terre et ℓ la profondeur de la couche hétérogène. C'est pourquoi seules les hétérogénéités du manteau supérieur se trouvant dans la couche d'une épaisseur effective

$$\ell_o \sim \frac{a}{n} \tag{1}$$

influencent γ.

Pour une courte longueur d'onde des hétérogénéités du manteau on peut négliger l'influence de l'autogravitation et de la sphéricité de la Terre sur les déformations élastiques en surface. On peut également négliger la variation des modules élastiques λ et μ avec la profondeur dans la couche même (1) et supposer que dans une approximation nulle $\lambda = \lambda_o$, $\mu = \mu_o$, $\rho = \rho_o$ sont les constantes. Dans l'approximation suivante nous poserons

$$\begin{aligned} \lambda(x_1, x_2, x_3) &= \lambda_0 + \delta\lambda(x_1, x_2, x_3); \\ \mu(x_1, x_2, x_3) &= \mu_0 + \delta\mu(x_1, x_2, x_3), \end{aligned} \tag{2}$$

où $\delta\lambda << \lambda_o$ et $\delta\mu << \mu_o$ sont les corrections aux valeurs λ_o et μ_o qui tiennent compte de la présence des hétérogénéités horizontales et x_1 et x_2 sont les axes de coordonnées cartésiennes dans le plan de la surface de la Terre. Dans la suite nous supposerons que l'origine des coordonnées $x_1 = x_2 = x_3 = 0$ correspond avec le point auquel on fait les observations clinométriques et que l'axe x_3 est orienté vers l'intérieur de la Terre.

Nous écrirons la correction à la valeur de l'inclinaison de marée dans la direction n sous la forme $t_n\big|_{x_1=x_2=x_3=0} = (n, \text{grad } H)$ où H est la correction à la valeur totale des déplacements verticaux de marées de la surface au point $x_1 = x_2 = x_3 = 0$.

A l'aide du rapport (10) tiré de [1] il est facile de démontrer que dans l'approximation envisagée

$$H = -\frac{1}{p} \iiint_V \left\{ d\lambda \operatorname{div} u^0 \operatorname{div} \tilde{u} + \delta\mu \frac{\partial \tilde{u}_i}{\partial x_k} \left(\frac{\partial u_i^0}{\partial x_k} + \frac{\partial u_k^0}{\partial x_i} \right) \right\} dv , \tag{3}$$

où u^o est la valeur connue des déplacements de marées dans l'approximation nulle (pour $\delta\lambda = \delta\mu = 0$) et $\tilde{u}$ est la solution de Boussinesq [5] décrivant les déplacements élastiques provenant de l'effet suivant la normale à la surface de la pression p appliquée au point de coordonnées $x_1 = x_2 = x_3 = 0$:

$$u_1 = \frac{P}{4\pi\mu_0}\,\frac{zx}{r^3} - \frac{P}{4\pi(\lambda_0+\mu_0)}\,\frac{x}{r(z+r)},$$

$$u_2 = \frac{P}{4\pi\mu_0}\,\frac{zy}{r^3} - \frac{P}{4\pi(\lambda_0+\mu_0)}\,\frac{y}{r(z+r)}, \qquad (4)$$

$$u_3 = \frac{P}{4\pi\mu_0}\,\frac{z^2}{r^3} + \frac{P(\lambda_0+2\mu_0)}{4\pi\mu_0(\lambda_0+\mu_0)r},$$

où, $r = (x^2 + y^2 + z^2)^{1/2}$. Les indices i et k prennent les valeurs de 1 à 3 et on somme sur les indices répétés.

Puisque nous supposons que les dimensions linéaires de la région V sont suffisamment petites vis à vis de la longueur d'onde de la marée non perturbée, les valeurs de div u° et $e_{ik} = \partial u_i^{\circ}/\partial x_k + \partial u^{\circ}_k/\partial x_i$ dans la région de V peuvent être considérées comme indépendantes des coordonnées et on peut les porter sous l'intégrale.

En utilisant les expressions (4) il est facile de calculer les composantes du tenseur des déformations $\tilde{e}_{ik}$ et div $\tilde{u}$. Pour div $\tilde{u}$ nous obtiendrons l'expression

$$\operatorname{div}\tilde{u} = -\frac{P}{2\pi(\lambda_0+\mu_0)}\,\frac{z}{r^3}. \qquad (5)$$

Après avoir substitué (5) en (3) nous obtiendrons l'expression générale pour H dans le cas d'une répartition horizontalement hétérogène arbitraire dans l'enveloppe du module λ

$$H(\delta\lambda)\Big|_{x_1=x_2=0} = \frac{\operatorname{div} u^{\circ}\big|_{x_1=x_2=x_3=0}}{2\pi(\lambda_0+\mu_0)} \iiint_V \delta\lambda\,\frac{x_3}{r^3}\,dV. \qquad (6)$$

Nous utilisons l'expression (6) pour obtenir une estimation simple de l'influence des hétérogénéités locales du module λ sur γ. Nous examinerons à titre d'exemple l'effet de l'hétérogénéité ayant pour configuration un parallélipipède rectangle du type suivant:

$$\delta\lambda = \delta\lambda_0\,\theta(x_3 - x_3^{(0)})\,(\theta(x_1 - x_1^{(1)}) - \theta(x_1 - x_1^{(2)}))(\theta(x_2 - x_2^{(1)}) - \theta(x_2 - x_2^{(2)}),$$

où

$$\theta(x) = \begin{cases} 0 \text{ pour } x \le 0, \\ 1 \text{ pour } x > 0 \end{cases}$$

(l'introduction de la limite inférieure du parallélipipède dans le résultat ne se fait pas fort sentir). Le vecteur n est pris comme étant dirigé le long de l'axe x_1. Alors nous obtiendrons

$$\delta t = \frac{\operatorname{div} u^{\circ}}{2\pi(\lambda_0+\mu_0)} \ln \frac{\left[\left(x_3^{(0)2} + x_1^{(2)2} + x_3^{(2)2}\right)^{1/2} + x_2^{(2)}\right]\left[\left(x_3^{(0)2} + x_1^{(1)2} + x_2^{(1)2}\right)^{1/2} + x_2^{(1)}\right]}{\left[\left(x_3^{(0)2} + x_1^{(2)2} + x_2^{(1)2}\right)^{1/2} + x_2^{(1)}\right]\left[\left(x_3^{(0)2} + x_1^{(1)2} + x_2^{(2)2}\right)^{1/2} + x_2^{(2)}\right]}. \qquad (7)$$

Dans certains cas cette intégrale peut diverger.

Ainsi pour $x_3^{(0)} = x_1^{(1)} = x_2^{(1)}$ (quand les mesures se font sur un des sommets du parallépipède)

$$|\delta| \to \infty \qquad \text{comme aussi} \qquad \ln(x_3^{(0)^2} + x_1^{(1)^2} + x_\ell^{(1)^2})$$

Si on rejette des cas particuliers semblables alors on peut affirmer qu'à cause de la variation très lente de la fonction $\ln x$ le facteur renfermant un logarithme dans l'expression (7) est toujours de l'ordre de l'unité.
C'est pourquoi

$$\delta t \sim \frac{div\ u^o}{2\pi} \frac{\delta\lambda}{\lambda_0 + 2\mu_0}. \qquad (8)$$

Sur la surface de la Terre:

$$div\ u^o \sim 0.5 \frac{V_o}{ga}$$

où V_o est la valeur du potentiel générateur des marées au point d'observation; $g = 980\ cm/s^2$ accélération de la pesanteur; $a = 6371$ Km, rayon de la Terre.
En comparant (8) avec la valeur non perturbée de l'inclinaison de marée

$$t_o = \frac{0.7}{g} \frac{\partial V_o}{\partial x_1}$$

On peut constater que les corrections à la valeur γ_n et au déphasage des variations de marées en l'inclinaison est d'un ordre

$$0.1 \frac{\delta\lambda}{\lambda_o + 2\mu_o}$$

C'est du même ordre aussi l'effet des hétérogénéités horizontales du module μ. Le calcul précis de l'intégrale (3) pour des répartitions arbitraires des paramètres $\delta\lambda$, $\delta\mu$ sont faciles à réaliser par la méthode numérique.

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STUDY OF GRAVITY TIDES IN SHANGHAI REGION

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ABSTRACT

The authors analyse and compare the observation data obtained with two gravimeters : Askania GS-15 N° 227 and CG-2 N° 317. They specially discuss the ocean loading effect and find that the Schwiderski Maps are very effective for the interpretation of the gravity tides in Shanghai region. The numerical values (O_1) and (M_2) before and after considering the loading effect are equal to 1.207 and 1.167, and 1.150 and 1.152 respectively.

We carried out tidal gravity observations for six months (from December 1980 to May 1981) by using the gravimeters Askania GS-15 N° 227 and CG-2 N° 317 installed at the Seismological Station of Shanghai. The over-burden thickness above the tunnel is about 40 m, and the length of the tunnel is about 120 m; the temperature fluctuation is less than 0.5°C a year.

In order to ensure that the astatic behaviour of gravimeter CG-2 does not influence the tidal output signal of the instrument, the range of displacement of the reference line in the field of vision on the microscope of the instrument is restricted between divisions -2.5 and +2.5 during the recording period, a range which corresponds to about 1200 μgals. The drift behaviour for this instrument is of positive tendency. When the line is close to the division +2.5, it is re-adjusted back to a place near the division -2.5, and a sensitivity calibration is carried out simultaneously.

Nakai fit and Venedikov filter are adopted for pre-process and harmonic analysis for the observed data. The analysis results for the six main tidal waves are presented in Tables 1 and 2, introducing the inertial corrections.

Table 1. δ,

Instr.	Epoch	O_1	K_1	N_2	M_2	S_2	M_3
CG-2 N° 317	1/XII.1980 10/V.1981	1.207 ±0.012	1.194 ±0.008	1.178 ±0.022	1.167 ±0.004	1.169 ±0.009	
GS-15 N° 227	1/X.1980 28/II.1981	1.207 ±0.005	1.178 ±0.003	1.156 ±0.005	1.152 ±0.001	1.144 ±0.002	1.06 ±0.05

Table 2. Δϕ,

Instr.	Epoch	O_1	K_1	N_2	M_2	S_2	M_3
CG-2 N° 317	1/XII.1980 10/V.1981	-0.92 ±1.05	-0.78 ±0.58	-2.49 ±1.89	-1.43 ±0.33	-2.02 ±0.72	
GS-15 N° 227	1/X.1980 28/II.1981	-0.37 ±0.23	-1.22 ±0.13	-2.61 ±0.25	-2.23 ±0.05	-0.96 ±0.10	2.78 ±2.53

The parameters of the rheological model for the gravimeters used here are given in the Table 3.

Table 3. Parameters of the rheological model

Instr.	$b(O_1)$	$b(M_2)$
CG-2 N° 317	-0°23	-0°28
GS-15 N° 227	-0.24	-0.48

The phase differences after considering rheological corrections for two main waves O_1 and M_2 are given in the Table 4.

Table 4. Phase differences

Instr.	(O_1)	(M_2)
CG-2 N° 317	-0.69	-1.15
GS-15 N° 227	-0.13	-1.75

The results for (O_1) and (M_2) show that the ocean loading effect is larger for O_1 than that for M_2 in Shanghaï region. The fact that $|\Delta\phi\ (M_2)| > |\Delta\phi\ (O_1)|$ indicates another behaviour of the ocean loading effect in Shanghaï region.

In addition, the values of $\delta(O_1) - \delta(K_1)$ indicate that our observations reflect the dynamical effect of the liquid core of the earth.

We introduce a "residual vector" $\vec{B}$ as follows :

$$\vec{B}_i\ (B,\beta) = \vec{H}_i\ (H,\Delta\phi) - \vec{R}_i\ (R,0)$$

where $\vec{H}_i$ is the observed vector corresponding to the tidal component considered, R_i the vectors of the elastic earth tides model and

$$R_i = \delta_{i,th} \cdot H_{i,th}$$

where the $H_{i,th}$ are the "theoretical" tidal amplitude calculated for a rigid earth model and the $\delta_{i,th}$ the "theoretical" tidal amplitude parameter, taking the deformation of an elastic Earth model with liquid core into account. We choose the Molodensky model I as reference i.e.

$$\delta_{i,th}\ (O_1) = \delta_{i,th}\ (M_2) = 1.160$$

Finally we solve for these vectors $\vec{B}$ as shown in Table 5.

Table 5. Residual vectors (B in microgals)

Instr.	O_1		M_2	
	B	β	B	β
CG-2 N° 317	1.35	-17°2	1.34	-73°9
GS-15 N° 227	1.29	- 3°3	1.99	-103°6

The corresponding ocean loading vectors $\vec{A}$ for the Shanghaï Station calculated by ICET with the Schwiderski Maps recommended by the Ninth International Symposium on Earth Tides as the "working standards" for the interpretation of Earth tide data are shown in Table 6.

Table 6. Loading vectors $\vec{A}$

Station	O_1		M_2	
	A	α	A	α
Shanghaï	1.23	- 10°	1.16	- 64°

The comparison of the numerical values of table 5 with those of table 6 shows that the vectors $\vec{B}$ and $\vec{A}$ are in agreement with each other very well for the gravimeter CG-2 N° 317. We now form a secondary vector $\vec{X}$ as follows :

$$\vec{X}\,(X,\chi) = \vec{B}\,(B,\beta) - \vec{A}\,(A,\alpha)$$

and obtain the numerical values for the Shanghaï Station as shown in Table 7.

Table 7. Secondary vectors $\vec{X}$

Instr.	O_1		M_2	
	X	χ	X	χ
CG-2 N° 317	0.20	-67°4	0.28	-119°1
GS-15 N° 227	0.16	60°1	1.33	-137°6

Finally we obtain the tidal parameters $\delta_{i,L}$ and phase differences $\Delta\phi_{i,L}$, after correction for the ocean loading effect, as shown in the Table 8.

Table 8. $\delta_{i,L}$ and $\Delta\phi_{i,L}$

Instr.	O_1		M_2	
	$\delta_{i,L}$	$\Delta\phi_{i,L}$	$\delta_{i,L}$	$\Delta\phi_{i,L}$
CG-2 N° 317	1.163	-0.33	1.158	-0.22
GS-15 N° 227	1.162	0.25	1.142	-0.81

By comparison of the numerical values of table 8 with the corresponding values of table 1, we can conclude that the tidal parameters δ_i and the phase differences $\Delta\phi_i$, corrected for the ocean loading effect calculated on Schwiderski Maps, can be improved very much for the Shanghaï Station. These numerical values also show that the data obtained with the gravimeter CG-2 N° 317 are better than those by Askania GS-15 N° 227 for the main waves O_1 and M_2. The first of these two instruments has principally two advantages : firstly, its elastic system is sealed in a vacuum, and the barometric effect is eliminated completly; and secondly, it has optical output signal and the influences of the statics are also avoided. Consequently the systematic error caused by atmospheric conditions for gravimeters CG-2 is certainly very much less than that for Askania GS-15, but the reading error of the gravimeter CG-2 is larger than that of the gravimeter Askania GS-15.

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GRAVITY TIDES MEASURED AT THE ZO SE STATION OF THE SHANGHAI ASTRONOMICAL OBSERVATORY

P. MELCHIOR HSU HOU TSE
M. VAN RUYMBEKE SONG XINGLI C. POITEVIN

In the frame of the cooperation between the Institute of Geodesy and Geophysics of the Chinese Academy of Sciences at Wuhan, the State Seismological Bureau of China and the Royal Observatory of Belgium a tidal gravity station has been established at Zo Sé by M. Van Ruymbeke and C. Poitevin in May 1981.

The station was honored by the visit of H.M. the King Baudouin of Belgium a few days after its installation.

The instrument is the Geodynamics gravimeter n° 783 which was installed previously at Wuhan and Lanzhou. The same procedures were applied for the calibrations, measurements and analysis (Melchior et al. 1981). Therefore we report here only the results so far obtained in order to compare them with those obtained with two other instruments in a nearby site in Shanghaï by Li Juihao, Chen Dongsheng and Fu Zhao Zhu.

In the Tables I and II we give the usual (δ, α) parameters as derived from the registrations and the residues

$$\vec{B} = \vec{A} - \vec{R} \qquad \vec{X} = \vec{A} - \vec{R} - \vec{L}$$

for each wave, where

- $\vec{A}$ is the observed tidal vector
- $\vec{R}$ is the corresponding theoretical vector computed with the Molodensky model I
- $\vec{L}$ is the load vector computed on the basis of the Schwiderski maps.

There is a fair agreement for all the waves which demonstrates that the different instruments (Geodynamics, Askania, CG) have been correctly calibrated and that the instrumental phase lags are also correctly evaluated.

TABLE I - Comparative results of the harmonic analysis of the registrations.

Diurnal waves

	O_1 δ	O_1 α	K_1 δ	K_1 α
G 783	1.191 ± 0.004	-0°61 ± 0°20	1.181 ± 0.003	-1°37 ± 0°14
CG 2	1.207 ± 0.012	-0°37 ± 0°23	1.194 ± 0.008	-1°22 ± 0°13
GS 15	1.207 ± 0.005	-0°92 ± 1°05	1.176 ± 0.003	-0°78 ± 0°58

Residues $\vec{B} = \vec{A} - \vec{R}$

	O_1		K_1	
G 783	0.93	-22°	1.98	-33°
CG 2	1.35	-17°		
GS 15	1.29	-10°		
Schwiderski maps	1.24	- 9°	1.49	-25°

Semi-Diurnal waves

	M_2 δ	M_2 α	N_2 δ	N_2 α	S_2 δ	S_2 α
G 783	1.153±0.001	-2°13±0°06	1.168±0.006	-2°12±0°31	1.138±0.003	-0°42±0°14
CG 2	1.167±0.004	-2°23±0°05	1.178±0.022	-2°61±0°25	1.169±0.009	-0°96±0°10
GS 15	1.152±0.001	-1°43±0°33	1.156±0.005	-2°49±1°89	1.144±0.002	(-2°02±0°72)

Residues $\vec{B} = \vec{A} - \vec{R}$

	M_2		N_2		S_2	
G 783	2.40	-101°	0.46	-81°	0.61	-160°
CG 2	1.34	- 74°				
GS 15	1.99	- 64°				
Schwiderski maps	1.16	- 64°	0.39	-61°	0.29	- 73°

Wave M_3

G 783 δ = 1.066 ± 0.032 α = 0.2 ± 1°7

GS 15 δ = 1.06 ± 0.05

TABLE II

Gravimeter G 783

	Parameters corrected by using the Schwiderski maps		Final unexplained residue $\vec{X} = \vec{A} - \vec{R} - \vec{L}$	
	δ	α		
O_1	1.1459	- 0°27	0.40	- 158°
P_1	1.1416	+ 0°34	0.18	151°
K_1	1.1454	- 0°60	0.55	- 57°
N_2	1.1493	- 0°54	0.16	- 135°
M_2	1.1430	- 1°21	1.63	- 126°
S_2	1.1345	+ 0°12	0.66	175°

These calibrations were completely independent from each other. The only contradiction is the S_2 large negative phase obtained with the Askania GS 15 instrument and the results obtained with G 783 thus reconfirm the conclusion of Li, Chen and Fu that the GS 15 has some pressurisation problems.

On the other hand the agreement with the Schwiderski maps is also fair, considering the fact that the observing places are coastal stations and that the near shore oceanic tides are rather important along this coast. The Table II shows that the Schwiderski maps must be complemented with near shore data at least for the M_2 wave.

Anyway the application of the Schwiderski maps corrections to the observed amplitudes give extremely homogeneous δ factors for all the waves as shown in the Table II.

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GRAVIMETRIC EARTH TIDE OBSERVATIONS IN WESTERN VENEZUELA

by C. Badell*, H. Drewes**, W. Torge***

and H.-G. Wenzel***

Summary

Gravimetric earth tide observations have been carried out in western Venezuela during 1978/1979 at the stations Maracaibo and Llano del Hato (Venezuelan Andes) by cooperation of the Escuela de Ingeniería Geodésica, La Universidad del Zulia (LUZ), Maracaibo, and of the Institut für Theoretische Geodäsie, Universität Hannover. The main purpose of the observations was to provide accurate tidal corrections for the high precision gravity measurements carried out in western Venezuela in order to detect gravity variations caused by tectonic processes and the extraction of oil (DREWES 1980). The gravimetric earth tide observations have been carried out with the LaCoste-Romberg gravimeter model G No. 298 (e.g. WENZEL 1976), the instrument has been compared before and after the Venezuelan observations in the earth tide station Hannover (e.g. TORGE and WENZEL 1977). The analysis of the observations shows significant deviations of the tidal parameters from standard tidal models as well as significant differences between the tidal parameters of the two stations.

1. Introduction

High precision gravity measurements have been carried out since 1977 in western Venezuela by cooperation of German and Venezuelan institutions (e.g. DREWES 1980). The main purpose of these investigations is the monitoring of active tectonic processes in the Venezuelan Andes and the subsidence of the Lake Maracaibo due to the extraction of oil. Because the amplitude of the tidal wave M2 is appr. 87 μGal in western Venezuela, a knowledge of the tidal parameters of the main waves to ±1% resp. ±0.5° is necessary to provide tidal gravity corrections accurate to ±1 μGal for the gravity field measurements. Gravimetric earth tide observations had been carried out in Caracas in the years 1959...1963 (FIEDLER 1970) using an Askania gravimeter GS11 with fotoelectric readout. The quality of these observations is only poor compared with modern gravimetric earth tide observations, and the tidal parameters seem not to be reliable. Because experience has shown, that gravimetric earth tide observations of some month's

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duration with LaCoste-Romberg model G gravimeters can provide tidal gravity corrections with an accuracy of ±1 μGal (e.g. TORGE and WENZEL 1976), it has been decided to install two temporary gravimetric earth tide stations in western Venezuela. The stations Maracaibo and Llano del Hato (Venezuelan Andes) have been selected mainly regarding technical and logistical facilities, but also in order to cover the area of the precise gravimetric nets (e.g. DREWES 1980). Besides the main purpose of providing accurate tidal gravity corrections, the observations should also improve the knowledge of the global distribution of tidal parameters (e.g. DUCARME and MELCHIOR 1977) and possibly improve the knowledge of the ocean tides in the Carribean Sea and Atlantic Ocean from inversion of the ocean tide effects on gravimetric earth tide observations (e.g. KUO et al. 1977).

2. Instruments

The observations have been carried out using the LaCoste-Romberg model G gravimeter No. 298, operated from a battery buffered regulated power supply. The gravimeters capacitive readout, filtered by an active low pass with 0.1 cps cut off frequency, has been recorded with a double channel strip chart recorder Yokogawa YEW 3047/2 using 24 mm/h recording speed. The time reference was given by hourly time marks provided from a Staiger Chrometron quartz signal clock, zeroing the recording pens. The clock has been controlled periodically with a short wave radio time signal. A schmematic diagram of the instrumental equipment is given in Fig.1, a recording sample showing a small earth quake at 1978.11.01.21 UT is given in Fig. 2.

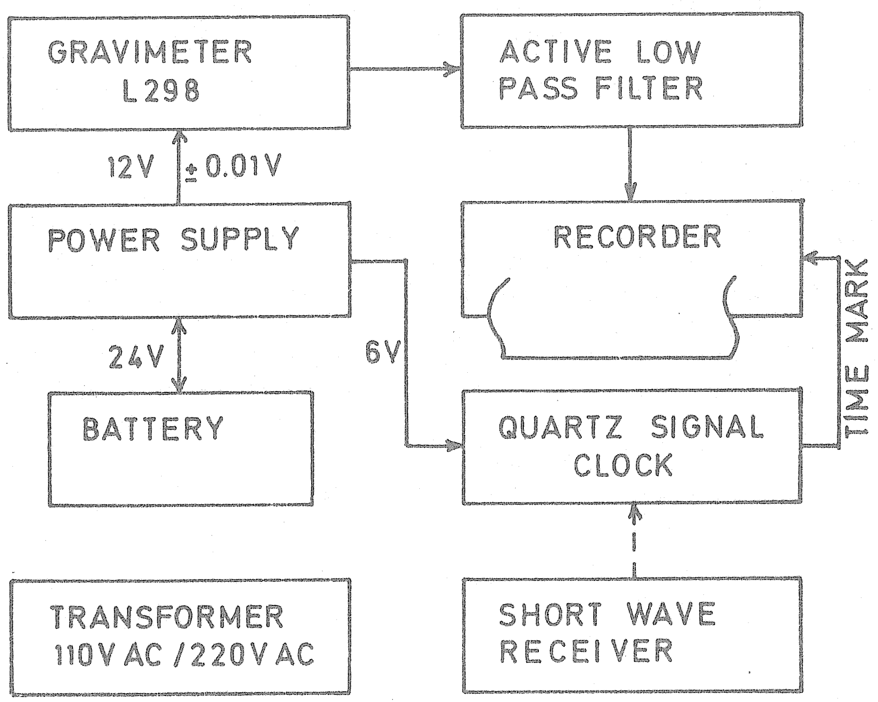

Fig. 1: Schematic diagram of the L298 gravimetric earth tide recording equipment

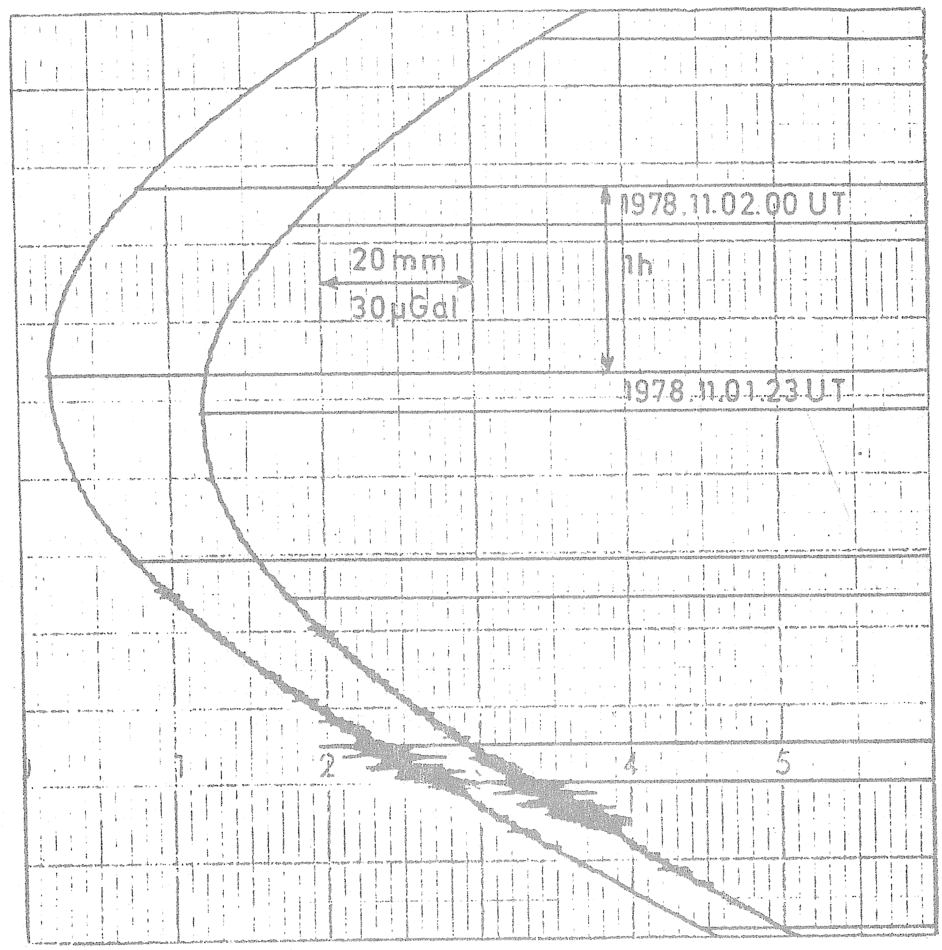

Fig. 2: Recording sample of gravimetric earth tide observations with L298, station Maracaibo, original scale

3. Station Descriptions

3.1 Station Maracaibo

The station Maracaibo has been installed in the Estación de Gravimetría y Sismología, Escuela de Ingeniería de Geodésica, La Universidad del Zulia (LUZ), Maracaibo (latitude 10.675°N, longitude 71.621°W, altitude 35 m). The distance to the open sea (Golfo de Venezuela) is appr. 30 km. The gravimeter has been installed on a pillar of concrete 0.7 m by 1.4 m, the observation room was theromstatized to 18°C by a standard air condition. The maintenance of the station has been carried out by H. Drewes and C. Badell (Escuela de Ingeniería Geodésica, LUZ). The observations have been carried out from 27. June 1978 until 24. November 1978 (150.5 days). Problems occured by several breaks of the electric power, a defect of the air condition after 24. October and a defect of the quartz signal clock after 1. September (replaced at 6. October by a digital quartz clock built at the elctronic laboratory of the Escuela de Ingeniería Geodésica).

3.2 Station Llano del Hato

The station Llano del Hato (Venezuelan Andes) has been installed in the observatory of the Centro de Investigación de Astronomía (CIDA), Llano del Hato (latitude 8.800°N, longitude 70.867°W, altitude 3600 m). The distance to the open sea (Golfo de Venezuela) is appr. 230 km. The gravimeter has been installed on a pillar of concrete with appr. 2 m diameter in an astronomic dome, the observation room was not thermostatized. The maintenance of the station has been carried out by H. Drewes (Escuela de Ingeniería Geodesica, LUZ) and G.E. Becerra, F.J. Pereira, N. Abuhalasky, J. Cova (CIDA).

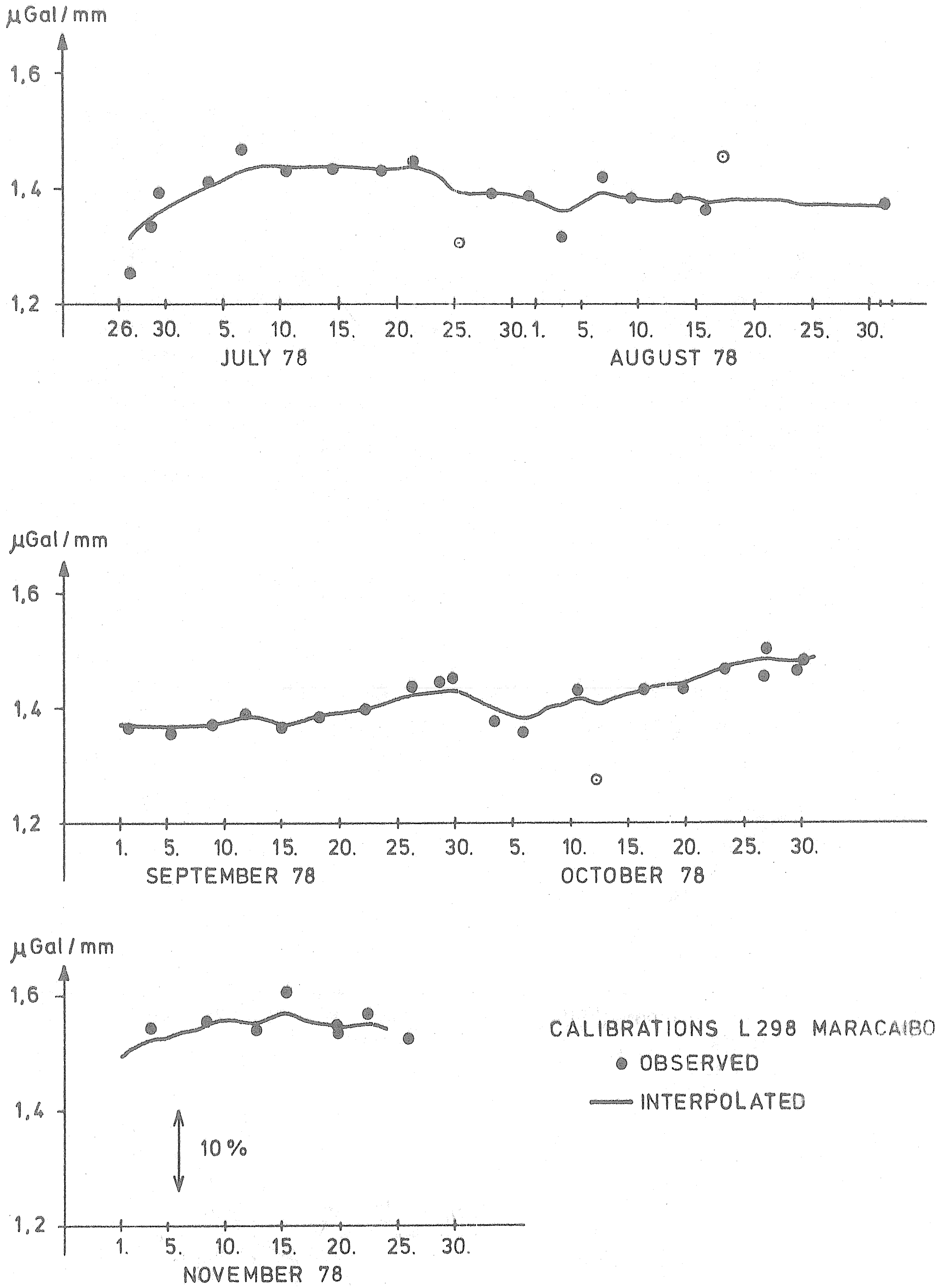

Fig. 3: Calibration of gravimetric earth tide observations with L298 in the station Maracaibo

e observations have been carried out from 6. December 1978 until 2. February 1979 (56.5 days). Problems occured by several breaks of the electric power; a one week power break after 2 nd of February has damaged the batteries of the gravimeters power supply and lead to a premature end of the observations.

4. Calibration

The spindulum of the gravimeter L298 has been calibrated 1979 in the Lake Maracaibo Network (DREWES 1980), giving a calibration factor of 1.00046 ± 0.00011. The earth tide recordings have been calibrated by spindulum displacements of appr. 100 μGal twice a week. The observed calibration values and the calibration functions, interpolated by a weighted moving average, are shown in Fig. 3 and Fig. 4. The stability of the calibration is much better in the station Maracaibo than in the station Llano del Hato, probably due to the thermostatization of the observation room and the more stable pillar. The accuracy of the observed calibration values is ±1% in Maracaibo; due to the collection of 48 calibration values, the random part of the total calibration is reduced to $\pm 1 \ldots 2 \cdot 10^{-3}$ in Maracaibo. Unfortunately, the accuracy of the calibration values in Llano del Hato is only ±2% due to the lower recording sensitivity, and the number of collected calibrations is only 23. Therefore, the random part of the total calibration can be estimated to $\pm 4 \ldots 6 \cdot 10^{-3}$ in Llano del Hato.

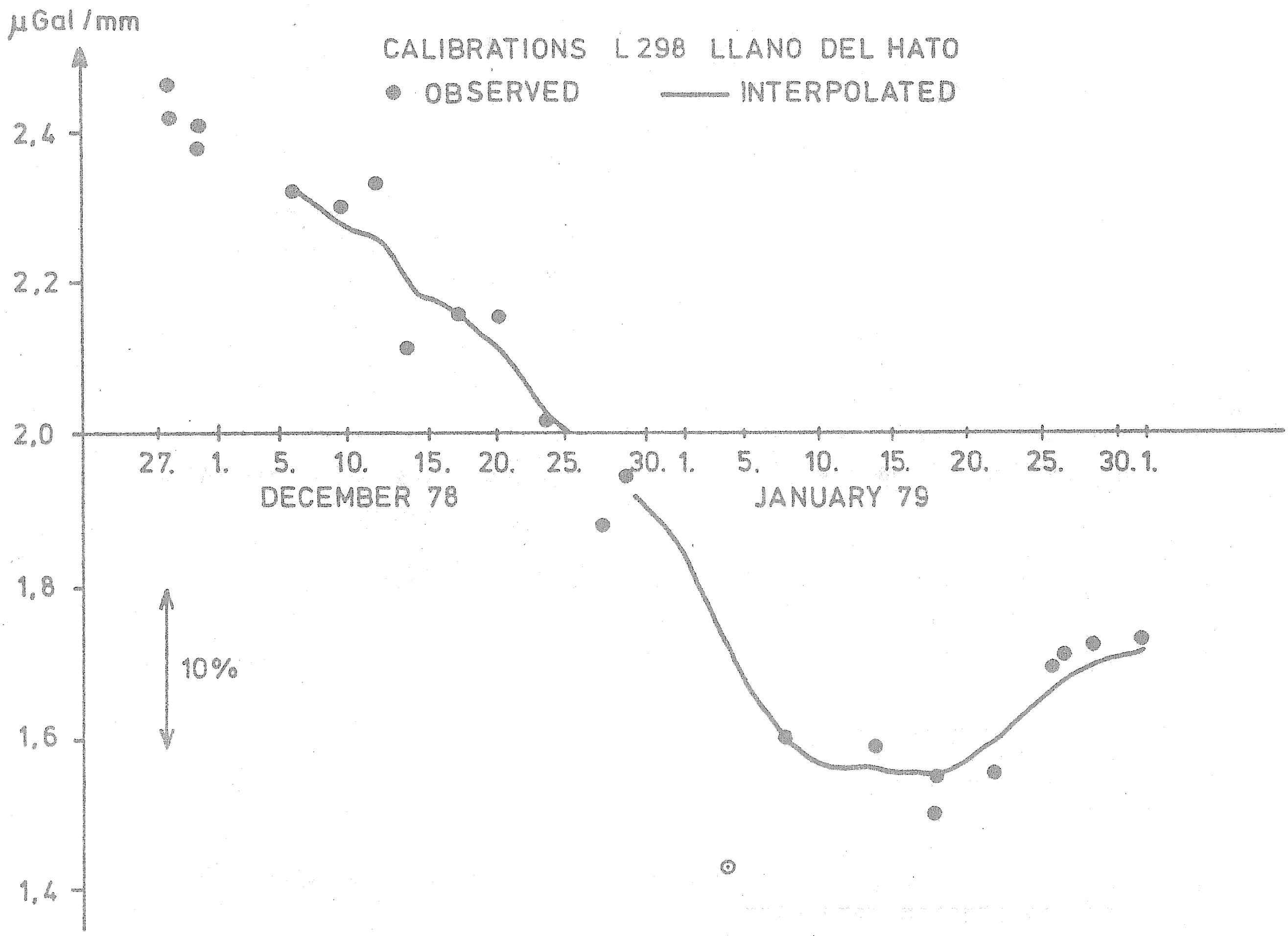

Fig. 4: Calibration of gravimetric earth tide observations with L298 in the station Llano del Hato

5. Instrumental Phase Lag

The frequency transfer function of the complete recording system (gravimeter, filter, recorder) has been determined in 1974 by Fourier transform of the recording systems differentiated step response (WENZEL 1976). The determination has been repeated in 1980, the results agree within $\pm 2 \cdot 10^{-3}$ for the amplitudes and $\pm 0.09^{o}$ for the phase lags (see Table 1). Thus, the instrumental phase lag has not significantly changed between 1974 and 1980.

Table 1: Frequency transfer function of L298 earth tide recording equipment (gravimeter, filter, recorder)

Wave	Frequency o/h	1974/11/10 Amplification	Phase Lag o	1980/05/05 Amplification	Phase Lag o
Q1	13.40	1.0017	0.85	1.0022	0.78
O1	13.94	1.0014	0.86	1.0018	0.78
M1	14.50	1.0012	0.86	1.0015	0.77
K1	15.04	1.0007	0.86	1.0015	0.77
J1	15.58	1.0005	0.87	1.0014	0.78
OO1	16.14	1.0003	0.87	1.0013	0.80
2N2	27.97	0.9957	0.97	0.9973	0.94
N2	28.44	0.9955	0.97	0.9971	0.94
M2	28.98	0.9954	0.98	0.9969	0.95
L2	29.53	0.9952	0.98	0.9968	0.94
S2	30.00	0.9950	0.99	0.9967	0.95
M3	43.48	0.9920	1.09	0.9942	1.11

6. Analysis of Observations, Results

After digitizing the earth tide recordings with hourly distance, the digitized values have been calibrated using the calibration functions shown in Fig. 3 and Fig. 4. Some gaps with a duration of 6 hours at maximum have been interpolated by predicted tides, using preliminary tidal parameters. The computation of tidal parameters has been carried out by least squares adjustment using a program developped by CHOJNICKI 1973 and modified by WENZEL 1976, the errors of the adjusted tidal parameters have been estimated from a Fourier spectrum of residuals (e.g. WENZEL 1976, WENZEL 1977). The gravimeters drift is given in Fig. 5 and Fig. 6, showing in the station Maracaibo an average drift of -5 µGal/day and irregularities correlated with defects of the air condition. The drift in the station Llano del Hato is up to -26 µGal/day, probably due to the larger variation of the room temperature. The noise of the observations (rms of residuals) in the station Maracaibo is ±1.1 µGal, which is comparable to earth tide observations with the same equipment in Hannover (e.g. WENZEL 1976). The noise of the observations in the station Llano del Hato is ±2.2 µGal, obviously due to the poorer station conditions. The amplitude spectra of the residuals are given in Fig. 7 and Fig. 8, displaying in both stations the highest peaks in the half daily band, associated with the maximum tidal energy in that band. Remarkable peaks occur also for both stations in the third and fourth daily band. The average amplitude of the noise is 0.07 µGal in the daily wave band, 0.13 µGal in the half daily wave band and 0.06 µGal in the third daily wave band for the station Maracaibo, and 0.24 µGal in the daily wave band, 0.46 µGal in the half daily wave band and 0.24 µGal in the third daily wave band for the station Llano del Hato.

The adjusted tidal parameters are given in Table 2 and 3, showing significant deviations of the amplitude factors and phase lags from a global model (amplitude factor 1.165 and 0^{o} phase lag), clearly reflecting the influence of the ocean tides (attraction and loading). Due to the lower accu-

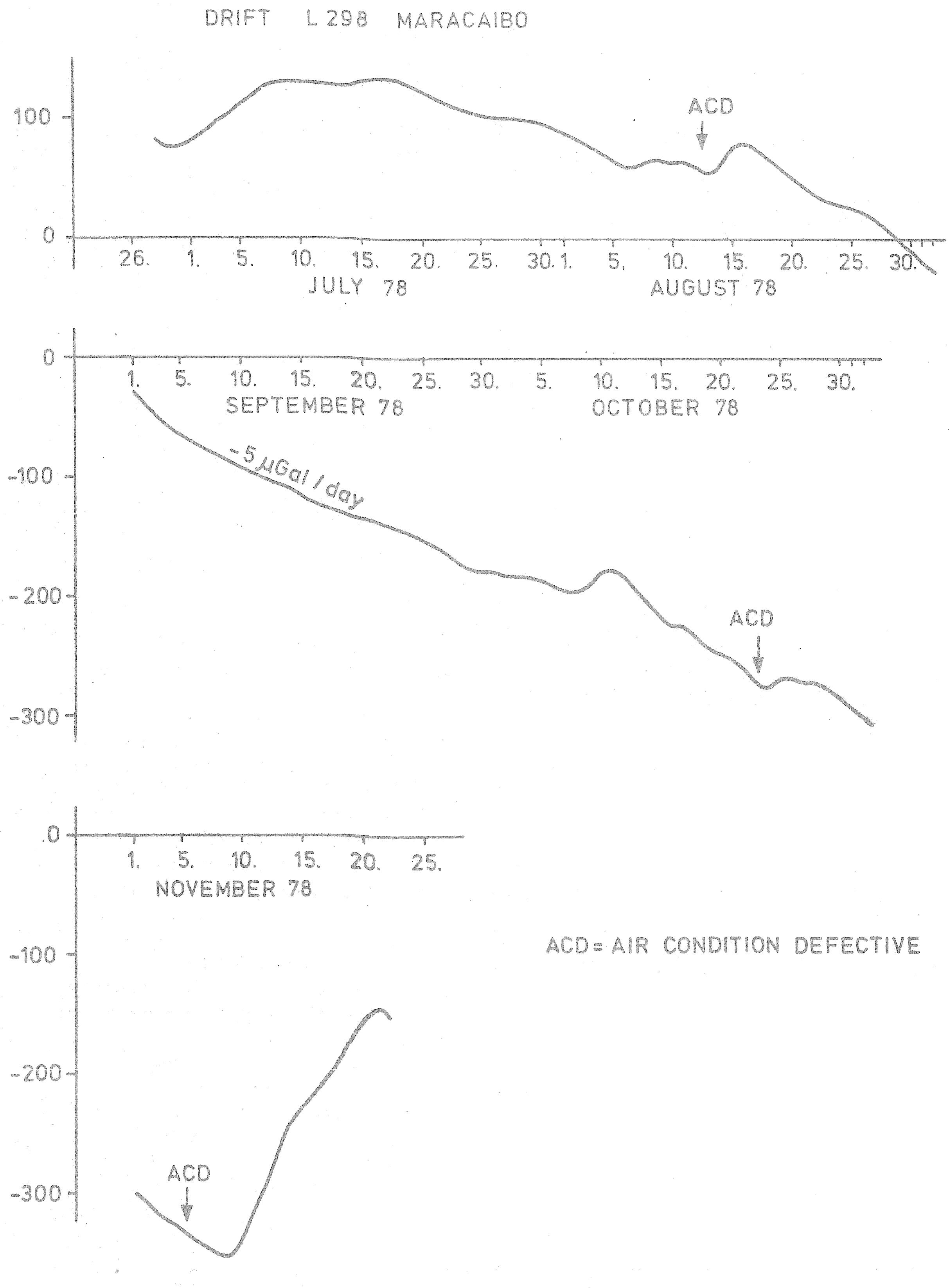

Fig. 5: Drift (low pass filtered observations) of L298 in the station Maracaibo

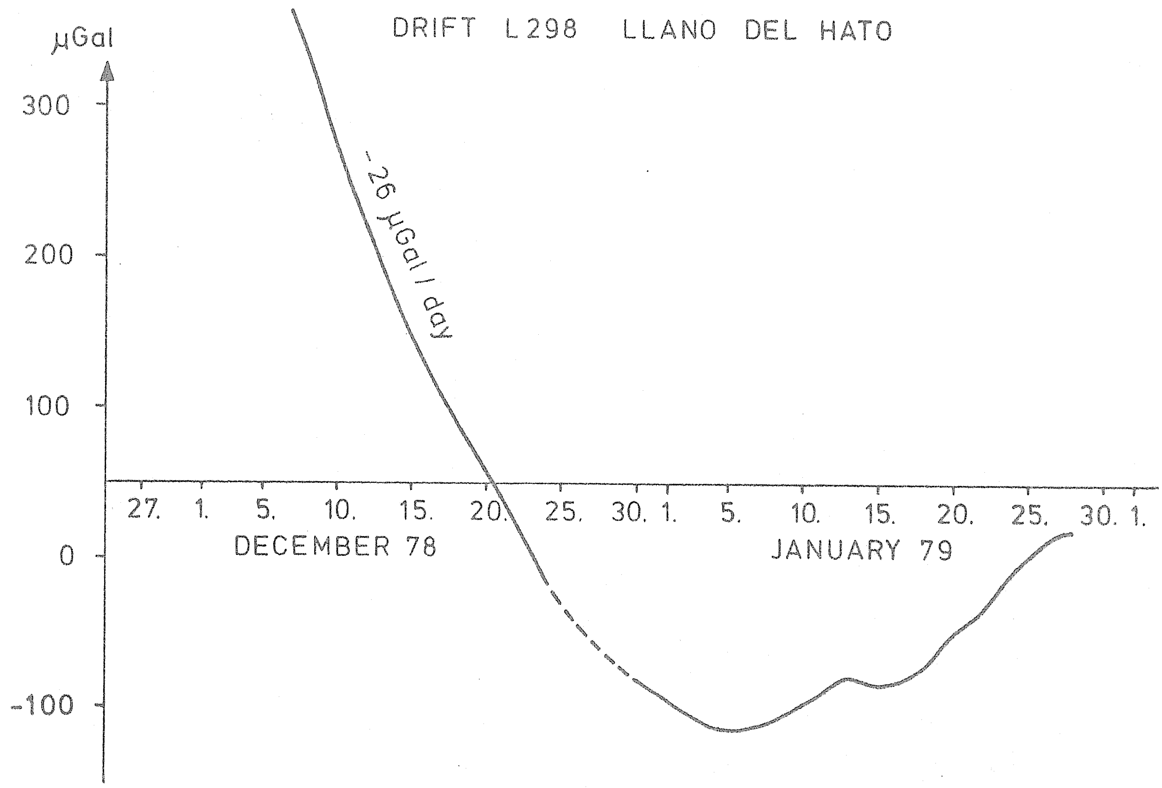

Fig. 6: Drift (low pass filtered observations) of L298 in the station Maracaibo

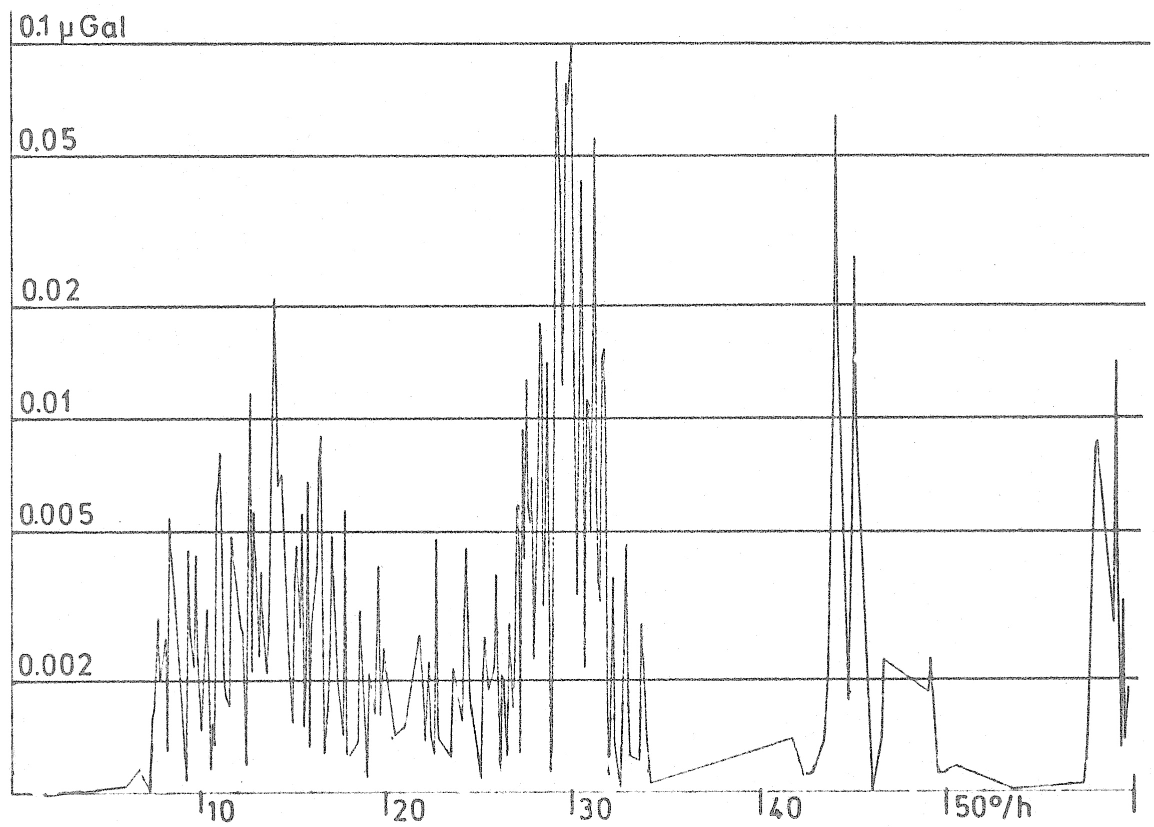

Fig. 7: Fourier amplitude spectrum of residuals, gravimetric earth tide observations with L298 in the station Maracaibo

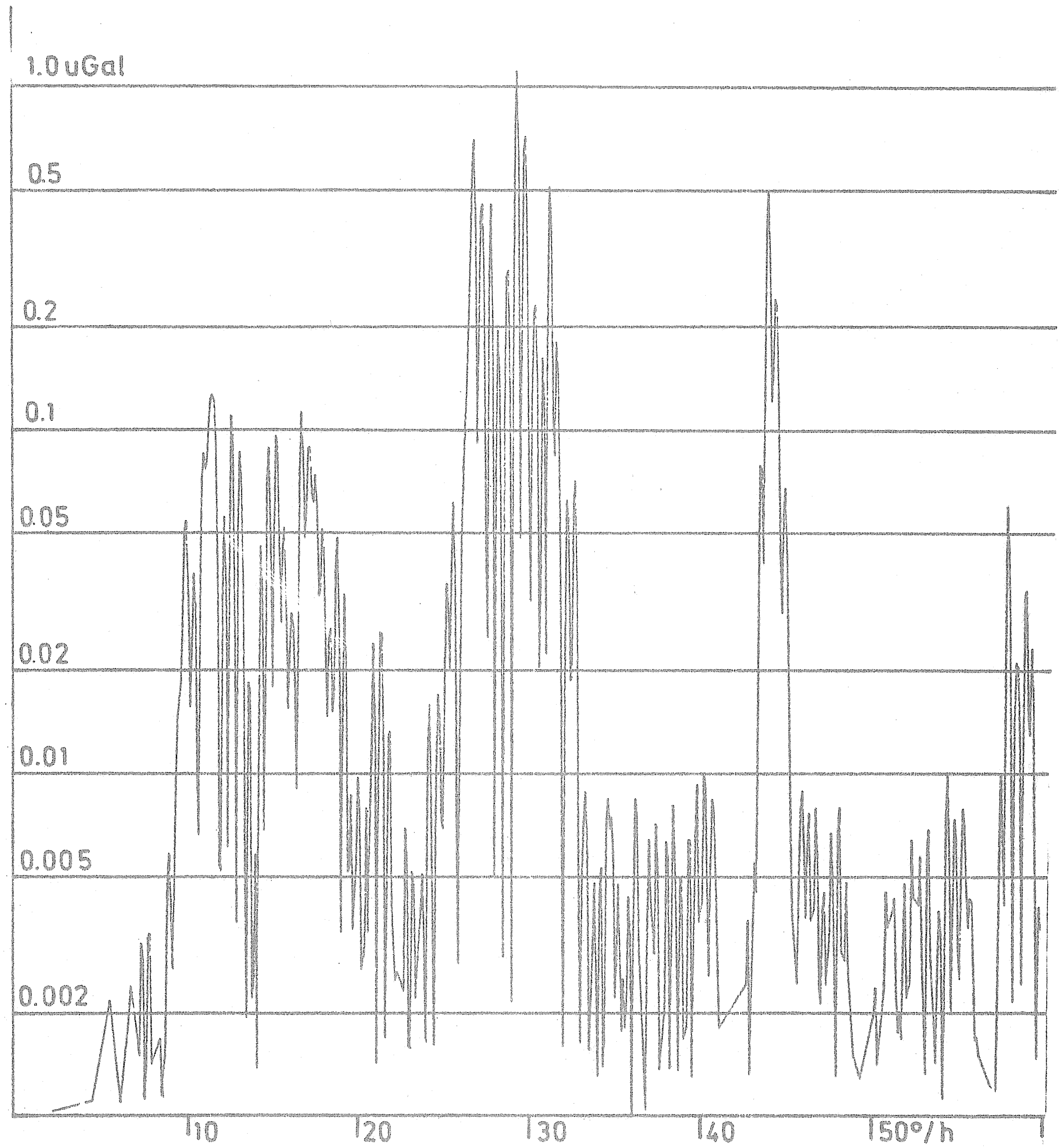

Fig. 8: Fourier amplitude spectrum of residuals, gravimetric earth tide observations with L298 in the station Llano del Hato

racy and shorter duration of the observations in the station Llano del Hato, omly the tidal parameters of the larger waves show significant differences between both stations with a tendency to smaller amplitude factors and smaller phase lags in the station Llano del Hato. This tendency is probably associated with the larger distance of station Llano del Hato to the open sea, thus having smaller influences of the oceanic tides.

7. Pre and Post Comparisons

The instrumental equipment has been compared before the observations in western Venezuela in the gravimetric earth tide stations Hannover, Brussels and Bonn (e.g. WENZEL 1976, TORGE and WENZEL 1977). The deviations from the stations mean are generally less $5 \cdot 10^{-3}$ for the amplitude factors and 0.1° for the phase lags. A one month post comparison from 27. March 1980 until 3. May 1980 in Hannover has given tidal parameters, which agreed within the error limits with prior observations. Thus, the instrumental characteristic has not changed significantly, as has been found from the redetermination of the instruments frequency transfer function (see chapter 5).

PROGRAM ET6 CHOJNICKI-WENZEL

GRAVIMETRIC EARTH TIDE STATION NO. 7202 MARACAIBO LUZ/VENEZUELA

10.675N 71.621W H35M VERTICAL COMPONENT

ESCUELA DE INGENIERIA DE GEODESIA, LA UNIVERSIDAD DEL ZULIA

INSTITUT FUER THEORETISCHE GEODAESIE, UNIVERSITAET HANNOVER

GRAVIMETER LACOSTE-ROMBERG NO. G298 PROF. TORGE HANNOVER

1978.06.27 - 1978.11.24

INSTALLATION H.-G.WENZEL/W.TORGE

MAINTENANCE H.DREWES/C.BADELL

CALIBRATED BY SPINDULUM DISPLACEMENTS

INSTRUMENTAL PHASE LAG CORRECTED

NUMBER OF DAYS 150.5

ESTIMATION OF NOISE BY FOURIER SPECTRUM OF RESIDUALS

DAILY WAVES .0696 MICROGAL
HALF DAILY WAVES .1336 MICROGAL
THIRD DAILY WAVES .0550 MICROGAL

ADJUSTED TIDAL PARAMETERS

NO.	FROM	TO	WAVE	AMPL. MYGAL	SIGNAL/ NOISE	AMPL.FAC. R.M.S.E.	PHASE LAG R.M.S.E.	
1	129	193	Q1	2.5319	36.3799	1.1712	1.0703	Q1
						.0333	1.5749	
2	194	219	O1	13.5743	195.0420	1.2021	.6912	O1
						.0062	.2938	
3	220	241	M1	1.0422	14.9749	1.1737	-10.2035	M1
						.0784	3.8261	
4	242	273	P1S1K1	19.1878	275.6985	1.2082	-.4436	P1S1K1
						.0044	.2078	
5	275	296	J1	1.1098	15.9462	1.2501	.4820	J1
						.0784	3.5931	
6	297	333	OO1	.6913	9.9335	1.4217	10.7710	OO1
						.1431	5.7680	
7	334	374	2N2	2.4706	18.4908	1.1159	4.3102	2N2
						.0603	3.0986	
8	375	398	N2	16.4582	123.1775	1.1868	1.3821	N2
						.0096	.4651	
9	399	424	M2	86.7031	648.9075	1.1970	1.0447	M2
						.0018	.0883	
10	425	441	L2	2.2850	17.1013	1.1160	-.6742	L2
						.0653	3.3504	
11	442	488	S2K2	40.7353	304.8727	1.2088	.2500	S2K2
						.0040	.1879	
12	489	503	M3	1.5372	27.9455	1.1001	.6699	M3
						.0394	2.0503	

MEAN SQUARE ERROR 1.146 MICROGAL DEGREE OF FREEDOM 3537

Table 2: Adjusted tidal parameters, station Maracaibo

PROGRAM ET6   CHOJNICKI-WENZEL

GRAVIMETRIC EARTH TIDE STATION NO. 7203 LLANO DEL HATO/VENEZUELA

08.800N 70.867W H3600M   VERTICAL COMPONENT

CENTRO DE INVESTIGACION DE ASTRONOMIA (CIDA)

INSTITUT FUER THEORETISCHE GEODAESIE, UNIVERSITAET HANNOVER

GRAVIMETER LACOSTE-ROMBERG NO. G298   PROF. TORGE HANNOVER

1978.12.06 - 1979.02.02

INSTALLATION   H.-G.WENZEL/H.DREWES

MAINTENACE   H.DREWES/G.E.BECERRA/F.J.PEREIRA/N.ABUHALASKY/J.COVA

CALIBRATED BY SPINDULUM DISPLACEMENTS

INSTRUMENTAL PHASE LAG CORRECTED

NUMBER OF DAYS   56.0

ESTIMATION OF NOISE BY FOURIER SPECTRUM OF RESIDUALS

DAILY WAVES   .2331 MICROGAL
HALF DAILY WAVES .4625 MICROGAL
THIRD DAILY WAVES .2434 MICROGAL

ADJUSTED TIDAL PARAMETERS

NO.	FROM	TO	WAVE	AMPL. MYGAL	SIGNAL/ NOISE	AMPL.FAC. R.M.S.E.	PHASE LAG R.M.S.E.	
1	129	193	Q1	2.0459	8.7753	1.1388	.2731	Q1
						.1298	6.5292	
2	194	219	O1	10.8811	46.6725	1.1596	.9028	O1
						.0248	1.2276	
3	220	241	M1	.8234	3.5319	1.1159	-7.1593	M1
						.3159	16.2224	
4	242	273	P1S1K1	14.9089	63.9487	1.1297	-2.5394	P1S1K1
						.0177	.8960	
5	275	296	J1	1.1047	4.7385	1.4976	.9119	J1
						.3160	12.0915	
6	297	333	OO1	.8654	3.7121	2.1418	90.8700	OO1
						.5770	15.4347	
7	334	374	2N2	2.0104	4.3472	.8974	-.8724	2N2
						.2064	13.1800	
8	375	398	N2	16.1860	34.9994	1.1535	-.8815	N2
						.0330	1.6371	
9	399	424	M2	87.2443	188.6501	1.1904	.0056	M2
						.0063	.3037	
10	425	441	L2	2.7321	5.9077	1.3188	-5.6126	L2
						.2232	9.6985	
11	442	488	S2K2	40.0564	86.6147	1.1748	-1.2549	S2K2
						.0136	.6615	
12	489	505	M3	1.4953	6.1434	1.0512	-.3238	M3
						.1711	9.3263	

MEAN SQUARE ERROR 2.174 MICROGAL   DEGREE OF FREEDOM 1218

Table 3: Adjusted tidal parameters, station Llano del Hato

Acknowledgements: The authors greatfully acknowledge the support of

the German Research Society, Bonn-Bad Godesberg,
the Dirección de Cartografía Nacional del Ministerio del Ambiente y de los Recursos Naturales Renovables, Caracas,
the Centro de Investigación de Astronomia (CIDA), Mérida
and of the Dirección de Investigaciones Geoanalytícas y Technológicas del Ministerio de Energía y Minas, Caracas.

The computations have been carried out on CDC Cyber 76 of the Regionales Rechenzentrum für Niedersachsen, Hannover.

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Traduction

EFFETS DE LA TOPOGRAPHIE DANS LES INCLINAISONS DE MAREE MESUREES DANS LES STATIONS DU PROFIL KIEV-ARTEMSOL

V.G. Balenko

Rotation et Déformations de marée de la Terre 13, pp 3-10 1981

On a conçu, en 1963, à l'Observatoire Gravimétrique de l'Institut Géophysique S.I. Subotin de l'Académie des Sciences d'Ukraine, un plan de recherches clinométriques pour déterminer les caractéristiques régionales les plus précises possibles de la marée élastique dans la région Dniepr-Donetz [1].

Lors de la mise en oeuvre de ce plan s'est posé le problème du choix des sites offrant les conditions optimales pour les stations clinométriques. Mais à cette époque, il n'y avait aucune recherche théorique qui aurait pu nous guider. Les premières publications relatives aux effets de cavité, de topographie et de géologie sont apparues en 1974 [15] [16]. Notre attention avait cependant été attirée sur les perturbations possibles provenant de grandes fractures et du relief local: selon nous, le relief local pouvait affecter les paramètres de marée d'une manière indirecte aussi bien que par le biais de l'onde météorologique diurne.

Pour éliminer l'influence des fractures on a décidé d'établir les stations clinométriques le long du confluent Dniepr-Donetz de telle sorte que les perturbations soient réduites et moyennées par une épaisseur de plusieurs kilomètres de roche sédimentaires. Quant aux perturbations liées aux accidents du relief, il fallait examiner les résultats des observations puisqu'à cette époque nous n'avions pas de moyens théoriques pour les étudier.

On a donc décidé de créer la première station du profil Kiev-Artemsol là où, outre la détermination des paramètres γ et $\Delta\phi$, une perturbation due au relief aurait pu se manifester dans ces paramètres. Un site approprié a été trouvé sur le territoire de Kiev-Petcherskii et est désigné ici sous le nom de "Kiev". Il est situé sur la rive droite abrupte du Dniepr, coupée de profonds ravins. Les observations sont effectuées dans deux grottes distantes de 270m l'une de l'autre qui sont creusées, la plus proche dans la pente NE d'un ravin profond, et la plus éloignée dans le SW. La profondeur à laquelle sont installés les clinomètres Ostrovski est d'environ 10m pour la plus proche et 16m pour la plus lointaine.

La Table I donne les valeurs γ, $\Delta\phi$ pour l'onde M_2, la moins perturbée par les effets météorologiques [2].

TABLE I. Paramètres γ et $\Delta\phi$ de l'onde M_2 pour la station Kiev ($p=1/m^2$ où p et m sont le poids et l'erreur quadratique moyenne de γ).

Site	Nord-Sud		Ouest-Est	
	γ	$\Delta\phi$	γ	$\Delta\phi$
Grotte proche	0.782±0.033	+0.17°±2.86°	0.758±0.024	-2.54°±1.90°
Grotte éloignée	0.627±0.017	+3.06 ±1.37	0.679±0.059	-8.42 ±2.96
moyenne vectorielle pondérée	0.659±0.063	+2.34 ±1.12	0.746±0.030	-3.30 ±1.77

Malgré la faible précision de ces résultats, on voit qu'en ces deux points distants de 270m les paramètres diffèrent sensiblement. Ceci ne s'explique pas par des erreurs instrumentales [1].

Le relief peut influencer:

1- directement, en tant que zone affaiblie d'un ravin profond
2- par une onde météorologique diurne importante
3- à cause de phénomènes de glissement amplifiés dans les pentes abruptes (le bloc dans lequel sont creusées les grottes est probablement divisé par des failles et des nappes aqueuses provenant de grande profondeur).

Nous avons déduit de nos observations à Kiev que le relief accidenté perturbe sensiblement les paramètres de marée et c'est pourquoi de telles régions ne conviennent pas pour obtenir les caractéristiques de marée régionales.

Nous avons choisi ultérieurement des endroits plats, à relief adouci, loin de constructions importantes. Il a aussi fallu chercher des sites où les gisements d'eau souterraine ne sont pas plus profonds que 15m pour protéger des inondations les appareils installés dans les galeries [1].

D'autre part la couche d'eau située au voisinage peut être une source de perturbations et ceci n'a pas permis de satisfaire toutes les exigences d'installation idéale.

Dans tous les cas les ravins étaient situés au moins à 2 à 3 km du lieu de creusement des galeries. Chevtchenkovo présente les conditions de relief idéales [3]: dans un rayon de plus de 1km la surface du sol ne présente aucune inclinaison. Dans les autres stations prédomine un relief adouci.

La station de Bieresovaya-Roudka [4] est dans une plaine qui s'étend loin vers l'E-SW; il y a, vers le Nord, à 200m environ, un ravin abrupt de 10m derrière lequel se trouve une prairie marécageuse.

La station Pokrovskaya-Bagatchka [5] se trouve sur un terrain qui s'étend du Nord au Sud en pente douce et dont la plus grande inclinaison est d'environ 3° près de la galerie.

La station Caterinovka [6] est dans une situation analogue mais la pente y est moindre et, dans un rayon de 50 à 60m autour de la mine la surface est quasi horizontale.

La station Carlo Libknechtovsk est dans une mine de sel, à une profondeur de 120m [1]. Près de la zone où se font les observations est située une vallée fluviale peu profonde.

A l'Observatoire gravimétrique de Poltava on fait les observations dans deux caves creusées dans une zone en pente douce près d'un ruisseau dont la rive est abrupte [7,8].

Dans la plaine Dniepr-Donetz les observations sont terminées en deux autres points, Velikié Boudicha et Soudievka, appartenant au profil Soumi-Kherson, réalisé par un groupe de l'Observatoire gravimétrique de Poltava sous la direction de P.S. Matvéev [9].

A Velikié Boudicha il n'y a aucune pente dans un cercle de plus de 100m près de la mine. A Soudievka elle ne dépasse pas 1°. Les ravins les plus proches sont situés à environ 500m.

Un court examen du relief dans les environs de nos stations montre que les résultats à Chevtchenkovo et à Carlo Libknechtovsk sont affranchis de l'effet topographique.

Dans les autres cas on peut s'attendre à des perturbations qui ne peuvent tout de même dépasser la dispersion des paramètres γ, Δφ. La Table 2 donne ces paramètres pour M_2. On notera que dans les stations de Velikié Boudicha et Poltava I des perturbations peuvent également provenir des eaux souterraines.

TABLE 2. Paramètres γ et Δφ de l'onde M_2

Sites	Composante NS		Composante EW	
	γ	Δφ	γ	Δφ
Beresovaia Roudka	0.712±0.005	-1.20°±0.78°	0.718±0.005	-4.23°±0.51°
Pokrovskaya Bagatchka	0.684±0.008	-1.00 ±0.62	0.717±0.008	-4.90 ±0.74
Chevtchenkovo	0.699±0.008	+0.57 ±0.94	0.710±0.007	-4.18 ±1.08
Caterinovka	0.689±0.009	-1.12 ±0.94	0.714±0.006	-0.53 ±0.48
Carlo Libknechtovsk	0.688±0.003	-0.32 ±1.26	0.718±0.003	-1.11 ±1.39
Soudievka	0.679±0.001	+0.78 ±0.12	0.719±0.002	-3.92 ±0.15
Poltava 2	0.681±0.025	+0.75 ±1.40	0.697±0.021	-0.48 ±3.62
Poltava 1	0.698±0.017	-0.84 ±0.74	0.690±0.007	+0.43 ±0.61
Velikié Boudicha	0.642±0.004	+0.22 ±0.35	0.701±0.004	-5.10 ±0.21

Si l'on rejette les résultats de ces deux stations on peut considérer comme limites supérieures de l'effet topographique sur γ: 5% en NS et 3% en EW. Si on considère qu'à Poltava la précision est faible, alors ces limites se ramènent à 1%.

Depuis 1976 L.E. Khassiliev s'occupe de recherches théoriques dans le domaine des effets de cavité et de topographie. Il a examiné d'un point de vue personnel, en comparaison avec la méthode des éléments finis utilisée par Harrison [16], le problème de l'influence du relief et il a élaboré un algorithme pour le calcul des effets topographiques.

D'après cet algorithme Doubiko a composé un programme sur ordinateur qui a permis de déterminer les corrections pour six de nos stations.

Avant tout il fallait déterminer le rayon du cercle dans lequel se fait sentir l'influence du relief sur les paramètres γ et Δφ dans une mesure compatible avec la précision actuelle. Plus grandes sont les dénivellations, plus grand doit être ce rayon.

Il résulte de ce travail [16] que l'influence de la topographie diminue très rapidement lorsque croît la distance aux instruments. C'est pourquoi dans une première phase nous avons choisi d'effectuer les calculs dans les deux variantes pour quatre stations: Beresovaia Roudka, Pokrovskaya Bagatchka, Velikié Boudicha et Soudievka qui ont un relief sensiblement différent auprès dès galeries.

Dans la première variante on a tenu compte du relief dans un cercle de 100 m de rayon (zone voisine). Dans la seconde variante on a étudié l'anneau de 100m à 4000m (zone éloignée).

Dans un rayon de 100 à 200m on a fait un levé tachéométrique et on a établi un plan à l'échelle 1/500 avec des lignes de niveau tous les 0,25m. A.N. Koutnii, V.G. Balenko et A.N. Novikova ont effectué ce travail.

Pour le calcul de la zone lointaine on a utilisé des cartes topographiques au 1/25000 sur lesquelles on a reporté les lignes de niveau tous les 2,5m. On y a relevé les accroissements en rayon tous les 5°. Sur cette base Khassiliev a calculé les effets topographiques donnés à la Table 3 qui montre que l'apport des zones lointaines est très faible par rapport aux zones proches et qu'il est du niveau des erreurs de calcul.

TABLE 3. Corrections topographiques aux constantes harmoniques des inclinaisons de marée semi-diurne dans la région Dniepr-Donetz.

Stations	$\Delta\phi$			$\Delta(\Delta\phi)$		
	1	2	3	1	2	3
	Composante NS					
Beresovaia Roudka	-0.0074	-0.0015	-0.0088	0.03°	0.04°	0.07°
Pokrovskaya Bagatchka	-0.0248	-0.0028	-0.0276	0.34	0.02	0.37
Soudievka	-0.0071	-0.0010	-0.0081	0.01	-0.03	-0.01
Poltava	-	-	-0.0024	-	-	0.91
Velikié Boudicha	-0.0006	0.0008	0.0002	0.09	0.05	0.14
	Composante EW					
Beresovaia Roudka	-0.0016	0.0002	-0.0014	-0.03	-0.03	-0.06
Pokrovskaya Bagatchka	-0.0058	-0.0008	-0.0067	-0.30	-0.09	-0.40
Soudievka	-0.0017	-0.0002	-0.0019	0.02	-0.01	0.01
Poltava	-	-	-0.0013	-	-	0.90
Velikié Boudicha	-0.0004	0.0001	0.0003	-0.08	-0.08	-0.16

Remarques:

1- apport de la zone proche de rayon 100m
2- apport de la zone lointaine, anneau de rayons 100 à 4000m
3- apport total

Comparant les erreurs sur les moyennes vectorielles avant et après application des corrections topographiques on observe une certaine diminution qui témoigne de la réalité des corrections introduites.

Une petite diminution de la divergence, indique d'une part leurs erreurs importantes et d'autre part confirme une fois de plus que, pour les stations clinométriques, (cf table 2) l'influence perturbatrice de la topographie est faible en comparaison des autres facteurs.

Pour augmenter la précision des calculs des effets topographiques il faut connaître toute une série de valeurs [14,16] qu'il est impossible d'atteindre sans renchérissement important des travaux clinométriques. C'est pourquoi dans la suite les stations clinométriques visant à obtenir les valeurs réelles de γ, $\Delta\phi$ pour l'étude des effets océaniques indirects, tectoniques et autres il faut choisir des endroits de relief calme: dans un rayon de 100 à 200m la pente ne doit pas dépasser 1° et des ravins ne peuvent se trouver plus près que 500 à 1000 mètres. C'est seulement dans ce cas qu'il suffit sans doute de calculer avec précision l'influence du relief. Les résultats obtenus dans les stations clinométriques ne satisfaisant pas à ces conditions ne peuvent être interprétées à mieux qu'une décimale. C'est pourquoi elles sont peu utiles pour les recherches géophysiques. Nous examinerons par exemple les résultats obtenus à Pokrovskaia Bagatchka située dans une large fracture limitée au Sud par le confluent Dnispr-Donetz [1]. Avant l'introduction de la correction topographique (Table 2) la valeur γ représentative en ce point correspondait avec la valeur régionale [1]. La correction est de 4% et conduit à une valeur γ qui diffère sensiblement de la valeur régionale. Dans ce cas nous ne pouvons déterminer à une décimale la validité d'une de ces deux variantes.

Il se peut qu'en cette station on ait une compensation exceptionnelle des effets topographiques et tectoniques mais il est aussi possible que nous observions les résultats des erreurs sur le calcul des effets topographiques à cause de l'absence de données sûres quant aux particularités sous jacentes de la galerie, (couches géologiques et eaux souterraines).

Nous comparerons alors cinq variantes les plus intéressantes de moyennes présentées dans la Table 4.

TABLE 4. Constantes harmoniques moyennes de M_2 obtenues dans la région Dniepr-Donetz (p: poids, m: erreur quadratique moyenne)

Type de moyenne	Composante NS		Composante EW	
	γ	Δϕ	γ	Δϕ
1 moyenne vectorielle pondérée $p=1/m^2$				
- pour six stations du profil Kiev-Artemsol	0.694±0.004	-0.52°±0.24	0.716±0.001	-2.19°±0.73
- pour toutes les stations de la Table 2	0.681±0.006	-0.02 ±0.30	0.715±0.003	-3.20 ±0.73
2 moyenne vectorielle pour p=1:				
- pour les stations de la Table 2 excepté Velikié Boudicha et Poltava 1	0.690±0.006	-0.08 ±0.37	0.713±0.003	-3.15 ±0.76
- idem, après correction topographique	0.683±0.006	0.15 ±0.42	0.711±0.003	-3.37 ±0.70
3 moyenne arithmétique de toutes les stations de la Table 2 et des stations Kiev, Samotoievka [12] tirées de [1]	0.690±0.004	-0.11 ±0.43	0.714±0.002	-3.38 ±0.51

Par l'analyse des données de la Table 4 il faut pour chacune des directions que les moyennes correspondent dans les limites des erreurs de détermination.

En NS l'erreur sur γ est de moins de 0,8% et en EW elle est de 0,5%. Aussi le choix de la valeur la plus sûre est difficile. Toutefois malgré la faible valeur des corrections topographiques et la précision médiocre de leur calcul pour Pokrovskaia Bagatchka, il faut donner une préférence à la quatrième ligne de la Table 4 car:

1. dans toutes les stations la surface est plane ou est en pente NS. Dans le dernier cas les clinomètres ont travaillé sur le bord Sud de la zone affaiblie et les observations donnent une valeur trop forte de γ [13]. C'est pourquoi, pour la direction NS les corrections topographiques doivent être négatives. La Table 3 montre qu'il en est ainsi.
2. pour la partie centrale de l'Ukraine on a obtenu dans la direction EW: Δϕ ≈ -3°. Ce retard disparaît après correction des effets océaniques

[1]. Les stations Poltava 1 et Poltava 2 sont des exceptions (Table 2). Le calcul de l'effet topographique augmente ici le retard de phase de 0,9° et le rapproche des valeurs obtenues à Velikié Boudicha, Soudievka, Chevtchenkovo et Pokrovskaia Bagatchka.

3. La quatrième ligne de la Table 4 ne contient pas les résultats de Velikié Boudicha et Poltava 1 qui sont perturbées par les eaux souterraines. Ainsi, en 1980, pour la région concernée, on a obtenu sans les corrections océaniques:

en NS $\gamma = 0.683 \pm 0.006$ $\Delta\phi = 0.15° \pm 0.42°$

en EW $\gamma = 0.711 \pm 0.003$ $\Delta\phi$ $-3.37° \pm 0.70°$

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