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TABLE DES MATIERES

19TH IUGG GENERAL ASSEMBLY

Hamburg, August 1983

REPORT OF THE INTERNATIONAL CENTRE FOR EARTH TIDES (ICET) DURING THE PERIOD 1980-1983

P. MELCHIOR
(Bruxelles)

The tasks ascribed to ICET as a FAGS Centre are basically :

1° - to collect all available measurements of earth tides (which is its task as World Data Centre C),

2° - to evaluate these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the desired and needed geophysical information.

3° - to compare the data from different instruments and different stations distributed all over the world, evaluate their precision from the point of view of internal errors as well as external errors,

4° - to help to solve the basic problem of calibrations and to organize reference stations or build reference calibration devices,

5° - to fulfil gaps in informations or data as far as possible,

6° - to build a DATA BANK allowing instantaneous and easy comparison of earth tide parameters with different earth models and different oceanic cotidal maps,

7° - to ensure a broad diffusion of the results and informations to all interested laboratories or individual scientists.

ICET has tried to contribute with all the means at its disposal to these different tasks. Most of its activity during the last two years was devoted to organize the Data Bank (B. Ducarme).

1. COLLECTION OF DATA

The collection of data is always a difficult task. Despite the often renewed recommendations of the World Data Centre ICSU Panel, some countries do not transmit any data measured on their territories. This creates apparent gaps in the ICET files.

Nevertheless data from 250 stations are presently collected. Of course many are temporary stations. (cf Table I).

2. EVALUATION OF DATA

Since its foundation one of the main activities of ICET has been the development of appropriate computation methods. A great number of programmes have been written and permanently improved to analyse and evaluate the submitted data.

These programmes have always been made freely available to interested Institutions, a number of which are using the ICET procedures. ICET has direct access to a powerful Univac 1100/81 Computer through a terminal. The method usually applied is still the least squares method with Venedikov filters but the new method of Venedikov, the Hycon method by Schüller and the spectral analysis are also applied in some specific cases. With the present level of precision of the instruments commonly used there is no significant difference between the different methods of analysis. However the reduction of data obtained with Superconducting gravimeters will raise new problems.

The ultimate outputs of the usual computer programmes are :

- a listing which gives all important informations : description of the concerned station with instrumental constants, method of computation, epochs of measurements and, for each main group of tidal waves, the amplitude, the amplitude factor, the phase and the residual (amplitude and phase) with respect to Molodensky model I. Of course internal errors are given.
- the automatic introduction of these informations in the DATA BANK.

3. COMPARISON OF DATA

Comparison of stations and instruments have been made as an obvious result of the analysis of data. This gives guidelines for the improvement of installations or of instruments. (Melchior and De Becker, 1983).

4. CALIBRATION OF DATA

Since the IGY it had been recommended to install different instruments at a same place for a sufficient long time in order to allow to investigate possible systematic instrumental errors.

In addition to previous comparisons ICET has now the possibility to compare classical spring gravimeters with a Superconducting GWR gravimeter installed at the Royal Observatory of Belgium since 1982.

This allows a precise check of instrumental phase lags, a correction to which great attention has to be given.

For horizontal pendulums, ICET has interferometrically calibrated a great number of dilatable crapaudines which are presently used in many laboratories in the world. Recalibrations are made when possible (or necessary) after some years.

ICET continues its support to the underground Laboratory of Geodynamics at Walferdange, Luxembourg, which offers a reference for every kind of instrument.

5. FILLING OF GAPS IN DATA

Since the end of 1973, ICET has obtained supports to develop in Africa, in Asia and the South Pacific Trans World Tidal Gravity Profiles which extends now over 17400 km, from Istanbul to Papeete and over some 7200 km from Cape to Cairo. These operations cover now a total of 69 stations where measurements of a duration of 4 to 8 months are already completed (Table II).

In october 1983 ICET will install a number of stations in Brazil and in West Africa.

6. DIFFUSION OF RESULTS AND INFORMATIONS

ICET has continued the edition of the Bulletin d'Informations (BIM) reaching now 89 issues with a total of 5848 pages. These Bulletins contain a great number of translations of russian papers. A General Bibliography is also regularly kept in order and published. It contains presently 3.698 references (see Table III). A catalogue of earth tide stations also exists but has not been published because of the lack of answers from several countries this produces gaps that we have not yet been able to fulfil.

OBJECTIVES 1984-1987

It is our opinion at ICET that the following objectives should be pursued.

- <u>Direct measurements of earth-ocean tidal interactions</u>

Most recent results demonstrate that the best gravimeters currently used (Geodynamics, LaCoste Romberg) can determine without bias a loading effect when its amplitude reaches 0.5 microgal or more. We have currently observed in our Trans World Profile M_2 loading effects reaching 4 or 5 microgals but also 10 to 15 microgals in some regions. There is thus fruitful experimental work still to be done in these regions with the currently available instruments.

But very small waves like K_2 and Q_1 can be analysed with success even if the loading effects seldom reach one microgal (Melchior, Ducarme, Chueca 1983).

Further progress can be expected with the realization of a zero method as indicated by Harrison and Sato (1983).

Experimental determinations of tidal loading effects are very important for different applications :

1 - Improvement of oceanic cotidal maps
2 - Investigations upon earth's lithosphere and asthenosphere properties.
3 - Observation of dilatancy effects as precursors of earthquakes
4 - Correct prediction of tidal variations to allow precise interpretation of nontidal gravity variations.

OCEANIC INTERACTIONS, EARTH'S FLATTENING AND INERTIAL FORCES EFFECTS, LIQUID CORE EFFECTS AND POSSIBLE EFFECTS OF LITHOSPHERE HETEROGENEITIES

In a recent paper Melchior and De Becker (1983) investigated these different aspects through a statistical analysis of the results from 180 tidal gravity stations stored in ICET data bank and which concern the six main tidal waves (O_1, P_1, K_1, N_2, M_2, S_2).

They found a highly significant correlation between the observed loading effects and the effects calculated on the basis of the Schwiderski oceanic cotidal maps. After subtraction of these oceanic contributions they calculated the latitude dependence of the gravimetric δ factor to be attributed to the flattening of the earth and the effect of inertial forces (Coriolis, centrifugal forces). The numerical coefficients of the P_4^2/P_2^2 and P_4^1/P_2^1 functions fit fairly well the Wahr's model :

	Observed	Wahr
semi-diurnal waves	-0.0046 ± 0.0010	-0.005
diurnal waves : O_1	-0.0028 ± 0.0015	
P_1	-0.0039 ± 0.0029	-0.006
K_1	-0.0059 ± 0.0013	

but the independant terms are all 1 % higher than Wahr's values :

	Observed	Wahr
semi-diurnal waves	1.1761 ± 0.0027	1.160
diurnal waves : O_1	1.1618 ± 0.0016	1.152
P_1	1.1522 ± 0.0029	1.147
K_1	1.1458 ± 0.0012	1.132

This of course raises a number of questions.

However the observed values fit the resonance trend of the Molodensky model I.

Finally Melchior and De Becker showed that a small number of stations exhibit significant discrepancies in the cosine component (B cos β) but not in the sine component (B sin β) which seems to be correlated to lithospheric thickness.

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TABLE I

Addition to the previous lists of stations communicating their data to ICET

(Réf. General Reports, Grenoble 1975, Canberra 1979)

CHINA	Guangzou, Kunming, Lanzhou, Qing Dao, Shanghaï Shenyang, Urumqi
DJIBOUTI	Arta
ETHIOPIA	Addis Ababa
KENYA	Nairobi, Voi
INDONESIA	Kupang, Banjar Baru
JAPAN	Kanoya, Kyoto, Tokyo, Mizusawa, Memambetsu
KOREA	Seoul
MOZAMBIQUE	Maputo, Nampula
NEW ZEALAND	Wellington
NORWAY	Nesna, Umbukta
RWANDA	Butare
SOUTH AFRICA	Johannesburg, Stellenbosch
SPAIN	Sepulveda, Cubillos, Barcelona, Carbonaro, Ciudad Real, La Granja, Arcas, Santiago, Calatayud.
TANZANIA	Dar es Salaam
ZIMBABWE	Harare.

TABLE II

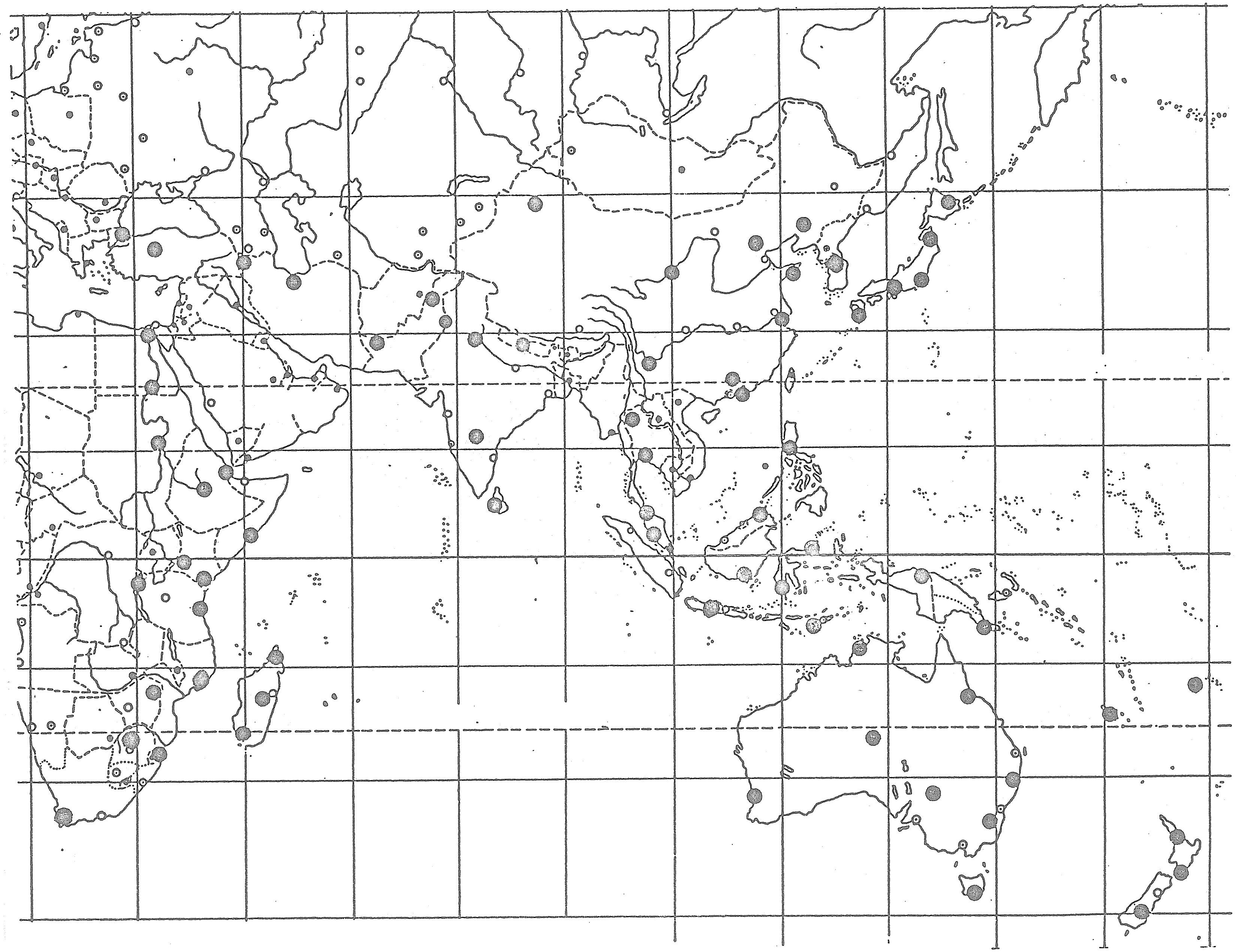
TRANS WORLD TIDAL GRAVITY PROFILES

ICET (Bruxelles)

1973 - 1982

Stations	Country	Stations	Country
Istanbul, Ankara	Turkey	Hamilton, Lauder	New Zealand
Tabriz, Teheran	Iran	Noumea	N. Caledonia
Peshawar, Quetta, Lahore	Pakistan	Suva	Fiji
Hyderabad	India	Apia	Samoa
Kathmandu	Nepal	Papeete	Tahiti
Colombo	Sri Lanka	Tsing Tao, Shenyang, Beijing, Lanzhou, Urumchi, Wuhan, Kunming, Canton, Shanghai, Hong Kong	China
Chiang Mai, Bangkok	Thailand	Kyoto, Memambetsu, Mizusawa, Tokyo, Kanoya	Japan
Penang, Kuala Lumpur, Kota Kinabalu	Malaysia	Seoul	Korea
Manila	Philippines	Helwan, Aswan	Egypt
Banjar Baru, Bandung, Manado, Makassar, Jaya Pura, Timor	Indonesia	Khartoum	Sudan
Port Moresby	Papua	Addis Ababa	Ethiopia
Darwin, Perth, Alice Springs, Broken Hill, Canberra, Charters Towers, Hobart	Australia	Mogadiscio	Somalia
Antananarivo, Tolagnaro, Nossi Bé	Madagascar	Nairobi, Voi	Kenya
Johannesburg, Stellenbosch	South Africa	Dar es Salaam	Tanzania
		Butare	Rwanda
		Harare	Zimbabwe
		Nampula, Maputo	Moçambique
		Arta	Djibouti

70 stations - each station: 6 months - 8 tidal equipments.



Trans World Tidal Gravity Profiles

by ICET 1973-1983

TABLE III

General Bibliography of Earth Tides

Number of published papers

Before the IGY		Since the IGY			
epoch	n	year	n	year	n
1800 - 49	3	1958	69	1970	188
1850 - 74	7	1959	39	1971	144
1875 - 99	64	1960	96	1972	114
1900 - 09	16	1961	91	1973	247
1910 - 19	46	1962	53	1974	116
1920 - 24	20	1963	91	1975	116
1925 - 29	33	1964	121	1976	195
1930 - 34	54	1965	68	1977	241
1935 - 39	30	1966	98	1978	203
1940 - 44	27	1967	78	1979	179
1945 - 49	27	1968	71	1980	120
1950 - 54	129	1969	86	1981	127
1955 - 57	116			1982	59
				1983	116
	572		961		2.165
				TOTAL	3.698

19TH IUGG GENERAL ASSEMBLY

Inter Disciplinary Symposium n° 6 : Data Management

Hamburg, August 1983.

A DATA BANK FOR EARTH TIDES

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SUMMARY

A data bank is operational at ICET. For more than 200 tidal gravity stations from which data were made available to ICET it can retrieve :

- a geographical and geological description of the station with the list of all operating instruments, and epochs of observations.
- the analysis results concerning the main tidal waves (up to 35 components depending upon of the registration length).
- the residual vector $\overline{B}$ obtained by subtracting from the observed tidal vectors the gravity tide of the Molodensky I earth model.
- the oceanic attraction and loading vector $\overline{L}$ computed from the Schwiderski oceanic cotidal maps taken as working standards for the waves Q_1, O_1, P_1, K_1, N_2, M_2, S_2 and K_2.
- the eight corresponding final vectorial residues $\overline{X} = \overline{B} - \overline{L}$.

The exploitation programs allow to extract tabulated results for conventional geographical areas as well as for individual stations.

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Besides of these mean results the Bank keeps track of all the individual results obtained in the stations (more than 400 analysis) and the oceanic attraction and loading effects were computed for more than 800 locations.

KEYWORDS : data bank, storage and retrieval of tidal gravity results, oceanic loading evaluation.

1. INTRODUCTION

In 1956 the International Center for Earth Tides (ICET/FAGS) located at the Royal Observatory of Belgium (ROB) has been established to strengthen the international cooperation.

The tasks ascribed to ICET are described in the Report that will be presented at the meeting of the Permanent Commission on Earth Tides (Melchior, 1983b).

As a World Data Centre C the gathering of the data is one of its main goals. It started 25 years ago and ICET keeps in its files several millions of hourly readings from original tidal records under an accepted international format.

However raw data are not directly useful to scientists in most applications. It is necessary to evaluate these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the required geophysical information.

A working group on "Data Processing in Tidal Research" defined a standard presentation of the tidal analysis results providing these parameters (table 1). Other parameters related to the effects of the Oceanic tides are also required for interpretation of the results (see section 2) and must be included in the Data Bank.

2. TIDAL ANALYSIS AND INTERPRETATION

To define the optimal content of the Data Bank it is necessary to briefly review the different steps of the analysis and interpretation of the tidal data.

The tidal forces derive from a tidal potential defined as an infinite sum of spherical harmonics (Melchior, 1983a).

In practice only the second and third order terms are taken into account and are expanded into a sum of purely sinusoïdal waves i.e. waves having as arguments purely linear functions of the time. The standard development is truncated to 505 waves. For analysis purposes these waves will be combined into a limited number of groups that we are able to separate on the basis of the registration length. These groups are identified by the name of their main tidal constituent (Table 1).

It is customary to compare the observed amplitude A and phase ϕ of a tidal group to the theoretical amplitude A_t and phase ϕ_t derived for a rigid Earth from the tidal potential.

For a gravimetric tidal wave generated by the potential of order n we define the factors :

$$\delta = \frac{A}{A_t} , \qquad \alpha = \phi - \phi_t .$$

On the other hand, for a purely elastic Earth, we define a theoretical response :

$$\delta_n = 1 + \frac{n}{2} h_n - \frac{n+1}{2} k_n, \quad \alpha_n = 0$$

where h_n and k_n are the well known Love numbers.

This theoretical response is frequency dependent in the diurnal frequency band due to hydrodynamical resonance inside the liquid core of the Earth.

Two models are mainly in use now :

- The well known Molodensky I model (1961).

- The Wahr model (1981) taking into account the ellipticity of the Earth as well as its diurnal rotation. It produces latitude dependant amplitude factors (δ_2).

For a given model we can directly compare the observed amplitude vector $\overline{A}$ (A, α) to the theoretical one $\overline{R}$ (R, 0) with

$$R = \delta_n A_t , \qquad A = \delta A_t$$

We define an observed residue $\overline{B}$ (B, β) as shown by figure 1, i.e.

$$\overline{B} = \overline{A} - \overline{R}$$

The main contribution to this observed residue comes from the tidal interaction between the body tides of the Earth and the oceanic tides. As the oceanic tides are generated by the same potential as the body tides there are no means to separate their effects in the records. The only way to get rid of them is to modelize these "indirect" effects. It requires the exact knowledge of the tides in world ocean at each of the main tidal frequencies. Using an elastic model of the Earth, Farrell computed an algorithm to evaluate the global effect of a unit mass i.e. direct gravitational attraction and change of gravity due to the bending of the crust and to the induced change of potential {Farrell, 1972}. It is necessary to make the convolution of these Green's functions with the oceanic tidal grid (some 45000 1°x1° cells).

The choice of the oceanic model is extremely important. The Schwiderski maps including 11 oceanic waves, 4 diurnals (Q_1, O_1, P_1, K_1), 4 semi-diurnal (N_2, M_2, S_2, K_2) and 3 long period (M_f, M_m, S_{sa}) have been adopted as a working standard {Schwiderski, 1980}.

The result of the computation is called the load vector $\overline{L}$ (L, λ).

In most of the places this load vector fits the observed residue within the error limits so that the final residue $\overline{X}$ defined as

$$\overline{X} = \overline{B} - \overline{L}$$

has no geophysical meaning.

However a study of the repartition of the $\overline{X}$ vector at the surface of the world allows to discover some regional anomalies {Melchior & alii, 1983}.

We can also compute other useful quantities.

From the corrected tidal amplitude vector $\overline{A}_c$ (A_c, α_c) defined as

$$\overline{A}_c = \overline{R} + \overline{X}$$

we can evaluate the corrected tidal factors

$$\delta_c = \frac{|\overline{R} + \overline{X}|}{A_t} = \frac{A_c}{A_t} \quad , \quad \alpha_c$$

This corrected amplitude factor δ_c has been used to check the latitude dependance in the Wahr model {Melchior and De Becker, 1983}.

We can also modelize the global tidal phenomenon $\overline{A}_m$ (A_m, α_m) as a sum of the body tides ($\overline{R}$) and the tidal load ($\overline{L}$) : $\overline{A}_m = \overline{R}+\overline{L}$. We define the corresponding gravimetric tidal factors

$$\delta_m = \frac{A_m}{A_t} \quad , \quad \alpha_m$$

to be used to produce accurate tidal predictions at locations where no observations are available.

Figure 2 is a flow diagram of the information in the tidal analysis procedure.

3. GENERAL ORGANIZATION

The general organization of the Data Bank is schematized in figure 3.

For each station, a central file FICHST allows to retrieve the addresses where the general information and the mean value of the tidal parameters are stocked in the four other data files :

- in FICHAP the list of the instruments and of their recording periods
- in FICHEFE the indirect effects computed from different oceanic models (Schwiderski 79 for 6 waves, Schwiderski 80 for 9 waves, local maps)
- in FICHANA the mean tidal analysis results and observed residues $\overline{B}$.
- in FICHRES the mean final residues $\overline{X}$ for different oceanic and Earth models, the corresponding corrected tidal factors (δ_c, α_c) and the global tidal model (δ_m, α_m).

The mean tidal analysis is either selected either computed from all the available results.

There are also complementary informations given by the partial analysis results and corresponding residues. All are kept in FICHANA and FICHRES under an identification number : instrument number followed by the station number and a sequence number between 0 and 9. The original output listing of each analysis is kept under the same identification as elements of a separate file ANAL.

A general catalog of all the available analysis is kept under two forms following the station number and following the instrument number (Table 4).

The structures of the five files are very similar. They consist of fixed records of 20 words. The 100 first records are used to store the file directory with a maximum of 1000 elements.

4. DATA RETRIEVAL

A general purpose program gives access to all the data concerning any station. An example of the output listing is shown in table 2. It can also produce a copy of the content of the data bank on a magnetic tape.

Several outputs are already available for external users :

- The indirect effects computed from oceanic model for a given area defined as a sequence of station numbers (table 3 : Belgium, stations 201-249).
- A summary of the analysis results available for a given station (table 4 : Walferdange) or a given instrument (table 4 : GEO 761).
- A regional edition of the data bank.

This last output provides mean results for twenty two regions (table 5). Four different formats are available.

1. Summary of the analysis results for each tidal wave. When the result is a mean the individual values are listed below (table 6).

2. Comparison of the observed residue $\overline{B}$ with the tidal loading vector $\overline{L}$ for the three main diurnal (O_1, P_1, K_1) or semi-diurnal (N_2, M_2, S_2) waves (table 7).

3. Comparison of the observed residue $\overline{B}$ with the final residue $\overline{X} = \overline{B}-\overline{L}$ for the three main diurnal or semi-diurnal waves (table 8).

4. A listing of the vectors $\overline{B}$, $\overline{L}$, $\overline{X}$ and of their sine and cosine components for each tidal wave (table 9).

This last output format is the most efficient tool to detect regional anomalies in the results.

5. CONCLUSIONS

This data bank is operational at ICET for tidal gravity results. In the future it will be expanded to tidal tilt and strain measurements. To be updated and expanded it requires a continuous stream of results to ICET on an international cooperation basis.

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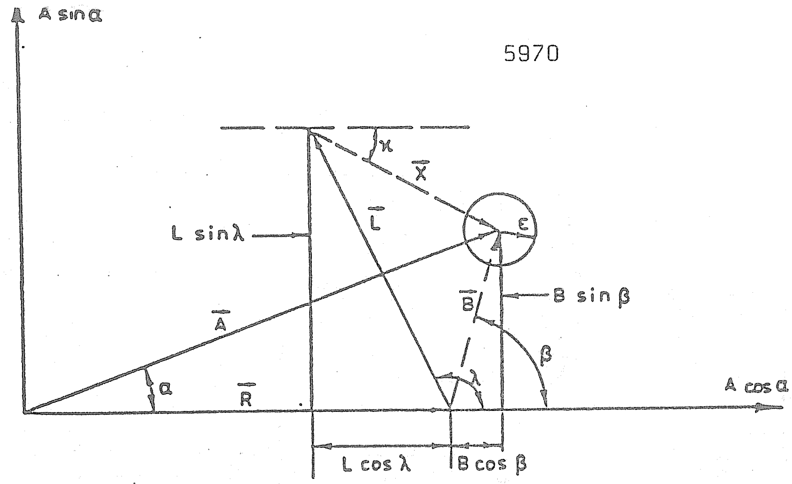
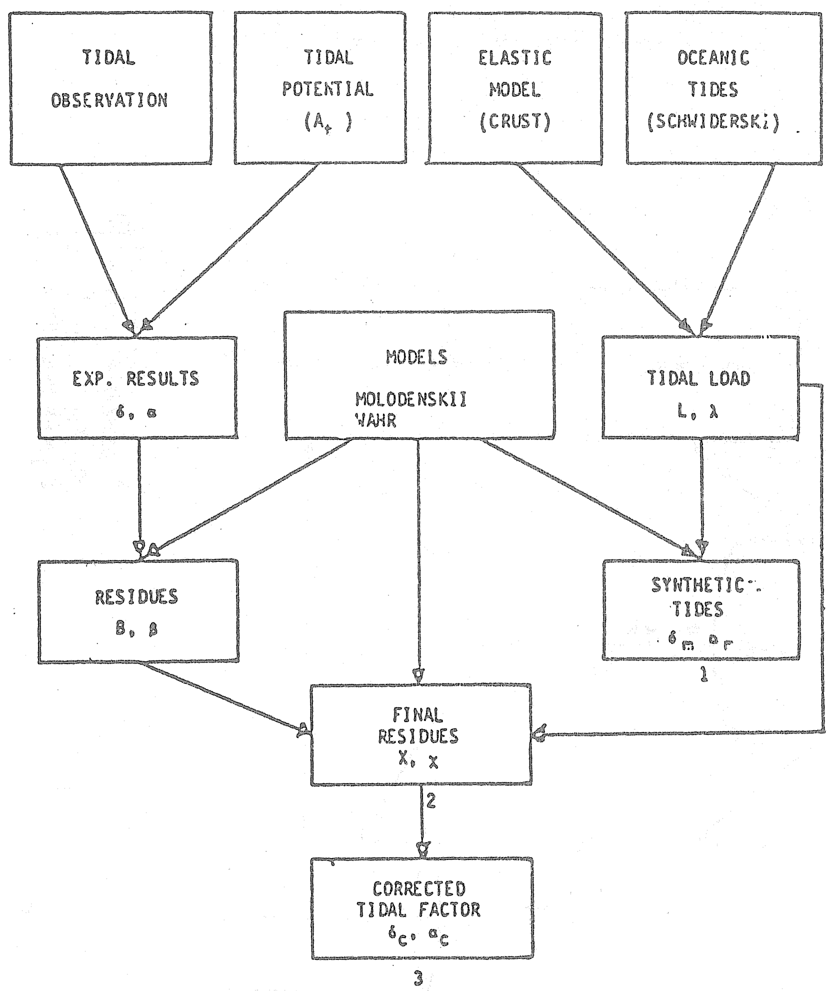


Fig. 1. Comparison of observed and calculated ocean–continent tidal interactions. For the semi-diurnal M_2 wave, the correct scale of this figure should be: $R \simeq A \simeq 40$ (Europe)–90 (Equator) μgal; $\alpha \simeq 0$–$\pm 5°$; $L \simeq B \simeq 2$ (Europe)–10 (South Pacific) μgal; $X \simeq 0.5$–5 μgal; $\epsilon \simeq 0.5$ (Europe)–1 (Equatorial zone) μgal (B = A − R, B − L = X).

T.W.P.

INTERPRETATION OF TIDAL DATA

FLOW DIAGRAM



1 corrected theoretical tides

2 local and regional anomalies

3 validity of models at planetary scale

Fig. 2

CONSTITUTION OF FILES

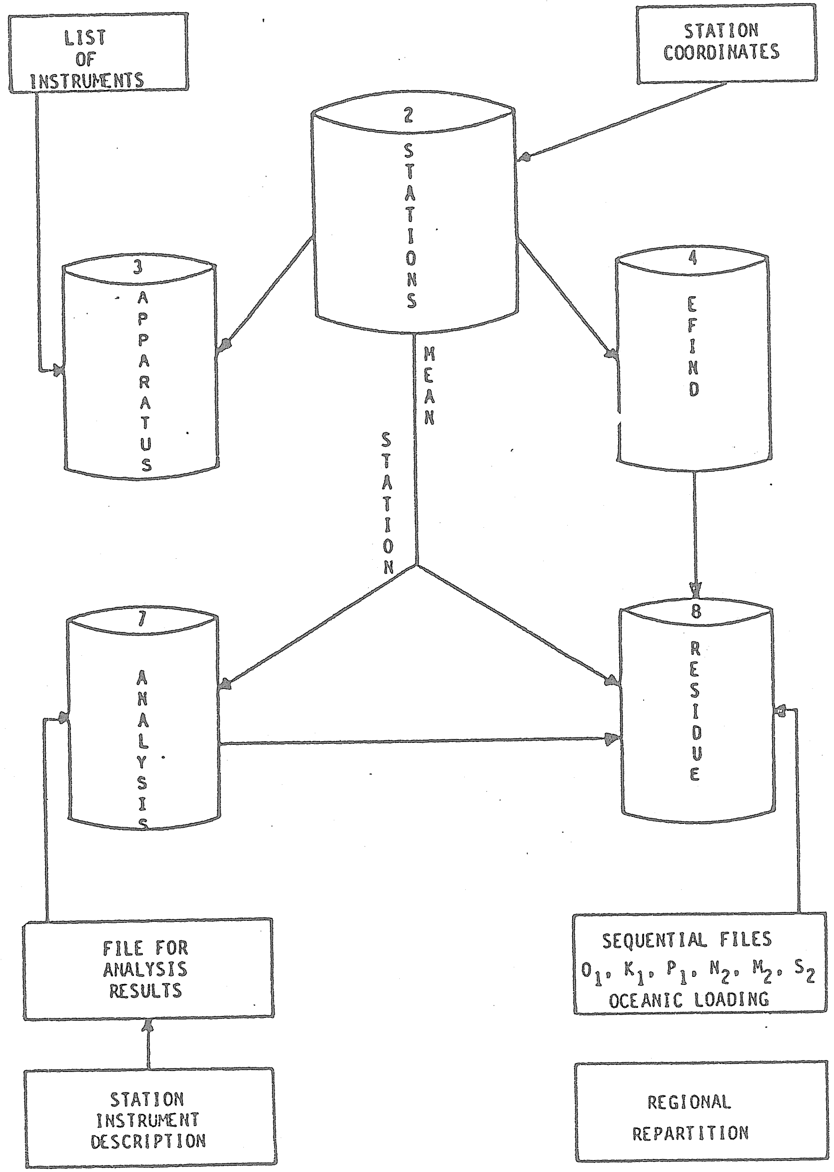


Fig.3

REGIONAL LISTING

TABLES 6 TO 9

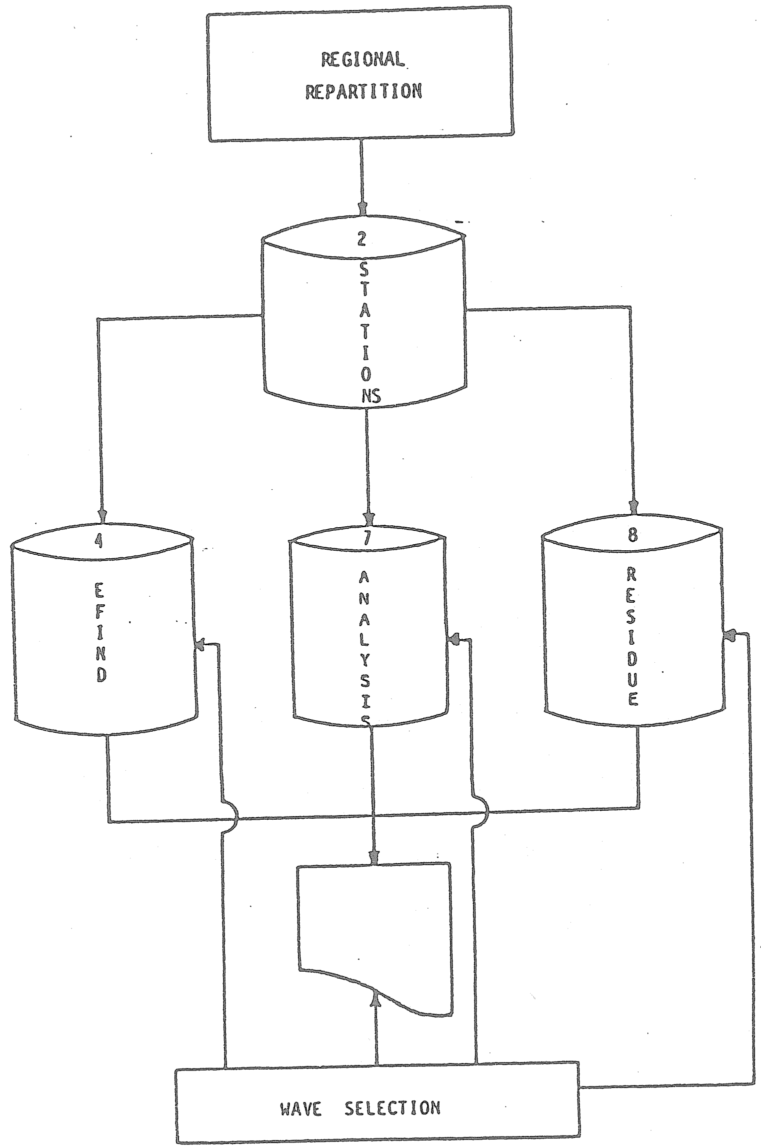


Fig. 4

TABLE 1 : Standard presentation of tidal analysis results. 5972

TRANS WORLD PROFILES BRUSSELS FUNDAMENTAL STATION
STATION 0201 BRUXELLES-UCCLE COMPOSANTE VERTICALE BELGIQUE

50 47 55 N 04 21 29 E H 101 M P 4M D 90KM 981 117 301
BASSIN EOCENE DE BRUXELLES SUR LE CAMBRIEN DU MASSIF DU BRABANT.
SABLES LUTETIENS.
OBSERVATOIRE ROYAL DE BELGIQUE DEPT.1 P.MELCHIOR
GRAVIMETRE A SUPRACONDUCTIVITE
ENREGISTREUR POTENTIOMETRIQUE
CALIBRATION BRUXELLES - STATION FONDAMENTALE
INSTALLATION R.WARBURTON,M.VAN RUYMBEKE,B.DUCARME
MAINTENANCE B.DUCARME,M.VAN RUYMBEKE,R.LAURENT,F.RENDERS

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 SPERRY-UNIVAC 1100/81 PROCESSED ON 83/ 7/ 7

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR 2.92214

G777	82 422/82 524	82 6 4/82 612	82 622/82 7 4	82 7 9/82 727	82 731/82 915
G777	82 919/8210 3	8210 9/821017	821021/821029	8211 2/83 210	83 214/83 222
G777	83 226/83 312	83 316/83 328	83 4 1/83 4 3	83 4 7/83 4 9	83 4 7/83 419
G777	83 423/83 425	83 429/83 5 7	83 510/83 613	83 617/83 625	

TIME INTERVAL 431.0 DAYS 9264 READINGS 19 BLOKS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
115.-11X.	11	SIGMQ1	.26	.03	1.1359	.1189	-1.896	5.987	.01	-123.0
124.-126.	10	2Q1	.90	.03	1.1673	.0347	1.915	1.702	.03	79.8
127.-129.	11	SIGMA1	1.07	.03	1.1546	.0302	-.482	1.497	.01	-117.4
133.-136.	20	Q1	6.80	.03	1.1669	.0046	-.227	.226	.05	-32.0
137.-139.	10	RO1	1.31	.03	1.1813	.0244	.099	1.182	.02	5.3
143.-145.	16	O1	35.35	.03	1.1610	.0009	-.121	.044	.09	-55.8
146.-149.	10	TAU1	.45	.03	1.1262	.0698	-8.710	3.544	.07	-105.1
152.-155.	15	NO1	2.83	.05	1.1815	.0225	.964	1.092	.07	41.2
156.-158.	7	KI1	.50	.03	1.0815	.0576	-2.071	3.051	.04	-153.3
161.-162.	3	PI1	1.00	.03	1.2081	.0326	-1.371	1.548	.05	-28.9
163.-163.	7	P1	16.43	.03	1.1595	.0019	.110	.095	.09	20.8
164.-164.	3	S1	.44	.04	1.3084	.1141	-2.949	5.862	.06	-23.3
165.-165.	11	K1	49.24	.03	1.1497	.0006	-.200	.032	.54	18.4
166.-166.	2	PSI1	.42	.03	1.2205	.0800	5.420	3.756	.04	102.7
167.-168.	7	PHI1	.76	.03	1.2443	.0448	-.530	2.059	.04	-9.4
172.-174.	8	TETA1	.52	.03	1.1395	.0595	2.968	2.991	.03	111.8
175.-177.	14	J1	2.79	.02	1.1653	.0100	-.011	.489	.01	3.3
181.-183.	7	SO1	.49	.03	1.2332	.0690	1.057	3.202	.03	17.5
184.-186.	11	OO1	1.46	.03	1.1149	.0246	.942	1.265	.06	158.2
191.-195.	14	NU1	.27	.03	1.0677	.1114	7.355	5.981	.04	126.6
215.-22X.	19	EPS2	.25	.01	1.1399	.0371	3.874	1.862	.02	106.5
233.-236.	10	2N2	.87	.01	1.1395	.0109	2.304	.547	.04	115.1
237.-23X.	10	MU2	1.09	.01	1.1837	.0103	4.297	.496	.08	77.1
243.-245.	13	N2	6.76	.01	1.1769	.0015	2.642	.073	.32	74.0
246.-248.	11	NU2	1.28	.01	1.1732	.0085	2.324	.412	.05	75.7
252.-258.	26	M2	35.74	.01	1.1904	.0003	2.463	.015	1.77	60.2
262.-264.	5	LAMB2	.24	.01	1.0976	.0406	2.665	2.122	.02	141.3
265.-265.	9	L2	.99	.01	1.1636	.0160	6.190	.787	.11	91.5
267.-272.	5	T2	1.00	.01	1.2184	.0111	.511	.522	.05	10.6
273.-273.	4	S2	16.90	.01	1.2100	.0006	1.107	.031	.77	25.2
274.-277.	12	K2	4.58	.01	1.2043	.0024	1.307	.116	.20	32.0
282.-285.	15	ETA2	.26	.01	1.2151	.0348	.772	1.638	.01	16.6
292.-295.	11	2K2	.05	.01	.9703	.1861	-1.660	10.942	.01	-171.6
335.-347.	5	MO3	.11	.01	1.0358	.0522	-1.529	2.863	.00	-139.1
353.-375.	11	M3	.39	.01	1.0498	.0143	.207	.774	.01	167.8

STANDARD DEVIATION D 1.64 SD .55 TD .31 MICROGAL
CENTRAL EPOCH TJJ= 2445296.0

TABLE 2 : Complete listing of the data bank content for station 225 VEURNE.

```
              XXXXX 83/ 8/ 5 XXXXX
                 XXXXXXXXXX

 225VEURNE    WEST-VL   BELGIQUE    51.07400   2.65800    6.    0.   10.  981165.
CST    1000    EFIND   659    EFSC80 1905    ANAL   1740    RESI    775
 V   T  LCR 487 829 835

 487  821209 821217  821221 821221  821225 830321  830325 830524  830528 830625

SCHO1  .06 123.7SCHP1  .07 121.3SCHK1  .25  96.9SCHN2  .41  99.9SCHM2 2.64 110.4SCHS2 1.02  81.7

SCWO1  .06 134.2SCWP1  .07 100.0SCWK1  .25  81.1SCWN2  .33  89.7SCWM2 2.00  95.8SCWS2  .74  66.8

SCWQ1  .01 -93.9SCWK2  .20  77.4SCWMF  .20   5.4

ANALYSIS  VEN 65   SEPARATION  6 MONTHS COMPUTING CENTER  ICET     NETWORK  TEP/TWP

48702251 821209 830625  4608  .99303 1.25 1.37 1.01707*
```

20	Q1	6.77	1.1637	.0192	-.86	.94	.10	-77.1
16	O1	35.45	1.1666	.0038	-.23	.18	.26	-33.3
15	NO1	3.01	1.2595	.0830	1.17	3.78	.25	14.4
10	P1	16.31	1.1529	.0079	-.83	.39	.24	-93.0
23	S1K1	49.16	1.1502	.0026	.42	.13	.65	33.8
14	J1	2.67	1.1156	.0417	-2.04	2.14	.15	-139.5
11	OO1	1.28	.9802	.0957	-7.74	5.61	.30	-145.1
20	2N2	1.02	1.1209	.0420	6.96	2.16	.13	109.3
24	N2	6.48	1.1401	.0084	2.17	.43	.27	115.8
26	M2	33.83	1.1405	.0017	2.84	.09	1.79	110.4
9	L2	.79	.9388	.0924	6.25	5.73	.21	155.7
9	S2	16.51	1.1963	.0036	2.52	.18	.87	56.4
12	K2	4.49	1.1954	.0132	1.53	.64	.18	42.5
16	M3	.40	1.0790	.0872	-2.05	4.71	.01	-74.1

RESIDUS : MODÈLE MOLODENSKII

	B	β	X	χ	δ_c	α_c	δ_m	α_m
O1	.26	-33.2	.32	-37.2	1.1677	-.31	1.1583	.08
P1	.24	-93.0	.30	-85.0	1.1557	-1.06	1.1509	.22
K1	.65	33.8	.58	11.0	1.1509	.13	1.1369	.29
N2	.27	115.8	.17	-106.4	1.1521	-1.41	1.1499	3.57
M2	1.79	110.4	.86	-69.6	1.1705	-1.33	1.1321	4.23
S2	.87	56.4	.44	-40.0	1.1847	-.99	1.1730	3.57

TABLE 3: Indirect effects computed from Schwiderski maps.

58OSTATIONS POUR ONDE O1
58OSTATIONS POUR ONDE P1
58OSTATIONS POUR ONDE K1
58OSTATIONS POUR ONDE N2
58OSTATIONS POUR ONDE M2
58OSTATIONS POUR ONDE S2

201 PRUXELLES			50.80		4.36	SCH.	9										
O1	.128	160.27	P1	.071	79.90	K1	.228	65.94	N2	.376	75.46	M2	1.879	63.06	S2	.619	35.22
203 DOURBES			50.10		4.60	SCH.	9										
O1	.147	167.77	P1	.073	78.16	K1	.234	65.11	N2	.383	78.11	M2	1.935	64.74	S2	.637	35.73
204 SCLAIGNEAUX			50.50		5.03	SCH.	9										
O1	.138	163.95	P1	.070	77.39	K1	.221	64.06	N2	.375	75.49	M2	1.866	61.25	S2	.610	32.97
207 WARMIF.			49.83		5.38	SCH.	9										
O1	.148	168.83	P1	.070	76.99	K1	.220	64.23	N2	.381	77.48	M2	1.901	62.43	S2	.622	33.59
212 COINTE			50.62		5.57	SCH.	9										
O1	.136	162.79	P1	.067	76.24	K1	.212	62.88	N2	.368	73.97	M2	1.815	58.71	S2	.589	30.72
213 BATTICE			50.63		5.80	SCH.	9										
O1	.136	162.59	P1	.066	75.83	K1	.208	62.48	N2	.365	73.53	M2	1.793	57.97	S2	.581	30.05
216 KANNE			50.80		5.67	SCH.	9										
O1	.133	161.19	P1	.066	76.03	K1	.208	62.51	N2	.366	72.90	M2	1.793	57.33	S2	.580	29.64
219 OOSTENDE			51.23		2.93	SCH.	9										
O1	.059	121.72	P1	.069	98.36	K1	.234	80.27	N2	.369	83.89	M2	1.950	85.29	S2	.706	59.15
220 BRUGGE			51.20		3.22	SCH.	9										
O1	.078	139.13	P1	.069	92.36	K1	.231	75.64	N2	.373	79.90	M2	1.901	76.46	S2	.664	50.46
221 LOUVAIN			50.66		4.62	SCH.	9										
O1	.133	162.21	P1	.071	78.70	K1	.226	65.05	N2	.376	75.54	M2	1.977	62.31	S2	.817	34.[illegible]2
225 VEURNE			51.07		2.66	* SCH.	9										
O1	.057	123.69	P1	.075	121.27	K1	.251	96.93	N2	.413	99.87	M2	2.645	110.38	S2	1.020	61.70
226 DAMME			51.25		3.26	SCH.	9										
O1	.079	138.55	P1	.068	91.76	K1	.227	75.17	N2	.378	78.56	M2	1.894	73.79	S2	.656	48.15

TABLE 4 : Repertory of analysis

A) Station Walferdange

a	b	c	d	e	f	g	h				
25602061	710702	711111	0	1.00000	.00	.00	.00000	STATION 0252 WALFERDANGE		7	83/ 7/29
25602581	720210	720323	0	.96125	.00	.00	.00000	STATION 0252 WALFERDANGE	+	4	83/ 7/29
25608041	700917	701201	0	.55658	.00	.00	.00000	STATION 0252 WALFERDANGE		0	83/ 7/29
25701451	751026	770824	8208	.96964	.00	.00	.00000	STATION 0257 WALFERDANGE		300	83/ 7/29
25701452	770824	820915	32448	.96743	.00	.00	.00000	STATION 0257 WALFERDANGE		300	83/ 7/29
25701601	760313	760803	2400	1.03837	.00	.00	.00000	STATION 0257 WALFERDANGE	P	0	83/ 7/29
25701602	760816	780405	9312	1.06232	.00	.00	.00000	STATION 0257 WALFERDANGE		300	83/ 7/29
25701751	790316	810504	9024	.99050	.00	.00	.00000	STATION 0257 WALFERDANGE		300	83/ 7/29
25701911	750701	790607	28080	1.00000	.00	.00	.00000	STATION 0257 WALFERDANGE	P	300	83/ 7/29
25701912	741225	10	56976	1.00000	.00	.00	.00000	STATION 0257 WALFERDANGE		300	83/ 7/29
25702331	801224	830504	16128	1.00000	.00	.00	.00000	STATION 0257 WALFERDANGE	*	7	83/ 7/29

B) Gravimeter GEO.761

a	b	c	d	e	f	g	h				
76108441	750509	750830	1536	.95230	1.30	1.20	1.01693	STATION 0844 TRONDHEIM		101	83/ 7/ 4
76108661	750911	760117	3024	.96730	1.30	1.20	1.01693	STATION 0866 KRAMFORS	*	101	83/ 7/ 4
76108671	760123	760602	3024	.97140	1.30	1.20	1.01693	STATION 867 GAVLE	*	101	83/ 7/ 4
76108681	760619	761015	2208	1.00000	.00	.00	1.01693	STATION 868 VIVATTNET	*	101	83/ 7/ 4
76108691	761112	770221	2208	.97800	.00	.00	.00000	STATION 0869 BOXHOLM	*	101	83/ 7/ 4
76108831	711101	720305	2784	.98072	1.30	1.20	1.01693	STATION 0883 HELSINKI 2		1	83/ 7/ 4
76108832	730925	731227	1776	.96515	1.30	1.20	1.01693	STATION 0883 HELSINKI 2		1	83/ 7/ 4
76108833	750401	750429	720	.94525	1.30	1.20	1.01693	STATION 0883 HELSINKI 2		1	83/ 7/ 4
76108834	790303	800317	8400	.98751	1.20	1.40	1.01664	STATION 0893 HELSINKI 2		201	83/ 7/ 4
76108851	720327	720624	1680	.98072	1.30	1.20	1.01693	STATION 0885 OULU		101	83/ 7/ 4
76108852	800416	801017	4176	.98751	1.20	1.40	1.01664	STATION 0885 OULU	*	101	83/ 7/ 4
76108861	720803	721218	3312	.98072	1.30	1.20	1.01693	STATION 0886 KEVO	*	101	83/ 7/ 4
76108871	801027	810417	3504	.98751	1.20	1.40	1.01664	STATION 0887 SODANKYLA		101	83/ 7/ 4
76108872	721222	730503	3216	.98072	1.30	1.20	1.01693	STATION 0887 SODANKYLA	*	101	83/ 7/ 4
76108881	740202	740521	2640	1.00362	1.30	1.20	1.01693	STATION 0888 VAASA		101	83/ 7/ 4
76108882	770917	771217	2016	.97796	1.30	1.20	1.01693	STATION 0888 VAASA		101	83 7 4
76108891	740703	741029	2880	.98737	1.30	1.20	1.01693	STATION 0889 JOENSUU	*	101	83 7 4
76108901	741124	750320	2352	.99230	1.30	1.20	1.01693	STATION 890 VAAJAKOSKI	*	101	83 7 4

* analysis chosen to represent the mean station
\+ analysis rejected
P partial analysis

a) identification
b) initial epoch
c) final epoch
d) number of readings
e) normalisation factor
f) phase lag M_2
g) phase lag O_1
h) attenuation M_2/O_1

TABLE 5 : Regional Repartition

1	10	GREENLAND/ARCTIC REGIONS
2	11	NORTHERN EUROPE
3	12	WESTERN EUROPE
4	121	IBERIA
5	13	CENTRAL AND SOUTHERN EUROPE
6	14	EASTERN EUROPE
7	20	EAST AFRICA
8	21	NORTH AND WEST AFRICA
9	22	SOUTH AFRICA
10	30	USSR/CHINA/SOUTH EAST ASIA
11	33	MIDDLE EAST/SOUTH ASIA
12	34	SOUTH EAST ASIA
13	35	CENTRAL ASIA
14	36	CHINA/FAR EAST/NORTH PACIFIC
15	40	INDIAN OCEAN
16	41	AUSTRALIA
17	42	NEW ZEALAND/SOUTH PACIFIC
18	43	NORTH PACIFIC
19	50	NORTH AMERICA
20	55	CENTRAL AMERICA/CARRIBEAN SEA
21	60	SOUTH AMERICA
22	90	ANTARCTICA
23	9999	

WAVE M2

STATION		INST	NR	EPOCH	SCALE FACTOR	WAVE AMPL.	AMPLITUDE FACTOR	MSE	PHASE DIFF.	MSE	OBS. RESIDUE AMPL.	OBS. RESIDUE PHASE	CITY		COUNTRY
2701	T	LCR 2	912	5711/5712	1.00000	86.39	1.1565	.0021	-.80	.10	1.24	-102.9	SAIGON		VIETNAM
4010	T	LCR 2	1008	5709/5710	1.00000	85.32	1.2035	.0026	-2.14	.12	4.39	-46.6	BAGUIO		PHILIPPINE
4011	T	LCR 3	2064	7311/7404	1.00460	62.00	1.1679	.0084	-1.96	.42	2.84	-79.9	MANILA	OBSERV.	PHILIPPINE
2600	T	GEO783	4272	8003/8009	.94886	73.96	1.1649	.0007	-.83	.03	1.11	-74.5	GUANGZHOU	KWANGTUNG	CHINE
2601	T	LCR 3	2640	7404/7409	.84338	77.14	1.2012	.0048	-.68	.24	2.79	-19.2	HONG KONG		HONG KONG
2604	T	LCR402	8784	8003/8104	.98462	72.26	1.1748	.0008	-.70	.04	1.26	-44.5	KUNMING	YUNNAN	CHINE
2502	T	GEO 84	2784	7404/7409	1.18255	77.14	1.1473	.0012	-.37	.06	1.00	-149.8	CHIANG MAI		THAILANDE
2450	T	GEO 84	1776	7410/7503	1.18255	67.32	1.1433	.0022	-.21	.11	1.02	-165.8	KATHMANDU		NEPAL
2605	T	GEO765	9648	8003/8105	1.15590	57.33	1.1690	.0006	-.62	.03	.76	-55.1	LANZHOU	KANSU	CHINE
2606	T	GEO 84	4368	8003/8009	1.17424	45.71	1.1684	.0011	-.99	.05	.85	-68.0	URUMQI-.	SINKIANG	CHINE
2603	T	GEO765	3792	7910/8003	1.15590	51.90	1.1798	.0010	.23	.05	.89	13.8	BEIAN HOE	PEIJING	CHINE
2607		MEAN 4	22320	0/ 0	1.00000	65.36	1.1736	.0013	-.59	.11	1.01	-41.8	WUHAN	HUPEH	CHINE
2612	T	GEO783	7248	8105/8204	.94886	63.47	1.1533	.0008	-2.09	.04	2.35	-100.2	SHANGHAI	KIANGSU	CHINE
2614	T	GEO 84	7008	8111/8210	1.17424	58.86	1.2005	.0010	1.06	.05	2.25	28.9	CINGDAO	SHANTUNG	CHINE
2610	T	GEO 84	5952	8010/8111	1.17424	49.27	1.1815	.0013	-.34	.07	.94	-18.4	SHENYANG	LIAONING	CHINE
2750	T	GEO 84	2544	8210/8305	1.17424	57.20	1.2086	.0034	1.30	.16	2.62	29.6	SEOUL/KWANAK KU		COREE
2875	T	LCR402	2928	8205/8211	.98462	67.25	1.2302	.0032	-1.85	.15	4.37	-29.7	KANOYA	KIU SHU	JAPON
2823	P	GEO783	4272	8211/8305	.94886	60.63	1.2044	.0010	-.05	.05	2.23	-1.4	KYOTO	HONDO	JAPON
2840	T	LCR477	4752	7712/7805	1.00000	62.50	1.2460	.0020	.69	.09	4.37	9.9	ABURATSUBO	HONDO	JAPON
2856	T	LCR 34	0	0/ 0	1.00000	60.71	1.2120	.0000	.50	.00	2.65	11.5	FUJIGAWA	HONDO	JAPON
2877	P	GEO783	3408	8205/8210	.94886	59.78	1.2079	.0006	.82	.04	2.51	20.0	TOKYO	HONDO	JAPON
2832	T	LCR 34	0	0/ 0	1.00000	58.23	1.1880	.0000	.35	.00	1.41	14.6	YATSUGAT.	HONDO	JAPON
2836	T	LCR 34	0	0/ 0	1.00000	56.46	1.2020	.0000	.89	.00	2.15	24.1	YAHIKO	HONDO	JAPON
2847	T	LCR402	3456	8106/8111	.98462	54.53	1.2071	.0013	1.53	.06	2.56	34.8	MIZUSAWA	HONDO	JAPON
2897	T	LCR402	3504	8111/8204	.98462	45.92	1.1778	.0017	2.01	.08	1.74	67.6	MEMAMBETSU	HOKAIDO	JAPON
6001	T	LCR 2	1901	5707/5709	1.00000	80.13	1.1705	.0026	1.18	.13	1.79	67.2	WAKE		USA
6003	T	LCR 2	1951	5709/5711	1.00000	78.60	1.1772	.0097	3.82	.47	5.33	79.5	HONOLULU	HAWAII	USA
6004	T	GEO 31	6912	7801/7812	1.00000	81.06	1.2146	.0010	2.16	.05	4.70	40.5	UWEKAHUNA	HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

T : TEMPORARY STATION   P : PERMANENT STATION
NR : NUMBER OF HOURLY READINGS
MSE : ROOT MEAN SQUARE ERROR
OBS.RESIDUE : OBSERVED VECTOR MINUS MOLODENSKII MODEL I VECTOR

WAVE M2

STATION 2607   WUHAN   HUPEH   CHINE

STATION		INST	NR	EPOCH	SCALE FACTOR	WAVE AMPL.	AMPLITUDE FACTOR	MSE	PHASE DIFF.	MSE	OBS. RESIDUE AMPL.	OBS. RESIDUE PHASE
2607	T	GEO 84	3024	7910/8002	1.17424	65.46	1.1755	.0008	-.53	.04	1.05	-35.2
2607	T	LCR402	3408	7910/8003	.98462	65.17	1.1702	.0012	-.31	.06	.66	-32.2
2607	T	GEO765	7152	8105/8203	1.15590	65.48	1.1758	.0008	-.82	.04	1.27	-47.1
2607	T	GEO783	8736	7910/8105	.94886	65.33	1.1731	.0005	-.70	.03	1.07	-48.0
2607		MEAN 4	22320	0/ 0	1.00000	65.36	1.1736	.0013	-.59	.11	1.01	-41.8

TABLE 7

CHINA/FAR EAST/NORTH PACIFIC

STATION	O1 OBSERVED RESIDUE		O1 SCHWIDERSKI MAP		P1 OBSERVED RESIDUE		P1 SCHWIDERSKI MAP		K1 OBSERVED RESIDUE		K1 SCHWIDERSKI MAP		CITY	COUNTRY
2701	1.73	-80.	2.01	-80.					3.00	-123.	2.08	-119.	SAIGON	VIETNAM
4010	2.73	-74.	1.96	-58.					2.42	-86.	1.75	-82.	BAGUIO	PHILIPPINE
4011	2.11	-95.	1.80	-56.					2.02	-80.	1.65	-77.	MANILA OBSERV.	PHILIPPINE
2600	1.21	-66.	1.32	-60.	.33	-94.	.40	-92.	1.39	-98.	1.18	-90.	GUANGZHOU KWANGTUNG	CHINE
2601	2.26	-69.	2.11	-66.					2.60	-84.	2.05	-100.	HONG KONG	HONG KONG
2604	.96	-47.	.40	-45.	.46	-34.	.09	-88.	1.03	-50.	.24	-82.	KUNMING YUNNAN	CHINE
2502	.58	-114.	.45	-63.					1.54	158.	.43	-121.	CHIANG MAI	THAILANDE
2450	.80	178.	.12	54.					.76	140.	.31	135.	KATHMANDU	NEPAL
2605	.36	-24.	.30	2.	.12	9.	.07	-7.	.49	-14.	.23	2.	LANZHOU KANSU	CHINE
2606	.27	0.	.17	57.	.18	-123.	.06	86.	.46	-21.	.19	86.	URUMQI SINKIANG	CHINE
2603	.75	13.	.51	10.	.28	61.	.16	-4.	.92	22.	.54	0.	BEIAN HOE BEIJING	CHINE
2607	.74	-42.	.65	-20.	.09	-36.	.20	-39.	.98	-45.	.63	-32.	WUHAN HUPEH	CHINE
2612	1.03	-17.	1.20	-10.	.38	-28.	.43	-32.	1.74	-36.	1.42	-25.	SHANGHAI KIANGSU	CHINE
2614	.69	-74.	.64	-24.					.64	-102.	.38	-24.	QINGDAO SHANTUNG	CHINE
2610	.59	-13.	.69	14.	.50	-143.	.23	-2.	.92	-9.	.78	1.	SHENYANG LIAONING	CHINE
2623	1.59	7.	.34	-19.	.60	-26.	.07	-44.	2.08	-19.	.21	-31.	CHENGDU SZECHUAN	CHINE
2750	1.13	-49.	.99	-6.					1.63	-30.	1.06	-23.	SEOUL/KWANAK KU	COREE
2875	1.28	-5.	2.11	-0.	.90	32.	.83	-20.	2.35	-38.	2.67	-17.	KANOYA KIU SHU	JAPON
2823	1.59	7.	1.69	11.	.60	-26.	.64	-7.	2.08	-19.	2.11	-6.	KYOTO HONDO	JAPON
2840	3.35	8.	2.19	15.					3.68	-9.	2.73	-2.	ABURATSUBOHONDO	JAPON
2856	2.35	-6.	2.05	14.					4.00	-37.	2.55	-3.	FUJIGAWA HONDO	JAPON
2877	2.05	7.	2.04	16.	.86	3.	.77	-2.	2.78	-2.	2.54	-1.	TOKYO HONDO	JAPON
2832	1.07	26.	1.81	15.					2.35	4.	2.25	-2.	YATSUGAT. HONDO	JAPON
2836	1.77	-1.	1.66	18.					2.69	-22.	2.05	1.	YAHIKO HONDO	JAPON
2847	2.59	4.	2.06	22.	1.13	4.	.76	5.	3.73	-6.	2.54	5.	MIZUSAWA HONDO	JAPON
2897	2.28	14.	2.40	23.					3.07	-0.	2.80	4.	MEMAMBETSUHOKAIDO	JAPON
6001	1.64	-18.	1.54	-1.					1.92	-48.	1.87	-28.	WAKE	USA
6003	1.97	116.	1.89	110.					3.24	94.	3.32	101.	HONOLULU HAWAII	USA
6004	1.82	93.	1.97	112.	1.17	83.	1.03	103.	3.43	82.	3.45	102.	UWEKAHUNA HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

CHINA/FAR EAST/NORTH PACIFIC

STATION	N2 OBSERVED RESIDUE		N2 SCHWIDERSKI MAP		M2 OBSERVED RESIDUE		M2 SCHWIDERSKI MAP		S2 OBSERVED RESIDUE		S2 SCHWIDERSKI MAP		CITY	COUNTRY
2701	1.19	-128.	.18	-117.	1.20	-103.	.67	-162.	.19	118.	.41	163.	SAIGON	VIETNAM
4010	.65	-4.	.44	-3.	4.27	-47.	2.55	-16.	2.02	-29.	.94	-32.	BAGUIO	PHILIPPINE
4011	1.87	-171.	.43	1.	2.85	-80.	2.47	-13.	.91	-68.	.93	-30.	MANILA OBSERV.	PHILIPPINE
2600	.21	-33.	.25	-44.	1.11	-75.	1.09	-55.	.27	-35.	.30	-68.	GUANGZHOU KWANGTUNG	CHINE
2601	.33	-77.	.43	-56.	2.79	-19.	1.86	-67.	1.45	-6.	.59	-86.	HONG KONG	HONG KONG
2604	.23	-48.	.09	-86.	1.26	-44.	.39	-95.	.39	-7.	.13	-173.	KUNMING YUNNAN	CHINE
2502	.20	-123.	.30	-106.	1.00	-150.	1.42	-110.	.99	160.	.59	-165.	CHIANG MAI	THAILANDE
2450	.23	-121.	.20	-102.	1.02	-166.	.87	-111.	.35	165.	.37	-156.	KATHMANDU	NEPAL
2605	.18	-19.	.02	-36.	.76	-55.	.02	-27.	.24	35.	.07	85.	LANZHOU KANSU	CHINE
2606	.15	2.	.06	-113.	.56	-35.	.27	-137.	.74	39.	.12	173.	URUMQI SINKIANG	CHINE
2603	.22	9.	.10	18.	.89	14.	.42	49.	.55	13.	.25	27.	BEIAN HOE BEIJING	CHINE
2607	.24	-15.	.15	-12.	1.01	-42.	.56	-10.	.35	8.	.23	-8.	WUHAN HUPEH	CHINE
2612	.44	-75.	.37	-54.	2.36	-100.	1.15	-55.	.61	-154.	.33	-63.	SHANGHAI KIANGSU	CHINE
2614	.35	33.	.47	22.	2.25	29.	2.44	68.	1.33	27.	.93	21.	QINGDAO SHANTUNG	CHINE
2610	.17	-35.	.14	21.	.94	-18.	.66	46.	.47	-7.	.37	18.	SHENYANG LIAONING	CHINE
2623	.33	10.	.04	-60.	2.23	-1.	.14	-74.	.99	-7.	.05	122.	CHENGDU SZECHUAN	CHINE
2750	.54	38.	.38	40.	2.62	30.	1.68	50.	2.19	14.	.80	19.	SEOUL/KWANAK KU	COREE
2875	.97	-37.	.85	-15.	4.37	-30.	4.24	-12.	1.97	-51.	1.85	-37.	KANOYA KIU SHU	JAPON
2823	.33	10.	.41	-1.	2.23	-1.	2.22	10.	.99	-7.	1.12	-13.	KYOTO HONDO	JAPON
2840					4.37	10.	2.67	24.	2.25	5.	1.40	-4.	ABURATSUBOHONDO	JAPON
2856					2.65	12.	2.59	19.	1.99	-6.	1.34	-7.	FUJIGAWA HONDO	JAPON
2877	.38	4.	.35	14.	2.51	20.	2.33	27.	1.46	3.	1.24	-2.	TOKYO HONDO	JAPON
2832					1.41	15.	2.03	23.	.59	27.	1.08	-5.	YATSUGAT. HONDO	JAPON
2836					2.15	24.	1.63	32.	1.08	7.	.90	1.	YAHIKO HONDO	JAPON
2847	.32	2.	.23	40.	2.56	35.	2.10	48.	1.41	16.	1.11	10.	MIZUSAWA HONDO	JAPON
2897	.05	67.	.17	72.	1.74	66.	2.00	61.	.98	25.	1.02	15.	MEMAMBETSUHOKAIDO	JAPON
6001	.16	-16.	.82	86.	1.75	67.	5.89	76.	1.83	10.	2.70	49.	WAKE	USA
6003	1.06	-148.	.59	97.	5.19	80.	2.41	71.	2.17	73.	1.00	97.	HONOLULU HAWAII	USA
6004	.87	59.	.74	92.	4.71	40.	3.10	68.	1.05	-8.	1.18	87.	UWEKAHUNA HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

TABLE 8

CHINA/FAR EAST/NORTH PACIFIC

STATION	O1 OBSERVED RESIDUE	O1 FINAL RESIDUE	P1 OBSERVED RESIDUE	P1 FINAL RESIDUE	K1 OBSERVED RESIDUE	K1 FINAL RESIDUE	CITY	COUNTRY
2701	1.73 -80.	.28 97.			3.00 -123.	.94 -131.	SAIGON	VIETNAM
4010	2.73 -74.	.99 -106.			2.42 -86.	.68 -98.	BAGUIO	PHILIPPINE
4011	2.11 -95.	1.34 -153.			2.02 -80.	.38 -94.	MANILA OBSERV.	PHILIPPINE
2600	1.21 -66.	.18 168.	.33 -94.	.07 101.	1.39 -98.	.27 -133.	GUANGZHOU KWANGTUNG	CHINE
2601	2.26 -69.	.21 -111.			2.60 -84.	.82 -44.	HONG KONG	HONG KONG
2604	.96 -47.	.56 -49.	.46 -34.	.41 -23.	1.03 -50.	.83 -41.	KUNMING YUNNAN	CHINE
2502	.58 -114.	.46 -163.			1.54 158.	1.54 142.	CHIANG MAI	THAILANDE
2450	.80 178.	.87 -175.			.76 140.	.46 143.	KATHMANDU	NEPAL
2605	.36 -24.	.16 -81.	.12 9.	.06 28.	.49 -14.	.28 -27.	LANZHOU KANSU	CHINE
2606	.27 0.	.23 -39.	.18 -123.	.23 -117.	.46 -21.	.55 -41.	URUMQI SINKIANG	CHINE
2603	.75 13.	.24 19.	.28 61.	.26 96.	.92 22.	.46 47.	BEIAN HOE BEIJING	CHINE
2607	.74 -42.	.28 -104.	.09 -36.	.10 139.	.98 -45.	.39 -65.	WUHAN HUPEH	CHINE
2612	1.03 -17.	.22 -154.	.38 -28.	.06 124.	1.74 -38.	.48 -80.	SHANGHAI KIANGSU	CHINE
2614	.69 -74.	.56 -135.			.64 -102.	.67 -136.	QINGDAO SHANTUNG	CHINE
2610	.59 -13.	.31 -108.	.50 -143.	.69 -155.	.92 -9.	.20 -51.	SHENYANG LIAONING	CHINE
2623	1.59 7.	.15 -123.	.60 -26.	.21 -119.	2.08 -19.	.46 -106.	CHENGDU SZECHUAN	CHINE
2750	1.13 -49.	.79 -108.			1.63 -30.	.59 -44.	SEOUL/KWANAK KU	COREE
2875	1.28 -5.	.54 -173.	.90 32.	.76 91.	2.35 -38.	.96 -136.	KANOYA KIU SHU	JAPON
2823	1.59 7.	.15 -123.	.60 -26.	.21 -119.	2.08 -19.	.46 -106.	KYOTO HONDO	JAPON
2840	3.35 8.	1.22 -6.			3.68 -9.	1.02 -28.	ABURATSUBOHONDO	JAPON
2856	2.35 -6.	.83 -65.			4.00 -37.	2.33 -73.	FUJIGAWA HONDO	JAPON
2877	2.05 7.	.33 -76.	.86 3.	.12 39.	2.78 -2.	.25 -11.	TOKYO HONDO	JAPON
2832	1.07 26.	.78 -179.			2.35 4.	.26 67.	YATSUGAT. HONDO	JAPON
2836	1.77 -1.	.59 -70.			2.69 -22.	1.13 -66.	YAHIKO HONDO	JAPON
2847	2.59 4.	.92 -43.	1.13 4.	.37 3.	3.73 -6.	1.32 -27.	MIZUSAWA HONDO	JAPON
2897	2.28 14.	.38 -90.			3.07 -0.	.37 -40.	MEMAMBETSUHOKAIDO	JAPON
6001	1.54 -18.	.48 -87.			1.92 -48.	.66 -124.	WAKE	USA
6003	1.97 116.	.22 -180.			3.24 94.	.42 -3.	HONOLULU HAWAII	USA
6004	1.82 93.	.65 -1.	1.17 83.	.41 23.	3.43 82.	1.18 1.	UWEKAHUNA HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

CHINA/FAR EAST/NORTH PACIFIC

STATION	N2 OBSERVED RESIDUE	N2 FINAL RESIDUE	M2 OBSERVED RESIDUE	M2 FINAL RESIDUE	S2 OBSERVED RESIDUE	S2 FINAL RESIDUE	CITY	COUNTRY
2701	1.19 -128.	1.02 -129.	1.20 -103.	1.02 -69.	.19 118.	.31 8.	SAIGON	VIETNAM
4010	.65 -4.	.21 -7.	4.27 -47.	2.46 -79.	2.02 -29.	1.09 -27.	BAGUIO	PHILIPPINE
4011	1.87 -171.	2.30 -173.	2.85 -80.	2.95 -130.	.91 -68.	.59 -141.	MANILA OBSERV.	PHILIPPINE
2600	.21 -33.	.06 94.	1.11 -75.	.37 -151.	.27 -35.	.17 51.	GUANGZHOU KWANGTUNG	CHINE
2601	.33 -77.	.17 170.	2.79 -19.	2.06 23.	1.45 -6.	1.46 17.	HONG KONG	HONG KONG
2604	.23 -48.	.17 -29.	1.26 -44.	1.05 -22.	.29 -7.	.51 -4.	KUNMING YUNNAN	CHINE
2502	.20 -123.	.12 102.	1.00 -150.	.93 115.	.99 160.	.61 126.	CHIANG MAI	THAILANDE
2450	.23 -121.	.08 -174.	1.02 -166.	.88 140.	.35 165.	.25 91.	KATHMANDU	NEPAL
2605	.18 -19.	.16 -16.	.76 -55.	.74 -56.	.24 35.	.20 19.	LANZHOU KANSU	CHINE
2606	.15 2.	.18 18.	.56 -35.	.67 -12.	.74 39.	.82 38.	URUMQI SINKIANG	CHINE
2603	.22 9.	.12 1.	.89 14.	.60 -10.	.55 13.	.31 2.	BEIAN HOE BEIJING	CHINE
2607	.24 -15.	.09 -20.	1.01 -42.	.61 -71.	.35 8.	.15 33.	WUHAN HUPEH	CHINE
2612	.44 -75.	.16 -129.	2.36 -100.	1.74 -128.	.61 -154.	.70 178.	SHANGHAI KIANGSU	CHINE
2614	.35 33.	.15 174.	2.25 29.	1.57 -48.	1.33 27.	.42 42.	QINGDAO SHANTUNG	CHINE
2610	.17 -35.	.15 -89.	.94 -18.	.88 -60.	.47 -7.	.20 -58.	SHENYANG LIAONING	CHINE
2623	.33 10.	.11 144.	2.23 -1.	.44 -85.	.99 -7.	.17 129.	CHENGDU SZECHUAN	CHINE
2750	.54 38.	.16 25.	2.62 30.	1.20 0.	2.19 14.	1.39 12.	SEOUL/KWANAK KU	COREE
2875	.97 -37.	.37 -96.	4.37 -30.	1.33 -105.	1.97 -51.	.49 -119.	KANOYA KIU SHU	JAPON
2823	.33 10.	.11 144.	2.23 -1.	.44 -85.	.99 -7.	.17 129.	KYOTO HONDO	JAPON
2840			4.37 10.	1.88 -10.	2.25 5.	.68 18.	ABURATSUBOHONDO	JAPON
2856			2.65 12.	.34 -64.	1.99 -6.	.65 -4.	FUJIGAWA HONDO	JAPON
2877	.38 4.	.07 -60.	2.51 20.	.33 -34.	1.48 3.	.27 27.	TOKYO HONDO	JAPON
2832			1.41 15.	.66 -140.	.59 27.	.66 148.	YATSUGAT. HONDO	JAPON
2836			2.15 24.	.58 2.	1.08 7.	.20 35.	YAHIKO HONDO	JAPON
2847	.32 2.	.20 -44.	2.56 35.	.69 -3.	1.41 16.	.33 37.	MIZUSAWA HONDO	JAPON
2897	.05 67.	.12 -107.	1.74 68.	.34 -157.	.98 25.	.19 125.	MEMAMBETSUHOKAIDO	JAPON
6001	.16 -16.	.87 -83.	1.75 67.	4.17 -101.	1.83 10.	1.72 -29.	WAKE	USA
6003	1.06 -148.	1.41 -126.	5.19 80.	2.83 86.	2.17 73.	1.32 55.	HONOLULU HAWAII	USA
6004	.87 59.	.48 1.	4.71 40.	2.41 4.	1.05 -8.	1.64 -54.	UWEKAHUNA HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

TABLE 9 : CHINA/FAR EAST/NORTH PACIFIC

WAVE M2

TATION	B	BETA	BCOS	BSIN	L	LAMBDA	LCOS	LSIN	X	CHI	XCOS	XSIN	CITY	COUNTRY
2701	1.20	-102.9	-.27	-1.17	.67	-161.5	-.64	-.21	1.02	-68.8	.37	-.96	SAIGON	VIETNAM
4010	4.27	-46.6	2.94	-3.10	2.55	-15.7	2.45	-.69	2.46	-78.6	.48	-2.41	BAGUIO	PHILIPPINE
4011	2.85	-79.9	.50	-2.80	2.47	-13.0	2.40	-.56	2.95	-130.3	-1.91	-2.25	MANILA OBSERV.	PHILIPPINE
2600	1.11	-74.5	.30	-1.07	1.09	-55.1	.62	-.89	.77	-151.4	-.33	-.18	GUANGZHOU KWANGTUNG	CHINE
2601	2.79	-19.2	2.63	-.92	1.86	-66.9	.73	-1.71	2.06	22.6	1.90	.79	HONG KONG	HONG KONG
2604	1.26	-44.5	.90	-.88	.39	-94.6	-.03	-.39	1.05	-27.8	.93	-.49	KUNMING YUNNAN	CHINE
2502	1.00	-150.0	-.86	-.50	1.42	-109.6	-.48	-1.34	.93	114.6	-.39	.84	CHIANG MAI	THAILANDE
2450	1.02	-166.0	-.99	-.25	.87	-111.0	-.31	-.82	.88	139.9	-.68	.57	KATHMANDU	NEPAL
2605	.76	-55.1	.43	-.62	.02	-27.1	.01	-.01	.74	-55.7	.42	-.61	LANZHOU KANSU	CHINE
2606	.56	-34.6	.46	-.32	.27	-136.8	-.19	-.18	.67	-11.9	.66	-.14	URUMQI SINKIANG	CHINE
2603	.89	13.5	.87	.21	.42	49.1	.27	.32	.60	-10.4	.59	-.11	BEIAN HOE BEIJING	CHINE
2607	1.01	-41.9	.75	-.67	.56	-9.8	.56	-.10	.61	-71.3	.20	-.58	WUHAN HUPEH	CHINE
2612	2.36	-100.2	-.42	-2.32	1.15	-55.4	.65	-.95	1.74	-128.0	-1.07	-1.37	SHANGHAI KIANGSU	CHINE
2614	2.25	28.8	1.97	1.08	2.44	67.7	.93	2.26	1.57	-48.4	1.04	-1.17	QINGDAO SHANTUNG	CHINE
2610	.94	-18.2	.89	-.29	.66	45.9	.46	.47	.88	-60.5	.43	-.77	SHENYANG LIAONING	CHINE
2623	2.23	-1.4	2.23	-.05	.14	-74.2	.04	-.13	.44	-84.6	.04	-.44	CHENGDU SZECHUAN	CHINE
2750	2.62	29.6	2.28	1.29	1.68	50.0	1.08	1.29	1.20	.5	1.20	.01	SEOUL/KWANAK KU	COREE
2875	4.37	-29.7	3.80	-2.17	4.24	-12.0	4.15	-.88	1.33	-105.3	-.35	-1.29	KANOYA KIU SHU	JAPON
2823	2.23	-1.4	2.23	-.05	2.22	10.0	2.19	.39	.44	-84.6	.04	-.44	KYOTO HONDO	JAPON
2840	4.37	9.9	4.31	.75	2.67	23.7	2.45	1.07	1.88	-9.8	1.86	-.32	ABURATSUBOHONDO	JAPON
2856	2.65	11.5	2.60	.53	2.59	18.8	2.45	.83	.34	-64.0	.15	-.30	FUJIGAWA HONDO	JAPON
2877	2.51	20.0	2.36	.86	2.33	26.5	2.09	1.04	.33	-33.7	.27	-.18	TOKYO HONDO	JAPON
2832	1.41	14.6	1.37	.36	2.03	22.7	1.87	.78	.66	-139.6	-.50	-.43	YATSUGAT. HONDO	JAPON
2836	2.15	24.1	1.96	.88	1.63	31.6	1.39	.85	.58	2.3	.58	.02	YAHIKO HONDO	JAPON
2847	2.56	34.7	2.10	1.46	2.10	47.5	1.42	1.55	.69	-7.7	.69	-.09	MIZUSAWA HONDO	JAPON
2897	1.74	67.6	.66	1.61	2.00	60.7	.98	1.74	.34	-157.1	-.31	-.13	MEMAMBETSUHOKAIDO	JAPON
6001	1.75	67.2	.68	1.61	5.89	75.8	1.44	5.71	4.17	-100.6	-.77	-4.10	WAKE	USA
6003	5.19	79.5	.94	5.11	2.41	71.5	.77	2.29	2.83	86.4	.18	2.82	HONOLULU HAWAII	USA
6004	4.71	40.5	3.58	3.05	3.10	67.7	1.18	2.87	2.41	4.4	2.40	.18	UWEKAHUNA HAWAII	USA

ALL AMPLITUDES ARE GIVEN IN MICROGALS

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AIG - Commission on Earth Tides - Hamburg 1983

The small tidal waves Q_1 and K_2 as an evidence of the accuracy of the trans world tidal gravity measurements

by

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In a previous paper Melchior and De Becker (1983) have shown that the observational results of the principal tidal gravity waves O_1 P_1 K_1 N_2 M_2 and S_2 fit with a very high degree of confidence a model combining an oceanless elastic earth with liquid core and the oceanic tidal models of Schwiderski.

We deal here with two smaller waves for which Schwiderski (1982) recently constructed oceanic cotidal maps.

The Q_1 wave is the elliptic wave of O_1 (argument $(\tau-s)-(s-p)$). It has a period of 26.86836 hours (26 h 52 m 6 s) and its amplitude is 19 % of the O_1 amplitude. In the tidal gravity variations its amplitude is proportional to sin 2 ϕ and reaches a maximum of 5.95 μgals at 45° latitude.

The K_2 declinational wave is the subharmonic of K_1 (argument 2 $(\tau+s)$). It has a period of 11.9672 hours (11 h 58 m 2 s) and its amplitude is 13 % of the M_2 amplitude. In the tidal gravity variations its amplitude is proportional to $\cos^2 \phi$ and reaches a maximum of 9.50 μgals at the equator.

As in previous papers (Melchior et al. 1981; Melchior and De Becker, 1983) we define $\vec{A}$ (A,α) as the observed tidal vector, $\vec{R}$ (R,o) the tidal gravity variation of an oceanless elastic earth model with liquid core (Molodensky I model) and $\vec{L}$ the tidal gravity variation due to attraction and loading effects of an oceanic cotidal distribution (Schwiderski model). Then :

$$\vec{B} = \vec{A} - \vec{R} \qquad \vec{B} = \vec{B}\ (B,\beta) \text{ is the observed residue} \qquad (1)$$

$$\vec{X} = \vec{B} - \vec{L} \qquad \vec{X} = \vec{X}\ (X,\chi) \text{ is the final residue} \qquad (2)$$

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(xx) Catedra de Astronomia y Geodesia, Universidad Complutense, Madrid.

Obviously the B and L residues obtained for waves as small as Q_1 and K_2 have very small amplitudes which only in a few cases reach one microgal.

Thus, the test we can use to demonstrate the accuracy of our tidal gravity measurements is that, after correction for oceanic attraction and loading effects, the final residual amplitude X is systematically and, possibly, substantially less that the directly observed residual amplitude B, that is :

$$|\vec{X}| = |\vec{B} - \vec{L}| < |\vec{B}| \qquad (3)$$

If the B amplitudes were just due to noise, such a result could not be achieved.

In a recent paper (Melchior and De Becker, 1983) it was suggested on the basis of M_2 wave observations that the noise amplitude ε was 0.5 µgal in Europe but 1.0 µgal in the equatorial zone, this increase being expected from possible calibration errors affecting larger amplitudes at the equator.

We consider here all the stations where the Q_1 or K_2 residual amplitude is 0.2 microgal at least.

The Tables I (Q_1) and II (K_2) show that at the exception of few stations (already suspected for anomalous behaviour like Penang and Manado) the condition (3) is fullfilled at all places.

We can conclude that, with six months registrations, having carefully determined the instrumental constants (amplitude calibration and frequency dependent phase lag) of the gravimeters, our measurements fit the Schwiderski cotidal maps to better than 0.5 microgal, probably to something like 0.3 microgal.

It is even interesting to point out that where the final residue X (Q_1) reaches 0.3 microgal, that is in Australia - New Zealand, its phase χ exhibits such a systematic behaviour in the six concerned stations that it may be ascribed to a real geophysical anomaly. Four different instruments have indeed been used at these places.

We take this opportunity to state that determinations of the instrumental (frequency dependent) phase lags, repeated at intervals of years, have not shown significative differences.

On the contrary we have sometimes experienced more difficulties to control the amplitude sensitivity with some instruments (ex : LCR 003) which have exhibited unexplained jumps. We could, fortunately, take account of these accidents.

Therefore we believe that a zero method applied to such gravimeters (Harrison and Sato, 1983) will surely improve the precision of measurements by essentially ensuring a perfect stability of the sensitivity with time.

The accidental (internal) errors of the observations as determined by the Venedikov method correspond to an error circle with a radius of the order of 0.1 to 0.2 microgal in the diurnal as well as in the semi-diurnal band.

Systematic (external) errors come from two sources :

- on the determination of instrumental constants at the Bruxelles fundamental station
- on the setting of the gravimeters at each individual station.

Obviously, when adjusting the constants of an individual instrument to the Bruxelles system of tidal constants (O_1 amplitude factor, O_1 and M_2 phases), there is an experimental error which is related to the internal error of the analysed series. It is, in general, of the order of 0.25 % in amplitude and 0.1° in phase.

Then, it is difficult to perfectly repeat the identical setting of one gravimeter when it is moved from one station to the other. A small difference in the setting slightly modifies the instrumental constants and this introduces a small systematic error which is different at each station. As we operate eight different equipments it will appear as an accidental error at continental scale.

Anyway, possible systematic errors on the calibration factors as determined at Bruxelles have only negligeable effects on wave as small as Q_1 and K_2 : an accuracy of 1 % in the amplitudes and 0.3° on the phases should produce an error which is less than 0.1 µgal on the Q_1 and K_2 residues.

A global error budget may thus reach 0.3 µgal which fit with the concluded amplitudes of the final residue X as given in the Tables I and II.

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TRANS WORLD TIDAL GRAVITY PROFILES

OBSERVED AND CALCULATED LOADING AND ATTRACTION EFFECTS
RESIDUES WITH RESPECT TO MOLODENSKY MODEL I

DIURNAL WAVE

Q1

STATION	OBSERVED RESIDUE		SCHWIDERSKI MAP		VECTORIAL DIFFERENCE		
	B	β	L	λ	X	χ	
0201 BRUXELLES	0.03	-115	0.03	-125	0.05	30	(*)
0765 POTSDAM	0.08	-150	0.04	-147	0.04	-152	
3019 ARTA	0.34	116	0.23	147	0.19	76	
3020 MOGADISHU	0.46	124	0.31	145	0.20	90	
3602 NOSY-BE	0.57	120	0.25	137	0.34	107	
2550 K.LUMPUR	0.26	-65	0.17	-71	0.10	-108	
2551 PENANG	0.13	64	0.16	-48	0.24	101	
2555 K.KINAB.	0.57	-81	0.44	-75	0.14	-100	
2601 HONG KONG	0.46	-59	0.39	-49	0.10	-100	
4010 BAGUIO	0.62	-54	0.36	-42	0.28	-69	
4011 MANILA	0.78	-128	0.33	-42	0.83	-151	
4105 BANJAR B.	0.42	-90	0.32	-75	0.14	-126	
4110 UJUNG P.	1.01	-90	0.39	-90	0.62	-89	
4111 MANADO	0.89	107	0.33	-50	1.20	113	
4115 KUPANG	0.20	-67	0.43	-106	0.30	49	
4120 JAYA PURA	0.53	10	0.25	-10	0.31	26	
4160 P.MORESBY	0.37	39	0.24	20	0.16	67	
2600 GUANGZHOU	0.31	-58	0.24	-42	0.10	-97	
2614 QINGDAO	0.29	-64	0.13	-9	0.07	69	
2823 KYOTO	0.53	26	0.34	20	0.20	36	
2877 TOKYO	0.46	30	0.41	24	0.24	-90	
2847 MIZUSAWA	0.54	-4	0.41	28	0.29	-52	
2897 MEMAMBET.	0.65	37	0.48	27	0.20	62	
4211 PERTH	0.84	-147	0.31	-112	0.61	-163	
4210 DARWIN	0.37	-166	0.23	-130	0.23	157	
4205 ARMIDALE	0.28	117	0.13	121	0.15	113	
4220 HOBART	0.71	155	0.39	166	0.34	142	
4400 HAMILTON	0.25	157	0.04	130	0.22	161	
4405 WELLINGT.	0.42	144	0.09	155	0.33	141	
4420 LAUDER	0.76	142	0.17	159	0.60	137	
6024 PINON FL	0.32	99	0.36	99	0.04	-81	(*)

(*) Superconducting gravimeters.

SEMI DIURNAL WAVE K2

STATION		OBSERVED RESIDUE		SCHWIDERSKI MAP		VECTORIAL DIFFERENCE		
		B	β	L	λ	X	χ	
0010	GODHAVN	0.41	-66	0.23	-90	0.22	-40	
0011	NARSSAQ	0.82	-11	0.51	-34	0.40	18	
0821	FAEROE	0.88	-25	0.11	-142	0.94	-18	
0201	BRUXELLES	0.21	34	0.15	36	0.06	29	(*)
0315	PARIS	0.28	32	0.20	41	0.09	11	
0312	BORDEAUX	0.39	58	0.50	51	0.12	-151	
0765	POTSDAM	0.10	10	0.09	13	0.01	-14	
0401	VALLE	0.37	79	0.41	75	0.05	-137	
0402	MADRID	0.45	52	0.38	74	0.17	-3	
0403	GRANADA	0.63	52	0.33	85	0.40	25	
0404	SANTANDER	0.77	68	0.83	63	0.09	-163	
0405	BURGOS	1.03	47	0.52	67	0.57	28	
0406	S.FERNAN	0.80	121	0.63	98	0.33	169	
0407	SEPULVEDA	0.17	53	0.42	71	0.26	-97	
0409	CUBILLOS	0.57	84	0.51	76	0.10	131	
0410	TOLEDO	1.53	72	0.38	78	1.15	70	
0411	BARCELONA	0.45	51	0.24	56	0.21	45	
0412	CARBONERO	0.90	36	0.43	73	0.61	11	
0413	CIUDAD R.	0.48	74	0.36	80	0.13	56	
0414	LA GRANJA	0.49	62	0.41	73	0.12	20	
0417	ARCAS	0.40	56	0.32	71	0.12	13	
0427	SANTIAGO	1.06	71	0.84	80	0.27	41	
0433	CALATAYU:	0.55	90	0.35	65	0.28	122	
3014	ADDIS A.	0.17	49	0.20	12	0.12	134	
3019	ARTA	0.77	-24	0.26	-26	0.51	-22	
3020	MOGADIS.	1.96	9	0.76	16	1.21	4	
3030	NAIROBI	0.55	28	0.46	30	0.09	17	
3031	VOI	0.60	63	0.62	30	0.35	139	
3040	DAR ES S.	1.60	74	1.17	31	1.09	120	
3451	BUTARE	0.35	56	0.30	36	0.12	112	
3505	NAMPULA	1.39	4	1.05	23	0.52	-36	
3500	MAPUTO	1.40	28	0.92	30	0.48	24	
3601	ANTANANA	0.96	-3	0.54	14	0.47	-22	
3602	NOSY BE	3.01	10	1.06	17	1.96	6	
3495	HARARE	1.40	56	0.55	35	0.91	68	
3801	JOHANNESB	0.08	50	0.58	42	0.50	-139	
3807	STELLENB.	0.89	81	0.84	74	0.12	142	
2550	K.LUMPUR	0.37	163	0.14	170	0.23	158	
2551	PENANG	0.16	-165	0.34	-185	0.20	-21	
4116	KUPANG	0.54	172	0.86	155	0.38	-49	
4160	P.MORESBY	1.57	-34	0.30	-45	1.28	-31	
2614	QINGDAO	0.40	-57	0.32	2	0.36	-106	
2750	SEOUL	0.69	49	0.27	3	0.54	70	
2875	KANOYA	1.03	-19	0.53	-37	0.55	-1	
2823	KYOTO	0.37	-12	0.33	-17	0.05	22	
2877	TOKYO	0.38	-4	0.35	-7	0.04	27	
2897	MEMAMB.	0.31	29	0.28	13	0.09	91	
6001	WAKE	0.52	23	0.60	49	0.26	-71	
6004	UWEKAHUNA	0.39	20	0.41	89	0.45	-37	
6024	PINON FL.	0.35	-58	0.23	-57	0.12	-59	(*)
4400	HAMILTON	0.97	-126	0.46	-120	0.51	-131	
4405	WELLINGT.	0.45	-143	0.33	-134	0.13	-165	
4420	LAUDER	0.61	67	0.29	-160	0.84	52	

(*) Superconducting gravimeters.

19th IUGG GENERAL ASSEMBLY

AIG - Commission on Earth Tides

Hamburg August 1983.

Effect of lateral heterogeneities in the lithosphere on tidal measurements

by

P. Melchior, M. De Becker, B. Ducarme, Ch. Poitevin, M. Van Ruymbeke

Observatoire Royal de Belgique

In a recent paper, Melchior and De Becker (Pepi 31 27-53, 1983) have shown that there is a very high correlation between the oceanic loading effects $\vec{L}$ calculated on the basis of the Schwiderski maps and the residues $\vec{B}$ of tidal gravity measurements.

For each tidal wave, the definition of the vector $\vec{B}$ and $\vec{L}$ is illustrated by the figure 1 where

$\vec{R}$ (R,O) is the tidal variation of gravity for an oceanless elastic earth model with liquid core,

$\vec{A}(A,\alpha)$ is the observed tidal gravity variation,

$\vec{L}(L,\lambda)$ contains the periodic attraction and loading effects of oceanic tides calculated by the Farrell procedure.

Then

$$\vec{B}(B,\beta) = \vec{A} - \vec{R}$$

$$\vec{X}(X,\chi) = \vec{B} - \vec{L} = \vec{A} - \vec{R} - \vec{L}$$

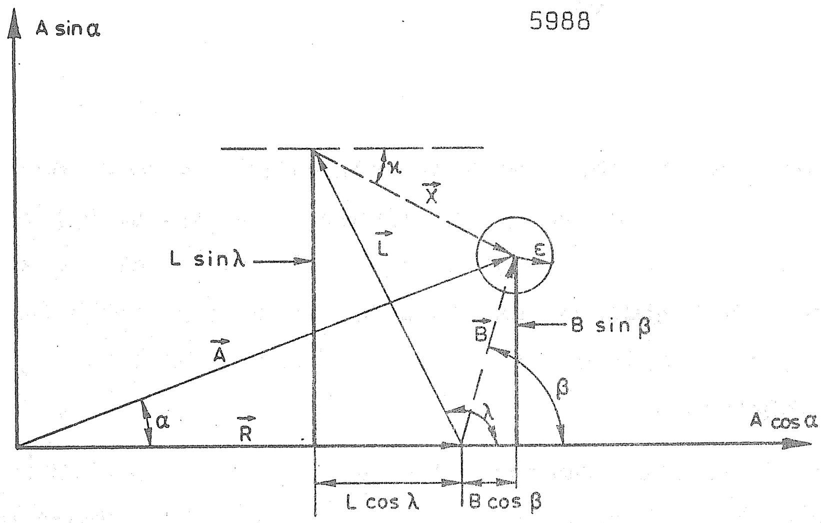

Fig. 1. Comparison of observed and calculated ocean–continent tidal interactions. For the semi-diurnal M_2 wave, the correct scale of this figure should be: $R \simeq A \simeq 40$ (Europe)–90 (Equator) μgal; $\alpha \simeq 0 - \pm 5°$; $L \simeq B \simeq 2$ (Europe)–10 (South Pacific) μgal; $X \simeq 0.5$–5 μgal; $\epsilon \simeq 0.5$ (Europe)–1 (Equatorial zone) μgal ($\mathbb{B} = \mathbb{A} - \mathbb{R}$, $\mathbb{B} - \mathbb{L} = \mathbb{X}$).

We have used the Molodensky model I to evaluate $\vec{R}$ and the Schwiderski oceanic cotidal maps to evaluate $\vec{L}$.

Melchior and De Becker have calculated the correlation coefficients between the sine components B sin β, L sin λ and between the cosine components B cos β, L cos λ for the six main waves O_1 P_1 K_1 N_2 M_2 S_2.

As clearly shown by the figure 1, the correlation between B sin β and L sin λ is not affected by the choice of the Earth model if the viscous phase lag of the Earth is negligible.

Melchior and De Becker had found that the correlation coefficient is very high (for 165 stations : 0,93 in M_2, 0,78 in N_2 and O_1) for the sine components (L sin λ, B sin β) but slightly and systematically lower (respectively 0.83, 0,68, 0,51) for the cosine components (L cos λ, B cos β).

The stations which are responsible for this decrease of correlation in the cosine components, evidently exhibit a "large" residue X cos χ (1 to 5 μgal on M_2) and a small residue X sin χ (0.5 μgal or less). (see Table 1).

These stations are situated in peculiar tectonic areas. For what concerns Europe , only four stations gave X cos χ ∿ 1 or 2 microgals with X sin χ ∿ 0.1 to 0.2 microgal only. These stations are situated in the two areas where Panza et al. (1980) found a considerable thickening of the Lithosphere from seismic S waves propagation analysis (figure 2). At all the other european stations X cos χ is negligible as well as X sin χ.

This induced the authors to correlate the high X cos χ residues with effects of lateral heterogeneities in the Lithosphere and Upper Mantle.

As is well known, the load tide deformation is more concentrated in the upper crust, so that it is likely that lateral heterogeneities in the crust would throw off the sine terms as well as the cosine terms. The effect observed exists only for the cosine terms and consequently should imply the existence of deep anomalies in the structure of the Earth.

The four stations concerned were Clermont Ferrand (France), Padova and Trieste (Italy) and Graz (Austria) where we had installed 3 different Geodynamics gravimeters.

To check the reality of such an effect we have installed, in 1983, another gravimeter (LaCoste Romberg n°336) at Avignon (France), which is situated at the centre of one of the two areas of greatest lithospheric thickness in Europe. The result obtained from the first 100 days of registration reconfirms the proposed interpretation.

Amplitudes of 1 to 2 microgals for X cos χ are significant, the general discussion of our measurements having shown that with series of four to six months of registration the noise is surely less than 0.5 or even 0.3 µgal on $\bar{B}$ or $\bar{X}$.

The most essential care to be taken for such measurements is with the determination of the frequency dependent instrumental phase lags which can reach one to two degrees with astaticized gravimeters. This was done by intercomparison of all our instruments, at the same station Bruxelles, with static instruments.

Very recently our phase measurements have been reconfirmed by comparison to one year registrations of a Superconducting gravimeter installed at ROB, Bruxelles (Ducarme 1983).

Acknowledgments: Thanks are due to Prof. J. Nougier, Laboratoire de Géologie, Faculté des Sciences at Avignon who maked possible the installation of our equipment and to Mr. M. Daniel for his excellent maintenance of the systems.

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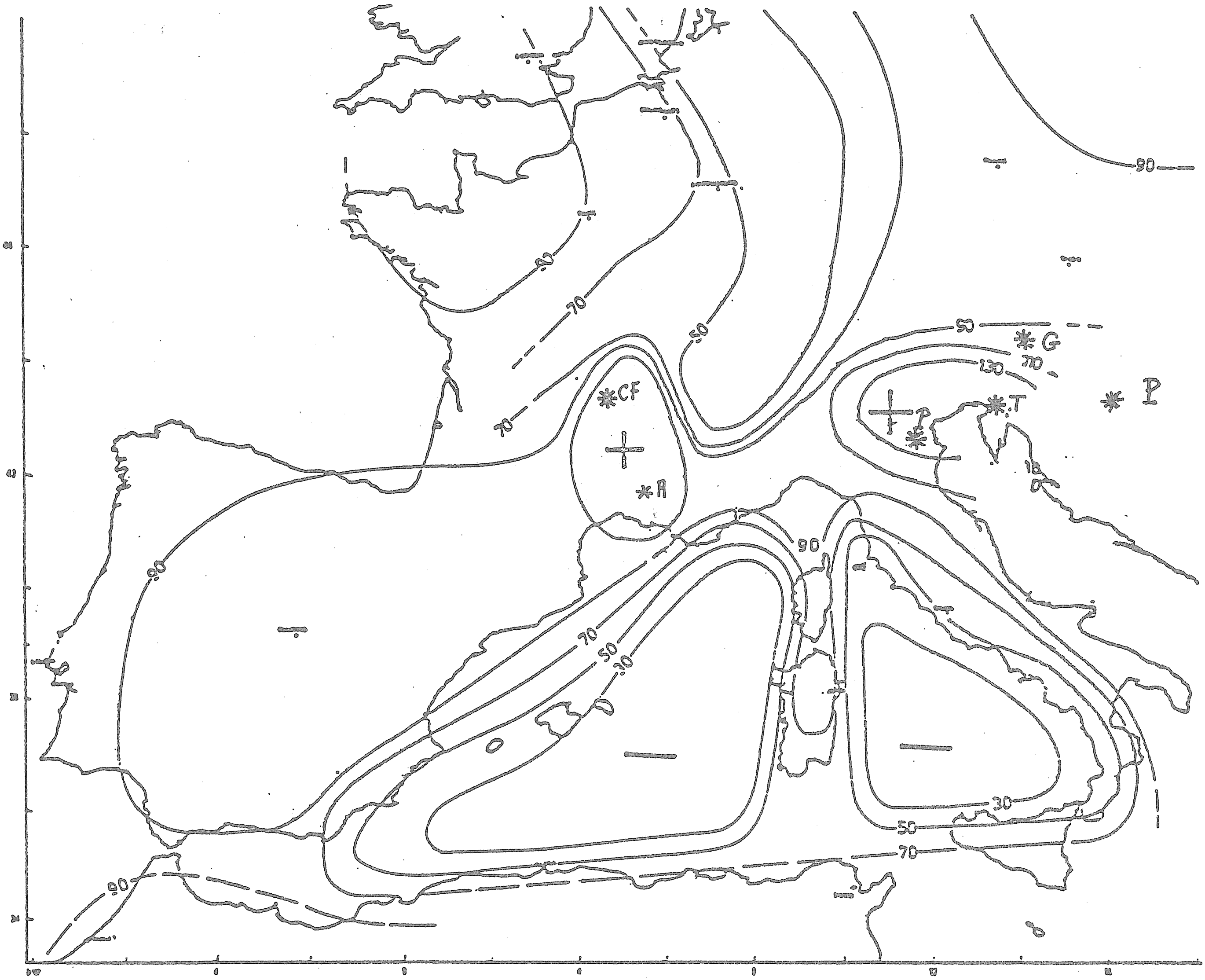
Table 1

Residuals in abnormal areas for M_2 wave

Station		$X \cos \chi$	$X \sin \chi$	d[a] (km)
2201	Teheran	2.02	0.28	600
2202	Tabriz	1.95	0.00	920
2350	Quetta	2.62	0.05	550
2351	Lahore	1.66	−0.35	1000
2352	Peshawar	1.64	−1.02	1080
Indonesia / Torrès Strait				
4100	Bandung	4.28	−0.15	70
4105	Banjar Baru	2.00	0.57	10
4110	Ujung Pandang	4.92	−0.78	12
4111	Manado	2.96	−0.63	4
4115	Kupang	2.28	−0.28	5
4120	Jaya Pura	3.10	−0.89	5
4160	Port Moresby	4.98	0.88	5
4210	Darwin	2.91	1.30	60
New Zealand / South Pacific				
4220	Hobart	1.73	−0.70	1
4400	Hamilton	2.11	−0.81	40
4401	Taupo	2.16	−0.04	100
4405	Wellington	1.32	−0.51	5
4420	Lauder	1.10	−0.27	100
4450	Noumea	4.94	−5.49	0
4460	Suva	2.23	0.08	15
4475	Apia	5.21	−4.53	0
4480	Papeete	2.38	−0.42	4
Corner of Africa				
3018	Arta-Djibouti	5.39	−0.25	10
3014	Addis Ababa	−0.56	−0.13	500
3020	Mogadishu	1.87	−0.40	5

[a] Distance to the nearest sea.



	M_2 Wave Residues	X cos χ	X sin χ
0310	Clermont Ferrand	0.95	0.07
0325	Avignon	1.16	0.26
0508	Padova	1.93	-0.24
0509	Trieste	1.24	-0.34
0695	Graz	1.10	0.00
0955	PECS	1.07	-0.16

amplitudes are in μgals.

Figure 2.

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SAMPLING AND PREPROCESSING OF TIDAL DATA AT ONE MINUTE INTERVAL

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Observatoire Royal de Belgique

ABSTRACT

The Royal Observatory of Belgium designed a new Digital Data Acquisition System based on a 8085 microprocessor from INTEL. It is operational since one year for the Superconducting Gravimeter and will also equip the stations of the Trans World Tidal Gravity Profile and the Underground Laboratory for Geodynamics at Walferdange.

The tidal signal recorded by a gravimeter is frequency converted, counted during one minute and stored on a magnetic cassette.

Special procedures are used for the processing of the original data and the extraction of the hourly values by interpolating and smoothing with cubic splines.

1. INTRODUCTION

After preliminary experiments performed with a Digital Data Acquisition System (DDAS) belonging to the National Geographical Institute of Belgium, see (Poitevin & De Becker, 1983), The Royal Observatory of Belgium designed a new DDAS based on a 8085 microprocessor from INTEL. It is operational since one year for the Superconducting gravimeter and will also equip the stations of the Trans World Tidal Gravity Profile and the Underground Laboratory for Geodynamics at Walferdange.

We give some details about the software developed for the processing of the data with special emphasis on the superconducting gravimeter.

2. THE DIGITAL DATA ACQUISITION SYSTEM (DDAS)

This system was built to accomodate simultaneously three different frequency modulated signals and integrate them during one minute (Rasson, 1978) in order to suppress the high frequencies that could produce aliasing. The sensitivity is adjusted by a frequency divider.

A Digital to Analog converter produces an analog signal which is used for visual control on a chart strip recorder.

A block diagram of the DDAS is shown in figure 1. A clock is driven by an external 1 Hz pulse and produces interrupts for the 8085 microprocessor and integrators.

Each minute the integration stops; the three input latches are scanned and the data stored in the memory.

Each hour the content of the memories is stored on the cassette recorder. A block diagram of the microprocessor program is given in figure 2.

A complete record comprises a heading of 12 hexadecimal characters (number of station, number of instrument, year, month, day, hour) followed by 60 minute-readings and an end of message word.

Heading:

XX XX	XX N* X	X X	X X
LSB MSB	LSB MSB		
number of station	day of the year	amount of readings	hour

Readings:

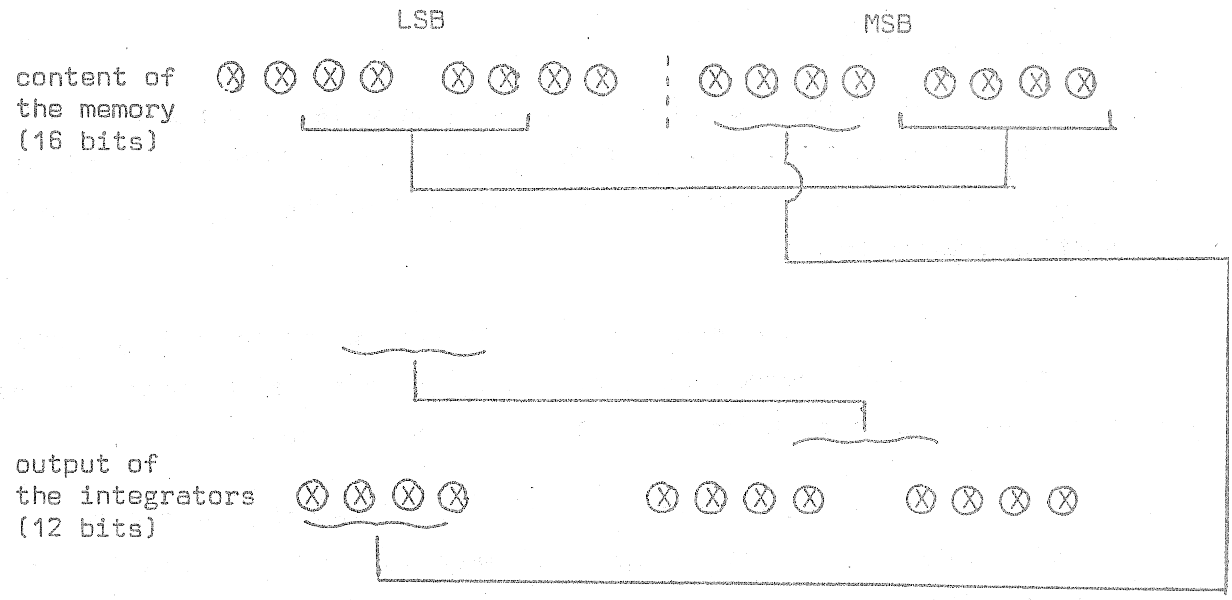
X X	XX XX	XX XX	....	XX XX
	LSB MSB	LSB MSB		LSB MSB
minute	first instrument	second instrument		last instrument

The data are written in binary code and the heading in BCD. The message is written byte per byte (1 byte = 8 bits = 2 hexadecimal characters). When a word has two bytes, the least significant bit (LSB) is written before the most significant bit (MSB).

The structure of the 16 bits words is the following :

---

* N is the amount of instruments recorded.



Duplication of bits inside words are used for parity test.

3. SIGNAL CONDITIONING

For the spring-gravimeters we have either a frequency modulated output (Geodynamics) or an analog DC voltage (Askania, LaCoste-Romberg) which is frequency modulated to be used by the DDAS. For the superconducting instrument the feedback signal is first digitized by a high speed 16 bits Analog to Digital converter and sent to the recording room where the 12 less significant bits are converted again to an analog DC signal to be frequency modulated.

The analog signal is fed to a chart strip recorder for control and the FM signal sent to the DDAS.

4. PROCESSING OF THE DATA

The cassette is transferred onto a tape reel and then processed by a mainframe. A first program convert the hexadecimal readings to the decimal code and detect the separation of the records.

Eventual errors are detected and corrected by the same program.

Finally, the minutes data are written in the ICET format to concur with international standards.

5. HOURLY SAMPLING

The sampling program currently used is an improvement of the first program explained in (Poitevin & De Becker, 1983). This first one had to be transformed in order to treat also the data from the very sensitive superconducting gravimeter.

The first step in the program aims to detect the perturbations like spikes, full scale corrections, drift corrections, calibrations and earthquakes, superimposed on the recorded tidal curve (fig. 3 and 4)

These discontinuities are detected by shifting a data-vector of variable length (12 values maximum) on which a parabolic least square fit is applied. When the error level is exceeded we consider that a perturbation had started. Then a new shifting vector is created to the right of the wrong values and displaced until the error becomes again lower than threshold.

All data in between are replaced by zero. The standard deviation on the least square fit is adjustable since the program is used for spring gravimeters as well as the superconducting one; It is also a good indicator of the noise level. For the superconducting gravimeter, the standard deviation is 200 units. The corresponding root mean square error of 14 units corresponds to 0.04 μgals. The data-block obtained in this way contains zeros in place of the rejected data.

The two series of non-zero data on both sides of the discontinuity are then used in the computation of a parabolic least square fit with two zero order unknowns : In case of a full scale or a drift correction, or a calibration, the difference of the two values indicate the height of the jump.

For spring gravimeters, calibrations and drift corrections require, of course, special care : the 30 minutes following a drift correction or a calibration are extracted as they are affected by the instrumental phase lag. In the next step, the program performs the interpolation of the rejected data and the smoothing of the tidal curve. This is done by means of a cubic spline function as described in (C.H. Reinsch, 1967) and with a fixed error of 50 units on each value for the superconducting gravimeter.

It must be noted that, in order to save computer time, the whole handling is done with blocks of 835 values and that two consecutive blocks overlap one another over 144 values. Finally the full-hour values are computed and organized into records in ICET format.

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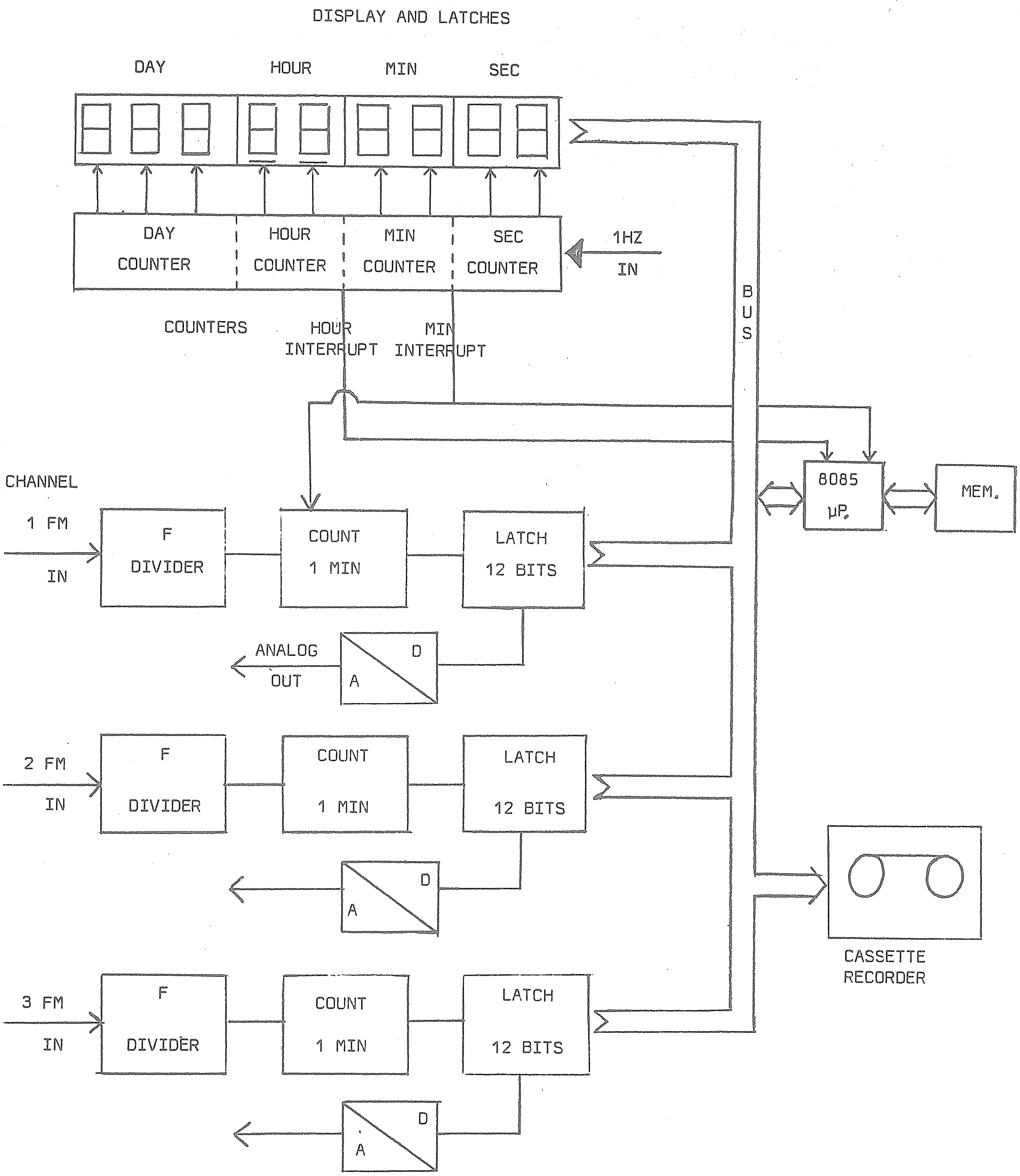
DISPLAY AND LATCHES
DAY
HOUR
MIN
SEC
DAY COUNTER
HOUR COUNTER
MIN COUNTER
SEC COUNTER
1HZ IN
COUNTERS
HOUR INTERRUPT
MIN INTERRUPT
B U S
8085 µP.
MEM.
CHANNEL
1 FM IN
F DIVIDER
COUNT 1 MIN
LATCH 12 BITS
ANALOG OUT
D
A
2 FM IN
F DIVIDER
COUNT 1 MIN
LATCH 12 BITS
D
A
CASSETTE RECORDER
3 FM IN
F DIVIDER
COUNT 1 MIN
LATCH 12 BITS
D
A

Figure 1.

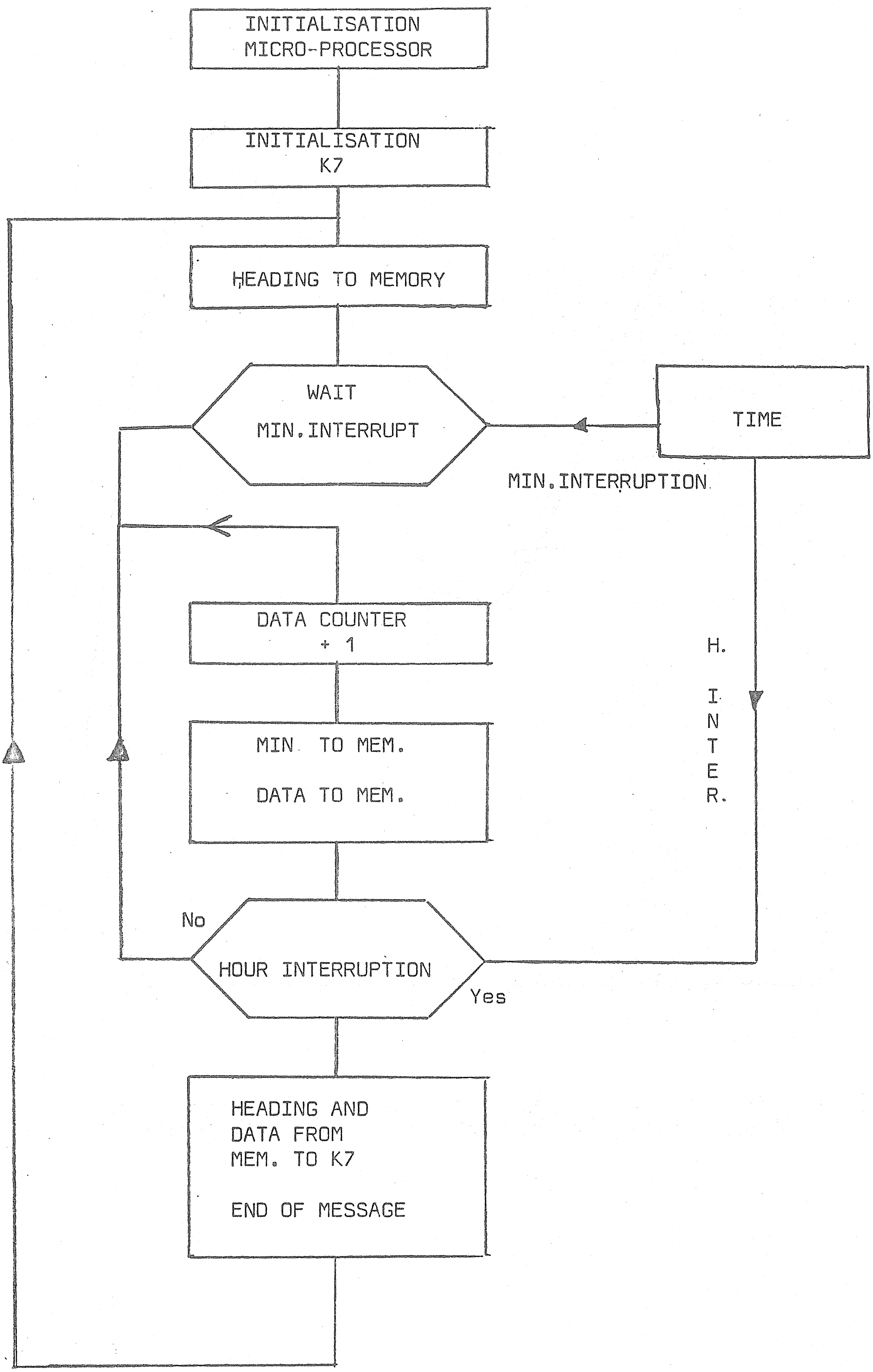
INITIALISATION
MICRO-PROCESSOR
INITIALISATION
K7
HEADING TO MEMORY
WAIT
MIN.INTERRUPT
TIME
MIN.INTERRUPTION
DATA COUNTER
+ 1
H.
INTER.
MIN TO MEM.
DATA TO MEM.
No
HOUR INTERRUPTION
Yes
HEADING AND
DATA FROM
MEM. TO K7
END OF MESSAGE

Figure 2

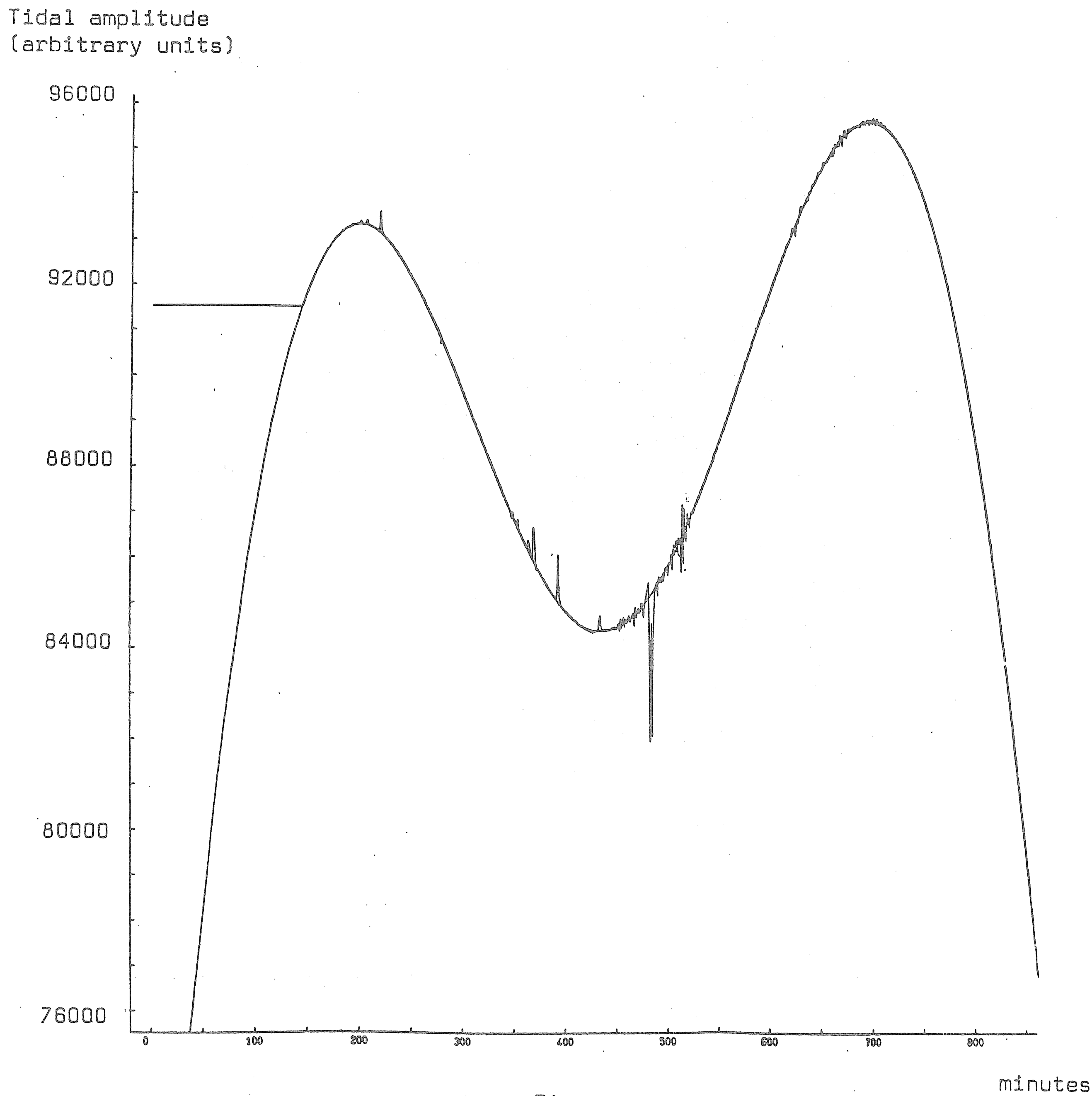

Figure 3

Tidal curve recorded by the superconducting gravimeter and perturbed by an earthquake : the computed curve is interpolated through the earthquake.

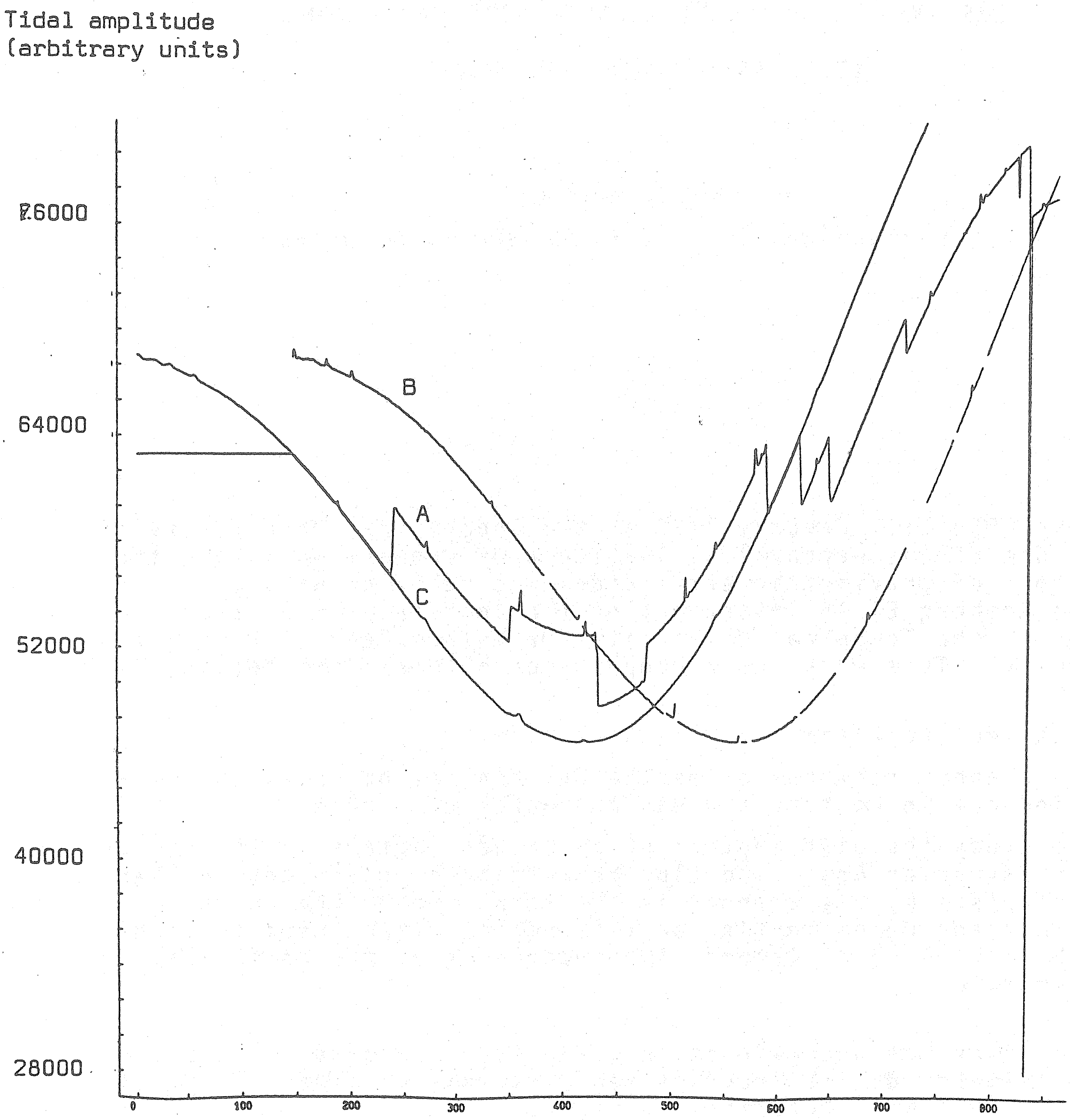

Figure 4

A : recorded curve
B : "cleaned" curve, perturbations being extracted
C : smoothed curve

This very bad part of the record should have been removed for the analysis but the sampling program corrected for jumps and peaks in such a way that the data are saved.

OBSERVATION OF GRAVITY EARTH TIDE VARIATIONS AT TIHANY STATION (HUNGARY)

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SUMMARY

From May 1980 till January 1982 at the Geophysical Observatory of the Loránd Eötvös Geophysical Institute of Hungary in Tihany the variation of gravimetric earth tides was recorded with the LaCoste-Romberg ET 16 Instrument of the Institute of Physical Geodesy of the Technical University, Darmstadt/Federal Republic of Germany/. This work was a cooperation between these two institutions.

The most important aims of this work were:

- to connect networks of earthtidal gravity observations carried out in western and eastern parts of Europe.
- to study the distribution of amplitude factors in the region of Pannonian Basin and Alps because this region can be characterised by big changes in the structure of the Earth's crust and upper mantle, so this region can be used to study the influence of lateral inhomogeneties on the earthtidal parameters .
- to check the anomalic phase differences observed with ET-16 gravimeter during previous registrations in Tihany where it is rather well determined already.

The first analysis results of measurements with ET-16 are very near to results obtained with BN-07 in the same station. This fact allows to compare earth tide parameters determined with these two instruments in Budapest, Tihany, Graz and Zürich.

1. Introduction

From May 1980 till January 1982 the variations of gravimetric earth tides were recorded at the Geophysical Observatory of the Loránd Eötvös Geophysical Institute of Hungary with the LaCoste-Romberg

ET-16 instrument of the Institute of Physical Geodesy of the Technical University Darmstadt/Federal Republic Germany/. This work was done in a cooperation between these two institutions.
The geophysical use of gravity earth tide records yields, first of all, the possibility to study, with their help, the lateral inhomogenities of the Earth which are better studied than other types of measurements (such as seismological, geoelectrical etc.) or can very well supplement them. With the aim of studying these parameters of the Earth a relatively dense network measurement was established for example in Western Europe (Melchior et al, 1981) and at many stations in Eastern Europe (Dittfeld et al, 1981).
To connect these two independently realized systems of observations is the main purpose of the measurements reported in this paper.

The first Earth tide observations on the Tihany station were carried out during the International Geophysical Year in 1957-58. Measurements with recording gravimeters with capacitive transducer are in progress since 1973. Since that time measurements with six different types of such instruments were carried out.
Tihany is situated on a peninsula of the Lake Balaton, which is composed of young vulcanic formations, sandstone and clay.
Coordinates of the station are:

$\phi = 46° 54'$ N

$\lambda = 17° 52'$ E

$h = 145$ m

and it is 55 m above the mean level of lake Balaton

2. Instrumentation

LaCoste-Romberg Earth tide gravimeter No. 16 was installed in the cellar of the main building of Tihany Observatory. This cellar was especially designed for the recording of gravity variations. The measuring room was kept at constant temperature (daily temperature variations < 0.05 C°). The installation of the ET 16 gravimeter was similar to the one already carried out in Zürich in 1976 (Gerstenecker, C., 1979). Both analog and digital records were obtained simultanously. An additional encoder enables the digital registration of the analog-mechanical output of the gravimeter. The digitalisation of the analog signal was controlled by a Hewlett-Packard coupler. The recorded data were printed and punched on a teletype. Sampling interval was 10 min. Because of the rather isolated position of the station from the electric network an emergency source of AC was installed. In spite of this fact, in some cases, the irregularities of the electric network produced interruptions or highly disturbed the record. Some problems were produced by the imperfect coupling of feedback system during the second half of the recording period. Using the possibilities given by the digital recording parallel with gravimetric data the temperature and barometric variation were also recorded together with the deviation of the beam from the zero position of the gravimeter. The temperature variations were measured in three different places: one thermosensor was installed outside, i.e. in the open air, one in the room where the Hewlett-Packard type coupler was in operation and the last one was kept above the gravimeter itself.

3. Processing and analysis of the recorded data

The punched records were transferred on magnetic tapes at the Lorând Eötvös Geophysical Institute of Hungary, which was processed than on the IBM computer 370/168 of the Technical University Darmstadt.

The data processing was divided into the following steps:

- separation data of different type
- smoothing the disturbed parts of the records, corrections of the wrong data produced by improper work of used puncher.
- interpolations of missing hourly values (the maximal lenghth of interpolations were 6 hours). Less as 1% of analysed data was interpolated.

For the analysis of records, first of all, Fourier transformations have been used. Amplitude and phase spectra of gravimetric and beam position hourly values were determined. From these we found that beam position spectras contained anomalies in tidal frequency bands in the second half of recording period. This problem was connected probably with a partial imperfect work of mechanical feedback system. The beam position anomalies on the frequency intervals of diurnal and semidiurnal waves prove that the feedback system couldn't fully compensate the total tide during this time, the beam deviated systematically from the zero position and the data set based on the mechanical feedback system showed nonlinear deviations which could not be connected on simple way. Therefore, for the analysis of the digital output, we used the first part of the record from 22.11.1980 till 13.11.1981. For the analysis we used a time series with 7571 hourly values from 8544 hours of record.

Our data analysis results are based on Schüller's method (Schüller, 1978) like previous records carried out with ET-16 in Zürich (Switzerland) (Gerstenecker, 1979). The advantage of Schüller's method lies in the extensive and detailed information on the analised record. For our present work the residual curve was very important which was printed simultaneously with earthtidal parameters. From this curve we could exclude some disturbed parts of the record and thus increase the reliability of the analysis results obtained in this way.

4. Discussion of the analysis results

Table 1. shows the analysis results of ET-16 in Tihany. All amplitude factors presented here are corrected because the small deviations of the beam from its zero position. The correction factor was determined on the basis of the non-lunisolar part of Fourier spectra of gravity and beam position records. The coefficient obtained was 1.008458 microgal/(beam position unit), and it was succesfully used to determine the real amplitude of observed main waves.

The Earth tide parameters obtained in Tihany are similar to the results obtained at Zürich in two aspects:

- the phase differences are of the same charakter. Big negativ values are characterising the diurnal waves, the semidiurnal ones can be characterised by large positiv values
- amplitude factor of N_2 wave is relatively small

In comparison with earlier results obtained in Tihany during previous measurements we can conclude, that amplitude factors of O_1, K_1 and M_2 obtained on the basis of ET-16 record are very close to those which have been accepted as basic results of Tihany station (Table 2.).

On the basis of above conclusions we can state that amplitude factors measured by ET-16 and BN 07 (instrument of L. Eötvös Geophysical Institute) are in agreement and we can therefore compare results obtained with this instruments in different places of the Pannonian Basin and in Alpic Region separately

Table 3. shows that amplitude factors of O_1 and M_2 tidal waves determined for stations Budapest, Tihany and Graz are in agreement but they are significantly smaller than earthtidal parameters obtained from observations with ET-16 in Zürich.

Table 1. Analysis results of earth tide records obtained with LaCoste-Romberg ET-16 gravimeter in Tihany

Length of the analysed series: 8544 hours

		Amplitude factors	Phase differences
Diurnal waves	Q_1	1.1556 ± 0.0029	- 1°90 ± 0°15
	O_1	1.1561 ± 0.0006	- 0°82 ± 0°02
	K_1	1.1378 ± 0.0004	- 0°85 ± 0°02
Semidiurnal waves	N_2	1.1561 ± 0.0075	- 1°25 ± 0°39
	M_2	1.1833 ± 0.0016	- 1.03 ± 0°08
	S_2	1.1771 ± 0.0039	- 2°03 ± 0°17

Table 2. Comparison of earth tide parameters determined with ET-16 with results obtained from previous registrations carried out in Tihany

	Amplitude factors		Phase differences	
	ET 16	Former results	ET 16	Former results
O_1	1.1561	1.1564	- 0°82	-0°03
M_2	1.1833	1.1876	- 1°03	+ 0°33

Table 3. Amplitude factors of O_1 diurnal and M_2 semidiurnal waves determined in the Pannonian Basin and in the Alpic Region

STATION	ϕ	λ	INSTRUMENT	LENGTH OF THE RECORD	O_1	M_2
Zürich	47°37	8°55	ET 16	15019 hours	1.168	1.195
Graz	47°08	15°44	BN-07	650 hours	1.153	1.185
Tihany	46°90	17°86	ET 16, BN-07	7571 hours and 4848 hours	1.156	1.185
Budapest	47°33	19°05	BN-07	5680 hours	1.156	1.189

Table 2 shows that a differnece is existing between the phase lags determined from the records of ET-16 instrument and the formerly determined ones.

Using the hysteresis model "HYSE" introduced by Gerstenecker and Schüller (1983) we corrected the phase differences obtained with ET-16 at Zürich and Tihany stations. A comparison of results obtained in Tihany with the former results of this station (Table 4) shows, that the introduced model can explain mainly the anomalic phase lag values obtained with ET-16 gravity meter earlier (Gerstenecker, Groten, 1976; Gerstenecker 1979).

Table 4. Phase differences for main diurnal and semi-diurnal waves in Zürich and Tihany obtained with ET-16.

	Zürich		Tihany		Former results in Tihany
	observed	corrected	observed	corrected	
O_1	-0°68	-0°25	-0°82	-0°40	-0°03
K_1	-0°47	+0°04	-0°85	-0°33	-0°38
M_2	0°40	+1°60	-1°03	+0°33	+0°33

Using the results obtained by the authors earlier - with the help of intercalibration carried out in Tihany - it is possible to determine a homogeneous set of residual M_2 vectors, determined on the basis of cotidal maps of Schwiderski (1980):

Darmstadt (ET-16)	0.28 μgal	-52°3
Zürich (ET-16)	0.42 μgal	-29°6
Graz (BN-07)	0.05 μgal	+ 0°4
Tihany (ET-16, BN-07)	0.48 μgal	+81°2
Budapest (BN-07)	0.25 μgal	-46°7

The indirect effect of oceanic tides, necessary to calculate these vectors were calculated by B.Ducarme (Royal Observatory of Belgium). The listed values of residual vectors show, that

- relatively big residual obtained formerly in Graz by different authors (see on this problem paper Lichtenegger et at, 1983) is not existing really. Probably it can be explained with anomalic behaviour of earlier used instruments.

- in the case of studied stations there are no anomalic ones. There is not existing any observable simple correlation with the geology.

The systematic character of amplitude factor deviations determined with ET-16 in Zürich and Tihany are shown in Table 5.

Table 5. Results for main diurnal and semidiurnal wave groups in Zürich and Tihany obtained on the basis of records of ET-16./ Corrections on the basis of "HYSE" model (Gerstenecker, Schüller, 1983) are introduced./

	Zürich	Tihany
Epoch	1976-78	1980-81
Length of the record	15019 hours	7571 hours
Q_1	1.1600 ± 0.0048 -0°61 ± 0°24	1.1556 ± 0.0029 -1°48 ± 0°15
O_1	1.1684 ± 0.0009 -0°25 ± 0°04	1.1561 ± 0.0006 -0°40 ± 0°02
K_1	1.1533 ± 0.0006 +0°04 ± 0°03	1.1378 ± 0.0004 +0°33 ± 0°02
N_2	1.1760 ± 0.0045 1.55 ± 0°43	1.1561 ± 0.0075 +0.08 ± 0°39
M_2	1.1954 ± 0.0008 1°60 ± 0°04	1.1833 ± 0.0016 +0.33 ± 0°08
S_2	1.2001 ± 0.0018 +0.74 ± 0°09	1.1771 ± 0.0039 1°95 ± 0°17

In spite of the fact, that both records are characterised with low values of internal errors - much smaller as the detected deviation between Zürich and Tihany - we must be very careful with the interpretation of the observed difference in amplitude factors between this two stations. First of all we must take into consideration the anomalic error distribution of the results obtained from registrations carried out in Tihany. Here we got bigger error values for the semidiurnal waves as for the diurnal ones, contrary to the other stations.

To verify that the observed difference is not of instrumental origin additional measurements are needed in Zürich.

Due to the big and sharp variations in the structure of the crust and the mantle in the studied region, it seems to be a good test area to investigate the influence of lateral inhomogenities on the amplitude factors determined from gravimetric records.

5. Acknowledgements

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Traduction

INFLUENCE DE LA VISCOSITE DU NOYAU SUR LES VARIATIONS DE LA VITESSE DE ROTATION DE LA TERRE DUES AUX MAREES

S.M. Molodenskii

Rotation et déformations de marées de la Terre Vol.14 pp 46-50 - 1982

On sait que les composantes à longue période des marées luni-solaires provoquent des variations du moment d'inertie de la Terre par rapport à l'axe de rotation et provoquent des variations de la vitesse de rotation de la Terre qui sont observées.

Si le couplage entre le noyau et le manteau est suffisamment fort (viscosité du noyau élevée) la variation de la vitesse angulaire de la rotation de la Terre $\delta\omega$ est déterminée par l'expression

$$\frac{\delta\omega}{\omega} = - \frac{\delta C}{C} \tag{1}$$

où C et δC sont respectivement le moment d'inertie de la Terre entière et sa variation par rapport à l'axe de rotation ($\bar{k} = \bar{\omega}/\omega$; ω est la vitesse angulaire moyenne de la rotation de la Terre). Si le couplage est faible, les variations de rotation du noyau, dues aux marées, peuvent ne pas correspondre aux variations de la vitesse de rotation de l'enveloppe et, au lieu de (1), on aura l'égalité

$$\frac{\delta\omega}{\omega} = - \frac{\delta\ C_1}{C_1} \tag{2}$$

où C_1 et δC_1 sont le moment d'inertie du manteau et la variation d'inertie du système "manteau-océan" par rapport à l'axe $\bar{k}$.

Dans ce travail on montre que la différence des résultats obtenus d'après les formules (1) et (2) augmente sensiblement les erreurs des variations de marées astronomiques {1} et qu'ainsi, les mesures de $\delta\omega$ peuvent fournir une estimation de la viscosité du noyau liquide aux fréquences des marées à longue période. En particulier, les résultats du travail (I) et l'estimation de l'influence de l'océan sur δC {2} montrent que la limite supérieure de la viscosité du noyau terrestre dans le domaine des périodes de l'ordre d'un mois et d'un an ne peut dépasser 10^{10} - 10^{11} poises.

I. La variation des moments d'inertie du noyau $\delta C(b)$ et de la Terre entière $\delta C(a)$ peut être représentée {3, formule (6)} par

$$\delta C = \frac{2r^2}{15\ G}\left[L_2^0\ (r) - 2r\ R_2^0\ (r)\right] \qquad (3)$$

où r est le rayon; b le rayon du noyau; a est le rayon de la Terre; G est la constante de gravitation; R_2^0 (r) est un facteur dépendant de r dans l'expression déterminant la variation du potentiel de gravitation R dans le corps de la Terre lors des déformations de marées

$$R = R\ (r)\ P_2^0\ (\cos\theta)\ \cos\sigma t$$

$P_2^0\ (\cos\theta) = \frac{3}{2}\cos^2\partial - \frac{1}{2}$ est le polynôme de Legendre; θ la colatitude; σ la fréquence angulaire de la marée; t le temps et

$$L = r^2\left[R'(r) - 4\pi G\rho(r)H(r)\right]$$

on désigne par "prime" la différenciation par rapport à r; ρ est la densité; H(r) le facteur déterminant la composante radiale des déplacements de marées:

$$H = H(r)\ P_2^0\ (\cos\theta)\ \cos\sigma t$$

Les valeurs numériques des fonctions R(r), L(r), H(r), pour toute valeur de r, sont déterminées par la solution des équations différentielles habituelles du 6ème ordre décrivant la marée statique dans le corps de la Terre réelle.

Sur la surface extérieure de la Terre les valeurs R(a) et L(a) satisfont aux conditions aux limites

$$(n+1)a\ R(a) + L(a) = 5a\ V_0\ (a) \qquad (4)$$

où $V_0(a)$ est l'amplitude du potentiel générateur de marée à la surface:

$$V = V_0 \frac{r^2}{a^2} P_2^0\ (\cos\theta) \cos\sigma t \qquad (5)$$

Compte tenu de (4), l'expression donnant la variation du moment d'inertie de toute la Terre (3) peut être écrite sous la forme

$$\delta C\ (a) = - \frac{2a^2}{3G} k\ V_0 \qquad (6)$$

où $k = R(a)/V_0 - 1$ est le nombre de Love pour la Terre entière avec noyau liquide et océans.

En l'absence d'océans, les valeurs numériques des fonctions entrant en (3), (6) pour le modèle de Terre 508 de Gilbert et Dziewonski (4) ont été calculées dans le travail (5). Leurs valeurs sont les suivantes:

$$L(b) - 2b\ R(b) = -1{,}071\ a\ V_0(a)$$
$$L(a) - 2a\ R(a) = -5k\ a\ V_0\ a = -1{,}497\ a\ V_0\ (a)$$

Après avoir substitué ces valeurs en (3), (6) et en posant $C/Ma^2 = 0{,}3308$, $C_1/C = 0{,}893$ (où M est la masse totale de la Terre), nous obtiendrons

$$\frac{\delta C}{C} = -2{,}02\ k \frac{V_0}{ga} \qquad (8a)$$

$$\frac{\delta C_1}{C_1} = -1{,}78\ k \frac{V_0}{ga} \qquad (8b)$$

Ainsi, en l'absence de lien entre le noyau et l'enveloppe les variations de marées de la rotation de la Terre sont 12% moins fortes dans le cas d'un lien fort.

Pour calculer la variation du moment d'inertie du système enveloppe-océan, nous représenterons la marée océanique (5) par une décomposition en fonctions sphériques. En négligeant le ratard de phase de la marée océanique, nous poserons

$$h = \cos\sigma t \sum_{n=1}^{\infty} \sum_{m=-n}^{n} h_n^m\ Y_n^m\ (\theta,\phi)$$

(le terme n = 0 manque en raison des condition de conservation de la masse de l'océan et de l'incompressibilité de l'eau).

Le coefficient h_2^0 détermine la variation de marée au moment d'inertie de l'océan. Il peut être trouvé par la formule (6) dans laquelle k V_0 représente le potentiel créé par l'onde de marée dans l'océan:

$$(kV_0)_{OC} = \frac{4\pi}{5} G\ a\ \rho$$

où

$$\rho = \rho_0\ h_2^0\ P_2^0\ (\cos\theta)\ \cos\sigma t \qquad (9)$$

densité de la couche simple par laquelle on peut remplacer l'onde de marée dans l'océan (ρ_0 est la densité de l'eau de mer). L'action réciproque de la couche (9) avec la Terre élastique provoque des déformations élastiques de l'enveloppe et provoque une variation du moment d'inertie de l'enveloppe et du noyau liquide. Pour le modèle de Terre 508 de Gilbert et Dziewonski les variations du moment d'inertie de toute la Terre et de l'enveloppe représentent respectivement -0,308 et -0,245 de la variation du moment d'inertie de l'océan.

Ainsi pour le modèle réel d'une Terre avec océans les variations relatives du moment d'inertie de toute la Terre et du système de l'enveloppe-océan peuvent être représentées sous la forme

$$\frac{\delta C}{C} = -2{,}02\ (k + 0{,}692\ \bar{k})\ \frac{V_0}{ga} \qquad (10a)$$

$$\frac{\delta C_1}{C_1} = -2{,}02\ (0{,}881\ k + 0{,}846\ \bar{k})\ \frac{V_0}{ga} \qquad (10b)$$

2. Pour estimer l'influence de la viscosité du noyau sur les variations de marée de la vitesse de rotation de la Terre il faut comparer l'épaisseur de la couche d'Ekman.

$$\ell = \left(\frac{2\nu}{\rho_\ell \sigma}\right)^{1/2} \qquad (11)$$

avec le rayon du noyau b. En (11) ν est la viscosité, ρ_c est la densité moyenne du noyau, σ est la fréquence angulaire de marée. Si $\ell \ll b$ la masse de liquide entraînée dans le mouvement par les forces d'adhésion visqueuse avec l'enveloppe est sensiblement plus petite que la masse du noyau. Dans ce cas on peut supposer que $\delta\omega$ est déterminé par les formules (2) et (10b). Pour $\ell >> b$ une rotation différentielle du noyau et de l'enveloppe est impossible et par conséquent $\delta\omega$ est déterminé par les formules (1) et (10a). Pour $\ell \approx b$, $\delta\omega$ a une certaine valeur intermédiaire et la phase de la vitesse angulaire diffère sensiblement de la phase de la force génératrice de marée. Les valeurs de σ sont comprises dans l'intervalle de 2.10^{-7} (pour l'onde annuelle Ssa) à 5.10^{-6} (pour l'onde de deux semaines Mf). Après les avoir substituées en (11) et en ajustant le résultat au rayon du noyau $b = 3.10^{8}$ cm, nous obtiendrons

$$\nu_0 = 10^{10} \div 2.10^{11} \text{ poises.}$$

Simultanément on obtient une estimation {6} $\nu < 10^{9}$ poises d'après les données sur l'amortissement des ondes séismiques traversant le noyau terrestre.

Les estimations théoriques de la viscosité des métaux dans les conditions de pression et de température régnant au centre de la Terre donnent {7} $\nu \sim 0{,}1$ poise. En comparant ces chiffres on peut tirer la conclusion que la valeur la plus probable de la viscosité du noyau terrestre est telle que $\nu << \nu_0$. Dans ce cas $\ell << b$ et les variations de marées de la vitesse de rotation de la Terre doivent être décrites par les équations (2) et (9b).

3. Les mesures les plus précises des variations de marées de la vitesse de rotation de la Terre ont été faites par G.P. Pilnik {1}. En supposant que la variation de rotation de la Terre est déterminée par la variation du moment d'inertie de la Terre entière et en ne tenant pas compte des corrections dues à l'influence de l'océan c'est à dire en utilisant les expressions analogues à (1), (8a) il a obtenu

$$k_0 = 0{,}495 \frac{\delta\omega}{\omega} \frac{ga}{V_0} = 0{,}301 \pm 0{,}004 \qquad (12)$$

La correction pour l'océan a été ensuite calculée par B.P. Pertsev et M.V. Ivanova. En adoptant $\bar{k} = 0{,}05$ et en utilisant au lieu de (8a) le rapport (9a) les auteurs {2} ont obtenu $0{,}692\ \bar{k} = 0{,}035$ ce qui représente environ 12% de k_0. Sur cette base on tire en {2} la conclusion que l'estimation de k_0 obtenue par la formule (12) augmente de 12 %. Ainsi, si l'on suppose que la rotation différentielle de l'enveloppe et du noyau est impossible c'est à dire que $\nu \gtrsim \nu_0$, il faut écrire pour le nombre de Love k d'une Terre élastique sans océans, la valeur:

$$k^{(1)} = 0,266 \qquad (13)$$

Nous examinerons le cas $\nu \ll \nu_0$. En supposant, comme en {2}, $\bar{k} = 0,05$ et après avoir substitué (2), (9b) en (11) nous obtiendrons:

$$k^{(2)} = 0,294 \qquad (14)$$

Il convient de noter que les modèles actuels de la structure interne de la Terre sont si précis que l'indétermination de la valeur théorique du nombre k ne peut dépasser 1 %. Ainsi pour les modèles 1066a, 1066b et 508 de Gilbert et Dziewonski {4} ces valeurs sont respectivement égales à 0,30088, 0,30097 et 0,29931 {8, 5}. Les corrections du module dynamique du déplacement calculés pour des périodes de 14 jours et 1 an ne représentent respectivement que $\delta k \sim 0,005$ et $\delta k \sim 0,007$ {6}.

Ainsi la valeur de k déterminée par la formule (13) diffère sensiblement de sa valeur théorique 0,305 ou 0,307. Quant à la valeur (14) elle coïncide avec la théorie dans les limites des erreurs de mesures {1}. Sur cette base on peut tirer la conclusion que l'estimation de la viscosité du noyau obtenue par les méthodes séismiques est confirmée par les données sur les variations de marées de la vitesse de rotation de la Terre.

En conclusion nous noterons que la viscosité du liquide réel peut dépendre sensiblement de la fréquence σ. Les valeurs de la viscosité déterminées d'après les données séismiques correspondent à peu près à 1 hertz alors que les variations de marées de la vitesse de rotation de la Terre donnent la possibilité d'évaluer ν pour $\sigma \sim 10^{-6} \div 10^{-7}$ hertz.

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Traduction

SUR LE MECANISME DE L'ACCELERATION DE MAREE DE LA ROTATION DIURNE DU NOYAU DE LA TERRE

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Rotation et déformations de marées de la Terre, vol. 14, pp 50-52, 1982

Le problème de la balance entre les moments qui accélèrent et ceux qui ralentissent la rotation diurne du noyau de la Terre présente un intérêt en raison du problème de la cause de la dérive du champ magnétique terrestre vers l'ouest. On suppose habituellement que des mouvements de convection dans le noyau de la Terre conduisent à une rotation différentielle du noyau dont les couches extérieures tournent un peu plus lentement que les couches internes {1}. Comme dans le noyau terrestre la condition du gel du champ magnétique est réalisée, la vitesse de la dérive vers l'ouest s'identifie avec la vitesse angulaire des parties du noyau dans lesquelles se trouve le champ magnétique.

Cette dérive vers l'ouest fait apparaître le moment des forces électromagnétiques accélérant la rotation diurne du noyau. Si l'on suppose que la vitesse angulaire de la rotation du noyau décroît de façon monotone depuis le centre jusqu'à la surface, alors la vitesse des couches extérieures du noyau contigües à l'interface noyau-enveloppe ne peut être plus grande que la vitesse des couches dans lesquelles se manifeste le champ magnétique. Par conséquent le moment des forces de friction visqueuse, comme aussi le moment des forces électromagnétiques doit accélérer la rotation diurne du noyau de la Terre.

Pour examiner l'équilibre de tous les moments agissant sur le noyau il faut évidemment ajouter au moment des forces électromagnétiques et de viscosité, le moment des forces extérieures génératrices de marées.

Ce présent travail a pour objet ce calcul. Nous montrons plus loin que le moment des forces de marées agissant sur le noyau terrestre doit accélérer la rotation diurne du noyau. Ainsi si les hypothèses faites plus haut sont vraies alors les moments des forces visqueuses, électromagnétiques et de marées ne meuvent se compenser réciproquement et par conséquent la vitesse de la dérive du noyau vers l'ouest doit disparaître avec le temps.

On sait que le frottement des marées océaniques exerce une influence importante sur le ralentissement séculaire de la rotation diurne de la Terre. Le retard de phase des variations de marées de la force de pesanteur déterminé par la viscosité de l'enveloppe n'est que de 2.10^{-4} rad {2}. Le freinage de marée de la Terre provoqué par ce retard est à peu près 30 fois plus petit que le frottement des marées océaniques. C'est pourquoi nous négligerons dans la suite la viscosité de l'enveloppe.

Pour calculer les moments des forces agissant sur l'enveloppe et le noyau nous examinerons un modèle de Terre parfaitement élastique avec un noyau "liquide parfait" et un océan. Pour le modèle de la Terre parfaitement élastique sans océan la phase des déformations de marées et du manteau correspond à la phase du potentiel générateur de marée, c'est pourquoi le moment des forces agissant sur le manteau et le noyau est nul. Mais l'onde de marée dans l'océan provoque une déformation élastique aussi bien de la surface extérieure de la Terre que de l'interface noyau-manteau et la répartition des masses dans le manteau et le noyau joue un rôle sensible. Pour une Terre parfaitement élastique la phase de ces déformations correspond à celle de l'onde de marée dans l'océan et par conséquent diffère sensiblement de la phase de la force génératrice de marée. L'élévation de l'onde de marée dans l'océan provoque un fléchissement élastique de la surface extérieure de la Terre et de la limite du noyau-manteau dans la direction vers le centre de la Terre. C'est pourquoi la direction du moment M_1 agissant sur le noyau terrestre est opposé à la direction du moment agissant sur l'océan. Pour le calcul numérique de M_1 nous écrirons la forme:

$$M_1 = \iiint_\tau \delta\rho\, r \sin\theta\, a_\varphi\, d\tau + \iint_S \rho(b) H(b)\, r \sin\theta\, a_\varphi\, ds, \qquad (1)$$

où τ est le volume occupé par le noyau; $\delta\rho$ est la variation de la densité due à la marée dans le noyau, liée à la variation du potentiel R par l'équation de Poisson:

$$\delta\rho = -\frac{1}{4\pi G}\Delta R, \tag{2}$$

r est le rayon; θ la colatitude; a_ϕ est la composante de l'accélération génératrice de marée:

$$a_\phi = -\frac{1}{r\sin\theta}\frac{\partial V}{\partial\phi} \tag{3}$$

ϕ est la longitude; V est le potentiel générateur de marée:

$$V = V_o\frac{r^2}{a^2}P_2^m(\cos\theta)\cos(\sigma t - m\phi); \tag{4}$$

a est le rayon de la Terre; P_2^m est le polynome associé de Legendre; t est le temps, σ est la fréquence angulaire; s est la limite du noyau avec le manteau; H(b) est la composante radiale des déplacements de la limite noyau-manteau déterminée par la formule de Love:

$$H(b) = H_o\,P_2^m(\cos\theta)\cos(\sigma t - m\phi);$$

H_o est une constante ne dépendant pas de θ, ϕ.

Après avoir substitué (2), (3) en (1) et tenant compte de l'harmonicité de la fonction $\partial V_2/\delta\phi$ nous introduisons l'intégrale de volume en (1) à celle de surface à l'aide de la formule de Green. Nous obtiendrons

$$\iiint_\tau \delta\rho\, r\sin\theta\, a_\varphi\, d\tau = -\iiint_\tau \delta\rho\frac{\partial V}{\partial\varphi}d\tau = \frac{1}{4\pi G}\iiint_\tau \Delta R\frac{\partial V}{\partial\varphi}d\tau =$$
$$= \frac{1}{4\pi G}\iiint_\tau\left(\Delta R\frac{\partial V}{\partial\varphi} - R\Delta\frac{\partial V}{\partial\varphi}\right)d\tau = \frac{1}{4\pi G}\iint_s\left(\frac{\partial V}{\partial\varphi}\frac{\partial R}{\partial n} - R\frac{\partial}{\partial n}\frac{\partial V}{\partial\varphi}\right)ds, \tag{5}$$

où $\partial/\partial n \sim \partial/\partial r$ est la dérivée suivant la normale extérieure à s.
Après avoir substitué (5) en (1) et tenant compte que conformément à (4) $\partial V/\partial r = 2/r\,V$, nous obtiendrons

$$M_1 = \frac{1}{4\pi G}\iint_s \chi(b,\theta,\varphi,t)\frac{\partial V}{\partial\varphi}ds, \tag{6}$$

où

$$\chi(b,\theta,\varphi,t) = \frac{\partial R(b)}{\partial n} - 4\pi G\rho(b)H(b) - \frac{2}{b}R(b). \tag{7}$$

Nous représenterons ensuite les valeurs de (b, θ, ϕ, t) par des décompositions en fonctions sphériques

$$x(b,\theta,\varphi,t)=\sum_{n,m}\left[x_{nm}^{(1)}(b)P_n^m(\cos\theta)\cos(\sigma t-m\varphi-\varepsilon_{nm}^{(1)})+x_{nm}^{(2)}(b)P_n^m(\cos\theta)\cos(\sigma t+m\varphi-\varepsilon_{nm}^{(2)})\right]. \quad (8)$$

Après avoir substitué (8) en (6) et en intégrant le résultat suivant les variables angulaires, nous trouvons

$$M_1=-\frac{mV_0\,cb^4}{4\pi Ca^2}x_{2m}^{(1)}(b)\sin\varepsilon_{2m}^{(1)}, \quad (9)$$

où $C=\frac{2\pi}{5}\frac{(2+m)!}{(2-m)!}$ – le carré de la norme de la fonction sphérique $P_2^m(\cos\theta)\cos m\phi$ pour m=1 et m=2.

On calcule d'une façon analogue le moment des forces agissant sur toute la Terre

$$M_2=-\frac{mV_0\,ca^2}{4\pi G}x_{2m}^{(1)}(a)\sin\varepsilon_{2m}^{(1)}=\frac{5am\,V_0^2\,ck}{4\pi G}\sin\varepsilon_{2m}^{(1)}, \quad (10)$$

où k est le nombre de Love.

Les valeurs numériques des paramètres $x_{2m}^{(1)}(b)$, $x_{2m}^{(1)}(a)$ et k dépendent uniquement de la structure interne de la Terre et peuvent être trouvés par la solution des équations différentielles décrivant les déformations de marées de la Terre. Après avoir représenté la marée dans l'océan par une décomposition en ondes analogues à (8)

$$h(\theta,\varphi,t)=\sum_{n,m}\left[h_{nm}^{(1)}P_n^m(\cos\theta)\cos(\sigma t-m\varphi-\varepsilon_{nm}^{(1)})+h_{nm}^{(2)}P_n^m(\cos\theta)\cos(\sigma t+m\varphi-\varepsilon_{nm}^{(2)})\right], \quad (11)$$

où h est la hauteur de l'onde de marée; $h_{nm}^{(1)}$; $h_{nm}^{(2)}$ sont les coefficients de la décomposition de h, et en utilisant les résultats de l'intégration numérique des équations aux déformations de marées {3}, nous obtiendrons

$$x_{2m}^{(1)}(b)=8{,}97\,G\rho_0\,h_{2m}^{(1)}, \quad (12)$$

$$x_{2m}^{(1)}(a)=-8{,}69\,G\rho_0\,h_{2m}^{(1)}, \quad (13)$$

où ρ_o est la densité de l'eau de mer. La substitution de (12) et de (13) en (10) détermine les moments des forces appliquées au noyau et à toute la Terre. Comme le montrent ces expressions, le rapport M_1/M_2 est le même pour les marées diurnes et semidiurnes et ne dépend pas des coefficients de décomposition $h(\theta,\phi,t)$ (11). Après avoir substitué (12), (13) en (9) et (10) et en prenant le ralentissement séculaire de la Terre égal à

$\omega = 5{,}5.10^{-22}$ rad/s^2, nous obtiendrons

$$M_I = -0{,}412.10^{16} \text{ nm}, \quad (14a)$$

$$M_2 = 4{,}495.10^{16} \text{ nm} \quad (14b)$$

$$\frac{M_1}{M_2} = -0{,}0917. \quad (14c)$$

Le signe moins dans la formule (14a) montre que le moment des forces de marées accélère la rotation diurne du noyau. Le moment d'inertie du noyau de la Terre représente 0,120 du moment d'inertie du manteau. C'est pourquoi en l'absence d'action réciproque visqueuse et électromagnétique entre le noyau et le manteau l'accélération du noyau doit atteindre environ 70 % du ralentissement de marée de la vitesse de rotation du manteau.

Le moment M_1 doit être pris en considération lors de l'examen de l'équilibre des forces provoquant le mouvement du noyau par rapport au manteau.

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Traduction

EQUATIONS DES DEFORMATIONS DE MAREES EN UN POINT SINGULIER

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Le problème des déformations de marées d'une planète hétérogène, compressible, idéalement élastique, solide, qui se trouve sous l'effet du potentiel extérieur perturbant, est décrit par un système de trois équations différentielles homogènes du second ordre

$$\begin{aligned} & y_1'' + \left[\frac{(\lambda+2\mu)'}{\lambda+2\mu} + \frac{2}{r}\right] y_1' - \frac{n(n+1)(\lambda+\mu)}{\lambda+2\mu}\frac{y_3'}{r} + \frac{\varrho}{\lambda+2\mu} y_5' - \\ & -\left[2 + \frac{n(n+1)\mu}{\lambda+2\mu} - \frac{2\lambda'}{\lambda+2\mu} r + \frac{2\varrho V' r}{\lambda+2\mu} - \frac{\varrho V'' r^2}{\lambda+2\mu}\right]\frac{y_1}{r^2} - \\ & -\frac{n(n+1)}{\lambda+2\mu}\left[-(\lambda+3\mu) - \lambda' r + \varrho V' r\right]\frac{y_3}{r^2} = 0, \end{aligned} \tag{1}$$

$$\begin{aligned} & y_3'' + \frac{\lambda+\mu}{\mu}\frac{y_1'}{r} + \left(2 + \frac{\mu' r}{\mu}\right)\frac{y_3'}{r} + \left[2(\lambda+2\mu) + r\mu' + \varrho V' r\right]\frac{y_1}{\mu r^2} - \\ & -\left[r\mu' + n(n+1)(\lambda+2\mu)\right]\frac{y_3}{r^2\mu} + \frac{\varrho}{\mu r} y_5 = 0, \end{aligned}$$

$$\begin{aligned} & y_5'' - 4\pi G\varrho y_1' + 2\frac{y_5'}{r} - 4\pi G(2\varrho + \varrho' r)\frac{y_1}{r} + n(n+1)\,4\pi G\varrho\frac{y_3}{r} - \\ & -n(n+1)\frac{y_5}{r^2} = 0 \end{aligned}$$

on peut se ramener par la substitution:

$$\begin{aligned} y_2 &= y_1'(\lambda+2\mu) + \frac{2\lambda}{r} y_1 - \frac{n(n+1)\lambda}{r} y_3 \\ y_4 &= \mu\left[y_3' + \frac{y_1}{r} - \frac{y_3}{r}\right] \\ y_6 &= y_5' - 4\pi G\varrho y_1 \end{aligned} \tag{2}$$

à un système de six équations différentielles du premier ordre par rapport aux fonctions inconnues Y_i (i = 1, 2, ... 6).

ρ est la densité

λ, μ sont les paramètres de Lamé

n est l'ordre de la marée

r est le rayon de la planète

V' = -g, g est l'accélération de la force de pesanteur

G est la constante de gravitation.

Les fonctions $Y_i(r)$ (i = 1, 2, ... 6) sont les $n^{èmes}$ coefficients dans la décomposition en harmoniques sphériques suivant le déplacement et la tension radials, le déplacement et la tension tangentiels, le potentiel perturbé de la planète et son gradient.

Il ne paraît pas possible de résoudre le système (1) à l'aide d'une intégration numérique directe pour tout point de la planète car, comme il est élémentaire de le noter, le point r = 0 (centre de la planète) est un point singulier pour le système donné des équations. En même temps on sait que toutes les planètes et les satellites dans le système solaire à l'exclusion probablement de la Lune ont une graine solide. C'est pourquoi la solution du problème de la marée au centre d'une planète solide est très utile au point de vue de l'étude des marées dans les planètes du système solaire. Jusqu'à présent nous savons que, parmi les chercheurs, il existe deux approches palliatives du problème. Soit que soit résolu le système (1) jusque tout près du centre mais, à la limite de ce voisinage, à titre de conditions aux limites, on prend la solution classique de Kelvin pour les marées d'une planète homogène incompressible.

Soit qu'on s'est servi du fait que l'irrégularité de la solution commence à devenir importante dans un voisinage relativement petit du centre, certains auteurs ont simplement utilisé une solution notoirement irrégulière (Lammlein, 1977).

Le même problème concernant les oscillations libres d'une planète à la graine rigide pour laquelle le centre de la planète, comme dans le cas des variations de marées, est un point singulier, a été envisagé par une série d'auteurs (Jeffreys 1970; Takeuchi et Saito, 1971; Crossley, 1975). Quant au problème de la singularité dans le cas des variations de marées il n'a pas encore, jusqu'à présent, attiré suffisamment l'attention des chercheurs.

Dans ce travail on essaye d'obtenir une solution analytique du système (1) au point singulier r = 0.

Cela ne représente pas un grand travail puisque, comme le montre le système (1), le point r = 0 est un point isolé et tous les coefficients des fonctions Y_i ont des pôles d'ordre pas plus élevés que le second ordre, c'est-à-dire pas plus haut que l'ordre du système des équations différentielles. Puisque r = 0 est le seul point particulier isolé, alors le système des équations différentielles linéaires homogènes (1) admet, comme on le sait, une solution de la forme

$$y_i = r^{\alpha_i} \sum_{k=0}^{\infty} a_{ik} r^k, \quad (i = 1, 3, 5) \tag{3}$$

où les premiers coefficients $a_{io} \neq 0$ dans le cas général peuvent être choisis arbitrairement et les autres coefficients a_{ik} sont déterminés successivement par les rapports récurrents qui ont été obtenus lors de la substitution de (3) dans le système (1). Les coefficients de degré α_i doivent satisfaire au système non linéaire d'équations caractéristiques suivant:

$$\begin{gathered}
a_{10} r^{\alpha_1}\left[\alpha_1(\alpha_1+1)-2-\frac{n(n+1)\mu}{\lambda+2\mu}-\frac{2\varrho V' r}{\lambda+2\mu}+\frac{\varrho V'' r^2}{\lambda+2\mu}\right]+ \\
+\frac{n(n+1)}{\lambda+2\mu} a_{30} r^{\alpha_3}[-(\lambda+\mu)\alpha_3+(\lambda+3\mu)+\varrho V' r]+ \\
+\frac{\varrho}{\lambda+2\mu}\alpha_5 a_{50} r^{\alpha_5+1}=0, \\
\frac{1}{\mu} a_{10} r^{\alpha_1}[\alpha_1(\lambda+\mu)+2(\lambda+2\mu)+\varrho V' r]+ \\
+a_{30} r^{\alpha_3}\left[\alpha_3(\alpha_3+1)-\frac{n(n+1)(\lambda+2\mu)}{\mu}\right]+\frac{\varrho}{\mu} a_{50} r^{\alpha_5+1}=0, \\
-4\pi G \varrho a_{10} r^{\alpha_1+1}(\alpha_1+2)+n(n+1)4\pi G \varrho a_{30} r^{\alpha_3+1}+ \\
+a_{50} r^{\alpha_5}[\alpha_5(\alpha_5+1)-n(n+1)]=0.
\end{gathered} \tag{4}$$

A cause de la quantité d'équations nous avons écrit le système (4) uniquement pour le cas d'une planète homogène. Ainsi il faut tenir compte que pour ρ = const., V' = -g = $-\gamma_1 r$, où $\gamma_1 = \frac{4\pi G}{3}\rho$. En principe le système d'équations caractéristiques peut avoir plus d'une solution. Alors chacune de ses solutions $\{\alpha_{ij}\}$ où j est le numéro de la solution, donne une solution linéairement indépendante du système des équations différentielles, $\{Y_i\}_j$. Cependant, en se servant des conditions physiques du problème, nous pouvons encore, avant la solution du système des équations caractéristiques (4), limiter la classe des Y_i physiquement acceptables, après avoir facilité par là-même la découverte des paramètres $\{\alpha_i\}$. A titre de condition à la limite au centre, on introduit habituellement comme contrainte que la solution du système (1) soit continue au point singulier. Ainsi, tous les $\{\alpha_i\}$ doivent être au moins non négatifs. Dans ce cas le système caractéristique n'aura qu'une solution, à savoir

$$\begin{aligned} \alpha_1 &= n - 1 \\ \alpha_3 &= n - 1 \\ \alpha_5 &= n \end{aligned} \qquad (5)$$

avec la condition suivante complémentaire

$$a_{10} = n\, a_{30}.$$

C'est ainsi que, dans la solution, restent arbitraires uniquement deux des coefficients de la décomposition (3) par exemple, a_{30} et a_{50}.

En utilisant les formules (2) les séries (3) et la solution (5), pour les fonctions Y_i avec indices pairs i nous pouvons obtenir les séries auxiliaires suivantes:

$$\begin{aligned} \alpha_2 &= n-2 \\ \alpha_4 &= n-2 \\ \alpha_6 &= n-1 \end{aligned}$$

$$y_i = r^{\alpha_i} \sum_{k=0}^{\infty} a_{ik} r^k, \ (i = 2, 4, 6), \qquad (6)$$

$$\begin{aligned} a_{2k} &= [\lambda(n+k+1) + 2\mu(n+k-1)]\, a_{1k} - n(n+1)\lambda a_{3k} \\ a_{4k} &= \mu[a_{1k} + (n+k-2)\, a_{3k}] \\ a_{6k} &= (n+k)\, a_{5k} - 4\pi G f_k, \text{ где} \end{aligned}$$

où f_k sont les coefficients de la série $\rho\, Y_1$ sous la condition que $\rho = \sum_{k=0}^{\infty} \rho_k\, r^k$. Dans le cas de ρ = const. $f_k = \rho\, a_{1k}$.

Il convient de remarquer que pour les décompositions des fonctions Y_i et avec des indices pairs, il n'y a pas un des premiers coefficients $a_{io} \neq 0$ (i = 2, 4, 6).

Après avoir substitué la décomposition (3) dans le système (1) et en tenant compte de (5) nous pouvons obtenir les formules récurrentes suivantes pour les coefficients a_{ik} (i = 1, 3, 5):

$$\left[(n+k+1)(n+k+2)-2-\frac{n(n+1)\mu}{\lambda+2\mu}\right]a_{1,\,k+2}-$$
$$-\frac{n(n+1)}{\lambda+2\mu}[\lambda(n+k)+\mu(n+k-2)]\,a_{3,\,k+2}=$$
$$=-\frac{\varrho\gamma_1}{\lambda+2\mu}[a_{1k}-n(n+1)a_{3k}]-\frac{\varrho}{\lambda+2\mu}(n+k)\,a_{5k}, \qquad (7)$$
$$\left[\frac{\lambda}{\mu}(n+k+3)+(n+k+5)\right]a_{1,\,k+2}+$$
$$+\left[(n+k+1)(n+k+2)-\frac{n(n+1)(\lambda+2\mu)}{\mu}\right]a_{3,\,k+2}=\frac{\varrho\gamma_1}{\mu}a_{1k}-\frac{\varrho}{\mu}a_{5k}$$
$$[(n+k+2)(n+k+3)-n(n+1)]\,a_{5,\,k+2}-4\pi G\varrho(n+k+3)\,a_{1,\,k+2}+$$
$$+n(n+1)\,4\pi G\varrho\,a_{3,\,k+2}=0.$$

De la même façon que les équations caractéristiques, les formules récurrentes (7) sont écrites, à cause de la quantité de travail, uniquement pour le cas d'une planète compressible homogène.Ainsi les séries cherchées ne seront constituées que des termes de degrés pairs k; quant aux coefficients pour k impair ils deviennent égaux à 0.

Ensuite, il est simple de noter que dans le cas de k = 0, c'est-à-dire lors de la détermination des coefficients a_{12}, a_{32}, a_{52} en tenant compte des conditions (5), les deux premières équations du système (7) correspondent, c'est-à-dire que l'ún des coefficients cherchés est arbitraire. En prenant comme coefficient arbitraire par exemple le coefficient a_{52} nous aurons

$$a_{12}=D_1/D,\quad a_{32}=D_2/D,\quad \text{где}$$
$$D=-2\mu(n+1)(2n+3),$$
$$D_1=-n(n+1)\{nB-C[\lambda n+\mu(n-2)]\},$$
$$D_2=-\{(n+3)B-C[\lambda(n+3)+\mu(n+5)]\}, \qquad (8)$$
$$B=\varrho(\gamma_1 n\,a_{30}-a_{50}),$$
$$C=\frac{2n+3}{2\pi G\varrho}a_{52}.$$

On trouve ainsi la solution générale du système (1).

Les coefficients arbitraires a_{30}, a_{50}, a_{52} doivent être déterminés par les conditions aux limites.

Pour illustrer la méthode proposée nous avons calculé l'harmonique principale de la marée (n = 2) dans une Lune solide homogène compressible pour

$$\begin{aligned} \rho &= 3{,}374 \ r/cm^3 \\ \lambda &= 6 \times 10^{''} \ dyn/cm^2 \\ \mu &= 4 \times 10^{''} \ dyn/cm^2 \\ R &= 1735 \ KM \\ g(r = R) &= 163{,}55 \ cm/ceK^2, \end{aligned} \tag{9}$$

où R est le rayon de la Lune. Ce modèle ne diffère pratiquement pas du modèle de la Lune avec une couche de surface Arkani-Hamed (1973). Le calcul a été fait en unités planétaires de Molodenski ($M = 4\pi/3$, $G = 3\pi/4$, $R = 1$ P.U. où M_C est la masse de la Lune).

Lors de l'analyse des résultats on note pour ces i impairs, que les séries (3) comme on le voit par la table 1 sont extrêmement semblables pour k fixé.

TABLE 1

Valeurs des coefficients du développement en séries de puissances (3) a_{ki} avec indice impair

k \ i	1		3		5	
0	-0,1997	1	0,9987	0	0,2209	0
2	-0,2403	0	-0,4343	0	0,3010	0
4	-0,7881	-2	0,2687	-2	-0,5941	-2
6	0,5571	-4	-0,5226	-4	0,3704	-4
8	-0,4373	-6	0,2517	-6	-0,1823	-6
10	0,1680	-8	-0,1072	-8	0,5654	-9

Les coefficients a_{ik} sont représentés dans cette table sous forme logarithmique, la première colonne renferme la mantisse, et la seconde l'ordre du coefficient correspondant. En commençant par les premiers coefficients arbitraires d'un ordre non inférieur à zéro, même pour k = 10 nous avons les coefficients $a_{ik} \sim 10^{-10}$ pour tous les i et les coefficients avec k = 100 $a_{ik} \sim 10^{-177}$ pour tous les i. Puisque on a utilisé pour le calcul un modèle homogène de la Lune, trois conditions seulement jouent à la surface libre pour la détermination de la solution unique. Ce sont les conditions aux limites:

$$Y_2 = 0$$
$$Y_4 = 0$$
$$Y + (n+1)\frac{Y_5}{r} = (2n+1)\,g \qquad (10)$$

pour $r = R$

ce qui signifie l'absence de tensions sur la surface libre et la continuité du potentiel. Dans ce cas les coefficients arbitraires de la solution calculée précédemment sont les suivants:

$$a_{30} = 0.04941$$
$$a_{50} = 1.03414 \qquad (11)$$
$$a_{52} = 0.00307$$

ainsi, dans le cas d'une planète complètement homogène la solution pour l'harmonique principale de la marée a la forme:

$$y_1 = 0.0988158r - 0.0350394r^3 - 0.0004517r^5 + \ldots$$
$$y_3 = 0.0494079r - 0.0315877r^3 - 0.0000343r^5 + \ldots \qquad (12)$$
$$y_5 = 1.0341375r^2 + 0.0030711r^4 - 0.0002462r^6 + \ldots$$

La variation des fonctions Y_i en fonction du rayon, pour le modèle de Lune que nous avons pris, est donné dans la table 2. Les nombres de Love pour ce modèle seront, comme nous le verrons par la Table 2:

TABLE 2

Valeurs des fonctions Y_i calculées pour une Lune homogène compressible

r/R	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
0.0	0.0000	0.8260	0.0000	0.4130	0.0000	0.0000
0.1	0.0098	0.8182	0.0049	0.4089	0.0103	0.1773
0.2	0.0195	0.7944	0.0096	0.3966	0.0414	0.3553
0.3	0.0287	0.7547	0.0140	0.3761	0.0931	0.5347
0.4	0.0373	0.6989	0.0177	0.3473	0.1655	0.7162
0.5	0.0450	0.6265	0.0208	0.3102	0.2587	0.9006
0.6	0.0517	0.5372	0.0228	0.2649	0.3727	1.0884
0.7	0.0571	0.4305	0.0237	0.2113	0.5074	1.2805
0.8	0.0610	0.3059	0.0233	0.1493	0.6630	1.4775
0.9	0.0631	0.1626	0.0214	0.0789	0.8395	1.6802
1.0	0.0633	0.0000	0.0178	0.0000	1.0370	1.8891

$$h = 0.0633$$
$$\ell = 0.0178$$
$$k = 0.0370$$

Les nombres dé Love correspondant pour une Lune homogène incompressible sont calculés d'après les formules de Kelvin, égaux à

$$h = 0.0599 \qquad \ell = 0.0180 \qquad k = 0.0360 \tag{13}$$

c'est-à-dire que la compressibilité, même dans ce cas simple, donne uns correction aux nombres de Love atteignant jusqu'à 5 à 6%.

L'autre cas de singularité est encore plus intéressant. Comme on le sait dans les conditions aux limites à l'interface des phases solide et liquide (par exemple manteau extérieur - noyau ou noyau-graine dans la Terre) entre un certain paramètre γ égal à

$$\gamma = \frac{Y'_5}{Y_5} - \frac{n}{r} \tag{14}$$

Après s'être servi précédemment de la décomposition en série pour Y_5 il est facile de démontrer que

$$\gamma\Big|_{r=0} = \frac{a_{51}}{a_{50}} \tag{15}$$

Comme il a déjà été mentionné précédemment $a_{50} \neq 0$. On peut obtenir le même résultat par un autre procédé. Après avoir substitué (14) dans l'équation de Poisson déterminant Y_5 nous obtiendrons une équation de Ricatti pour la détermination de γ:

$$\gamma' + \gamma^2 + \frac{2\,\pi+2}{r}\,\gamma + 4\,\pi\,G\,\frac{\rho'}{V'} = 0 \tag{16}$$

En utilisant la formule (15) dans le cas $\rho' = 0$ (planète homogène), il est simple de montrer que $\gamma\big|_{r=0} = 0$. De même aussi pour le système (1), le point $r = 0$ est un point singulier pour l'équation (16). Cependant il ne paraît pas possible d'appliquer la méthode utilisée pour trouver la solution régulière du système (1) directement à l'équation (16) à cause de sa non-linéarité. On peut linéariser l'équation (16) par la substitution $\gamma = y'/y$ où y est une certaine fonction nouvelle, en la donnant sous la forme:

$$y'' + \frac{2\pi+2}{r} y' + 4\pi G \frac{\rho'}{V'} y = 0 \qquad (17)$$

Après avoir pris en considération que $E = \frac{\varrho'}{V'} = \frac{1}{r}\sum_{k=0}^{\infty} e_k r^k$, nous verrons que le point r = 0 pour l'équation (17) comme pour le système (1) est un point singulier juste c'est-à-dire que cette équation admet une solution de la forme

$$y = r^{\alpha} \sum_{k=0}^{\infty} a_k r^k, \qquad (18)$$

ainsi α se détermine par l'équation caractéristique

$$\alpha(\alpha + 2n + 1) = 0 \qquad (19)$$

ayant pour solution

$$\alpha_1 = 0$$
$$\alpha_2 = -(2n + 1) \qquad (20)$$

qui, comme nous l'avons déjà noté précédemment sont en principe tout à fait équivalents. La première racine (20) conduit à la solution de la forme

$$y_1 = \sum_{k=0}^{\infty} a_k r^k.$$

Ainsi, tenant compte du fait que $\gamma = y'/y$, nous verrons que la solution y_1 donne une solution régulière en zéro et aussi pour γ. Puisque α_2 diffère de α_1 par un entier on ne peut se servir de la substitution simple de α_2 dans (18) pour obtenir une seconde solution linéiarement indépendante de l'équation (17).
En utilisant la solution connue pour l'élévation de l'ordre de l'équation (17) nous obtiendrons une seconde solution linéairement indépendante de la première, de la forme

$$y_2 = [A \ln r + r^{-(2n+1)}] \sum_{k=0}^{\infty} (a_k + b_k) r^k, \qquad (21)$$

où A est une certaine constante. Il est simple de démontrer que non seulement la solution y_2 même est irrégulière en zéro mais que son utilisation ne permet pas d'obtenir une solution régulière en zéro et aussi pour γ.

Les relations récurrentes pour les coefficients a_k sont faciles à trouver après avoir substitué la série pour y_1 dans l'équation (17)

$$k\,[(k-1) + 2(n+1)]\, a_k = -4\pi G C_{k+1}, \qquad (22)$$

où les c_K sont les coefficients de la série $C = E\, y_1 = \sum_{k=0}^{\infty} c_k r^k$, par exemple

$$c_0 = \frac{\varrho_1 a_0}{\gamma_1}$$

$$c_1 = \frac{1}{\gamma_1}\left[\left(2\varrho_2 - \frac{\varrho_1 \gamma_2}{\gamma_1}\right) a_0 + \varrho_1 a_1\right]$$

et ainsi de suite.

Ainsi on a tenu compte que $\varrho = \sum_{k=0}^{\infty} \varrho_k r^k$.

Le coefficient $a_o \neq 0$ est, dans ce cas, arbitraire et est déterminé par les conditions aux limites. Quant à la série pour γ elle a la forme:

$$.\gamma = \frac{a_1}{a_0} + \frac{1}{a_0}\left(2a_2 - \frac{a_1^2}{a_0}\right) r + \ldots \qquad (23)$$

dont nous déduirons que pour une planète homogène ($\rho_1 = 0$) il sera correct d'écrire $c_o = 0$, $a_1 = 0$ et par ce fait même $\gamma|_{r=o} = 0$. C'est à dire que nous sommes arrivés au résultat de la formule analogue (15).

Cette étude ouvre la possibilité d'obtenir une solution analytique du système d'équations différentielles décrivant la marée dans une planète solide hétérogène compressible, en séries des dégrés du rayon de la planète. Cela donne à son tour la possibilité d'obtenir les caractéristiques de marée au point le plus singulier et pour l'étude de l'allure assymptotique de la solution aux environs du point singulier.

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Results of analysis of Tidal Gravity Observations of the Working Group 3.3. KAPG

These results were published in the Bulletin n°4 of Lorand Eötvös Geophysical Institute of Hungary: "Study of the Earth Tides", 1981.

They are reproduced here with, in addition the calculation by ICET of the $\vec{B}$ residue, which is, for each wave, the vectorial difference between the observed tidal vector and the corresponding vector calculated for the Molodensky I model.

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 0930 PECNY VERTICAL COMPONENT CZECHOSLOVAKIA

49 55 12 N 14 47 24 E H 534 M
GRAVIMETER BN-07 EOTVOS LORAND GEOPH.INST., P.VARGA
INSTALLATION P.VARGA/Z.SIMON/J.BROZ/S.HOLUB
MAINTENANCE Z.SIMON/J.BROZ/E.HOLUB

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/15
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G190 750202/750309 750312/750409 750412/750419 750421/750516 750522/750525

2412 HOURS
2412 HOURS 67 INTERVALS FILTERED, WEIGHED, SHIFT 36

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL. R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.59	1.1231	.0288	-2.730	1.470	.38	-125.2
143.-149.	26	O1	35.37	1.1546	.0059	-.530	.290	.36	-114.0
152.-158.	22	M1	2.69	1.1171	.0472	3.250	2.410	.18	124.4
161.-168.	33	K1	48.82	1.1334	.0040	1.720	.210	1.48	97.9
172.-177.	22	J1	3.08	1.2788	.0602	3.520	2.700	.34	34.3
181.-1X3.	37	OO1	1.21	.9162	.1033	7.070	6.530	.36	155.8
207.-23X.	41	2N2	.86	1.0840	.0494	4.450	2.580	.09	133.3
243.-248.	24	N2	7.06	1.1842	.0105	2.800	.500	.37	68.6
252.-258.	26	M2	36.87	1.1832	.0021	.750	.100	.86	34.0
262.-267.	17	L2	.99	1.1286	.0728	6.890	3.670	.12	106.3
271.-2X5.	47	S2	17.38	1.1988	.0037	.490	.200	.58	14.9
327.-375.	17	M3	.45	1.1456	.1090	8.480	5.310	.07	68.7

STANDARD DEVIATION D 7.01 SD 2.20 TD 1.21 MICROGAL
O1/K1 1.0188 1-O1/1-K1 1.1594 M2/O1 1.0248

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 0930 PECNY VERTICAL COMPONENT CZECHOSLOVAKIA

49 55 12 N 14 47 24 E H 534 M
GRAVIMETER GS 15/222 (DIGITAL) Z.I.P.E., H.DITTFELD
INSTALLATION H.DITTFELD
MAINTENANCE Z.SIMON/J.BROZ/S.HOLUB

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/15
B RESIDUES CALCULATED BY ICET

TIME OF THE RECORD CORRECTED BY -90.0 SECONDS
PHASE CORRECTIONS O1 0.073 K1 0.078 M2 0.151 S2 0.156

INERTIAL CORRECTION NOT APPLIED

G222 750204/750209 750211/750218 750225/750302750314/750317 750327/750419
G222 750421/750516

1728 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.67		1.1369	.0147	-1.250	.700	.20	-132.7
143.-149.	26	O1	35.30		1.1523	.0031	-.130	.160	.23	-159.5
152.-158.	22	M1	2.71		1.1254	.0278	1.520	1.350	.11	138.5
161.-168.	33	K1	48.93		1.1360	.0020	.370	.120	.32	102.5
172.-177.	22	J1	2.83		1.1758	.0346	-2.840	1.540	.14	-77.4
181.-1X3.	37	OO1	1.60		1.2088	.0561	-1.300	2.640	.07	-29.8
207.-23X.	41	2N2	.92		1.1665	.0337	6.190	1.660	.10	90.2
243.-248.	24	N2	6.97		1.1685	.0072	1.830	.350	.23	78.2
252.-258.	26	M2	36.98		1.1871	.0014	1.010	.070	1.06	38.0
262.-267.	17	L2	.95		1.0766	.0456	4.170	2.540	.10	137.8
271.-2X5.	47	S2	17.37		1.1984	.0023	.320	.120	.56	9.9
327.-375.	17	M3	.42		1.0572	.0499	-2.850	2.720	.02	-102.3

STANDARD DEVIATION D 3.28 SD 1.26 TD 0.63 MICROGAL

O1/K1 1.0144 1-O1/1-K1 1.1205 M2/O1 1.0301

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 0930 PECNY VERTICAL COMPONENT CZECHOSLOVAKIA

49 55 12 N 14 47 24 E H 534 M
GRAVIMETER GS 15/228 V U G T K, PRAGUE, ZD.SIMON
INSTALLATION S.HOLUB/ZD.SIMON
MAINTENANCE J.BROZ

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/15
B RESIDUES CALCULATED BY ICET

PHASE CORRECTIONS 01 0.090 K1 0.100 M2 0.190 S2 0.200
AMPLIT.CORRECTIONS 01 0.9992 K1 0.9992 M2 0.9992 S2 0.9992

INERTIAL CORRECTION NOT APPLIED

G228 750228/750312 750314/750320 750321/750516 750517/750519 750522/750531

2052 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.76		1.1524	.0131	.360	.650	.06	134.6
143.-149.	26	O1	35.22		1.1489	.0026	-.120	.130	.33	-167.0
152.-158.	22	M1	2.82		1.1702	.0215	-1.840	1.040	.09	-73.8
161.-168.	33	K1	49.11		1.1392	.0016	-.030	.090	.07	-20.5
172.-177.	22	J1	2.73		1.1340	.0278	-.180	1.430	.07	-172.6
181.-1X3.	37	OO1	1.54		1.1650	.0485	.570	2.400	.02	69.5
207.-23X.	41	2N2	.90		1.1386	.0469	2.870	2.340	.05	111.9
243.-248.	24	N2	7.03		1.1777	.0087	1.350	.420	.20	58.1
252.-258.	26	M2	36.90		1.1836	.0017	.220	.080	.75	10.9
262.-267.	17	L2	1.06		1.2023	.0571	2.770	2.690	.06	54.9
271.-2X5.	47	S2	17.29		1.1921	.0030	-.520	.160	.49	-18.7
327.-375.	17	M3	.38		.9702	.1322	-6.480	8.010	.06	-133.3

STANDARD DEVIATION D 2.51 SD 1.56 TD 1.40 MICROGAL
O1/K1 1.0085 1-O1/1-K1 1.0697 M2/O1 1.0301

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG
STATION 0930 PECNY VERTICAL COMPONENT CZECHOSLOVAKIA

49 55 12 N 14 47 24 E H 534 M
GRAVIMETER GS 15/220 INST.PHYSICS OF EARTH,AS USSR, VOLKOV
INSTALLATION V.VOLKOV
MAINTENANCE Z.SIMON/J.BROZ/S.HOLUB

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/15
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY 0.99770
TIME OF THE RECORD CORRECTED BY -230.4 SECONDS

INERTIAL CORRECTION NOT APPLIED

G220 750131/750406 750408/750519 750522/750529

2772 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.67		1.1372	.0125	-.940	.660	.17	-140.3
143.-149.	26	O1	35.28		1.1517	.0024	-.030	.120	.23	-175.5
152.-158.	22	M1	2.86		1.1895	.0207	.580	.980	.08	21.4
161.-168.	33	K1	49.07		1.1392	.0015	.190	.090	.18	67.2
172.-177.	22	J1	2.81		1.1683	.0266	-.280	1.300	.02	-39.4
181.-1X3.	37	OO1	1.63		1.2353	.0473	-1.090	2.210	.10	-17.5
207.-23X.	41	2N2	.92		1.1646	.0308	1.100	1.510	.02	79.1
243.-248.	24	N2	7.05		1.1822	.0059	2.160	.290	.29	64.5
252.-258.	26	M2	36.94		1.1859	.0011	.880	.050	.98	35.4
262.-267.	17	L2	1.02		1.1532	.0401	.470	2.000	.01	126.3
271.-2X5.	47	S2	17.27		1.1918	.0021	.250	.110	.47	9.3
327.-375.	17	M3	.42		1.0598	.0652	1.670	3.600	.01	104.5

STANDARD DEVIATION D 3.75 SD 1.65 TD 1.03 MICROGAL
O1/K1 1.0110 1-O1/1-K1 1.0902 M2/O1 1.0297

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 K A P G

STATION 0952 TIHANY VERTICAL COMPONENT HUNGARY

46 54 00 N 17 53 24 E H 145 M
GRAVIMETER BN-07, GEOPHYSICAL INST. R.EOTVOS, P.VARGA
INSTALLATION P.VARGA
MAINTENANCE P.VARGA

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
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COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY 9.82200

INERTIAL CORRECTION NOT APPLIED

G190 770617/771002

2592 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.84		1.1513	.0542	-1.620	2.710	.20	-104.9
143.-149.	26	O1	36.03		1.1618	.0092	-.310	.460	.21	-68.4
152.-158.	22	M1	2.67		1.0934	.1067	4.700	5.540	.28	127.6
161.-168.	33	K1	50.90		1.1670	.0052	-.580	.280	1.38	-21.9
172.-177.	22	J1	2.33		.9550	.1174	-2.980	7.120	.52	-166.6
181.-1X3.	37	OO1	1.79		1.3432	.3288	11.580	14.260	.41	60.1
207.-23X.	41	2N2	1.20		1.3499	.1186	.360	5.040	.17	2.6
243.-248.	24	N2	8.05		1.1992	.0198	.580	.950	.27	17.3
252.-258.	26	M2	41.82		1.1922	.0032	.050	.160	1.13	1.9
262.-267.	17	L2	1.00		1.0082	.0710	-1.330	4.000	.15	-171.3
271.-2X5.	47	S2	19.62		1.2021	.0067	-3.280	.350	1.30	-59.8
327.-375.	17	M3	.44		.9431	.2633	9.620	15.870	.10	131.1

STANDARD DEVIATION D 12.08 SD 5.47 TD 5.12 MICROGAL
O1/K1 0.9956 1-O1/1-K1 0.9690 M2/O1 1.0262

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 K A P G

STATION 0952 TIHANY VERTICAL COMPONENT HUNGARY

46 54 00 N 17 53 24 E H 145 M
GRAVIMETER BN-07, GEOPHYSICAL INST. R.EOTVOS, P.VARGA
INSTALLATION P.VARGA
MAINTENANCE P.VARGA

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G190 771003/771023 771106/780122

2340 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	7.11		1.1983	.0490	.370	2.450	.23	11.3
143.-149.	26	O1	35.73		1.1520	.0105	.040	.520	.23	173.7
152.-158.	22	M1	2.96		1.2142	.1126	-4.500	5.300	.26	-61.5
161.-168.	33	K1	49.78		1.1414	.0048	-.760	.290	.68	-76.3
172.-177.	22	J1	2.65		1.0852	.1120	-9.970	6.060	.51	-116.2
181.-1X3.	37	OO1	1.58		1.1806	.4914	8.300	23.700	.23	87.4
207.-23X.	41	2N2	.88		.9858	.0815	3.480	4.750	.17	161.2
243.-248.	24	N2	7.96		1.1847	.0190	-.340	.930	.17	-16.0
252.-258.	26	M2	41.59		1.1858	.0038	.640	.180	1.01	27.3
262.-267.	17	L2	1.16		1.1712	.0724	2.210	3.500	.05	77.2
271.-2X5.	47	S2	19.24		1.1789	.0083	-1.720	.430	.65	-62.7
327.-375.	17	M3	.57		1.2162	.1861	6.950	8.550	.10	46.4

STANDARD DEVIATION D 11.34 SD 4.95 TD 2.98 MICROGAL
O1/K1 1.0093 1-O1/1-K1 1.0752 M2/O1 1.0294

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 K A P G

STATION 0952 TIHANY VERTICAL COMPONENT HUNGARY

46 54 00 N 17 53 24 E H 145 M
GRAVIMETER GS 15/220 INST.PHYSICS OF EARTH, AS USSR, VOLKOV
INSTALLATION V.VOLKOV/S.ZASIMOV/VL.STANCHEV/I.PETKOV
MAINTENANCE V.VOLKOV/S.ZASIMOV/VL.STANCHEV/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

TIME OF THE RECORD CORRECTED BY -230.4 SECONDS

INERTIAL CORRECTION NOT APPLIED

G220 730925/740117 740123/740303 740306/740416 740420/740611 740616-740623

6120 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.87		1.1577	.0119	-.140	.580	.02	-122.7
143.-149.	26	O1	35.86		1.1563	.0023	.050	.110	.10	161.4
152.-158.	22	M1	3.01		1.2364	.0366	-.960	1.680	.20	-15.0
161.-168.	33	K1	50.00		1.1464	.0013	-.120	.080	.40	-15.3
172.-177.	22	J1	2.86		1.1731	.0234	.570	1.160	.04	44.9
181.-1X3.	37	OO1	1.61		1.2063	.0469	3.840	2.210	.12	62.0
207.-23X.	41	2N2	1.00		1.1199	.0311	1.700	1.580	.05	140.8
243.-248.	24	N2	7.94		1.1817	.0060	.980	.290	.20	43.3
252.-258.	26	M2	41.74		1.1900	.0012	.290	.060	1.07	11.4
262.-267.	17	L2	1.32		1.3357	.0627	.680	2.720	.17	5.2
271.-2X5.	47	S2	19.40		1.1888	.0022	.320	.110	.48	13.0
327.-375.	17	M3	.49		1.0401	.0436	-1.000	2.420	.02	-146.5

STANDARD DEVIATION D 5.21 SD 2.54 TD 1.08 MICROGAL
O1/K1 1.0086 1-O1/1-K1 1.0671 M2/O1 1.0291

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 K A P G

STATION 1010 SOFIA VERTICAL COMPONENT BULGARIA

42 40 48 N 23 19 48 E H 546 M
GRAVIMETER GS 15/220 INST.PHYSICS OF EARTH, AS USSR, VOLKOV
INSTALLATION V.VOLKOV/S.ZASIMOV/VL.STANCHEV/I.PETKOV
MAINTENANCE V.VOLKOV/S.ZASIMOV/VL.STANCHEV/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY 1.06527
TIME OF THE RECORD CORRECTED BY -230.4 SECONDS

INERTIAL CORRECTION NOT APPLIED

G220	780122/780201	780202/780225	780227/780301	780302/780308	780309/780409
G220	780410/780607	780608/780615	780616/780619	780621/780623	780624/780629
G220	780703/780726	780731/781115	781117/781212	781215/781223	781227/781230
G220	790101/790102	790103/790208	790209/790211		

8316 READINGS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-128.	31	SIG1	1.17		1.2360	.0486	3.700	2.260	.10	47.2
129.-135.	19	Q1	6.88		1.1603	.0099	.140	.480	.02	74.5
136.-139.	15	RHO1	1.41		1.2513	.0475	3.910	2.160	.14	43.8
143.-149.	26	O1	35.44		1.1444	.0017	-.070	.090	.46	-174.6
152.-158.	22	M1	2.71		1.1139	.0186	.300	.960	.11	172.6
161.-162.	3	PI1	.97		1.1534	.0510	6.940	2.570	.12	94.3
163.-163.	7	P1	16.45		1.1412	.0029	-.020	.150	.18	-178.2
164.-164.	3	S1	.05		.1489	.1919	211.080	75.310	.43	-176.6
165.-165.	11	K1	49.10		1.1273	.0011	.290	.060	.51	151.1
166.-166.	2	PSI1	.43		1.2291	.1264	4.020	6.030	.03	99.8
167.-168.	7	PHI1	.70		1.1343	.0681	-.040	3.400	.02	-178.9
172.-177.	22	J1	2.80		1.1496	.0205	-.520	1.030	.04	-138.5
181.-186.	18	OO1	1.55		1.1646	.0587	3.320	2.920	.09	88.3
207.-22X.	21	EPS2	.35		1.1779	.0824	.500	4.000	.01	30.1
233.-236.	10	2N2	1.24		1.2079	.0264	-.590	1.250	.05	-14.6
237.-23X.	10	MU2	1.43		1.1493	.0192	.370	.960	.02	145.6
243.-245.	13	N2	9.18		1.1816	.0031	.490	.150	.18	25.2
246.-248.	11	NU2	1.75		1.1850	.0157	-1.130	.760	.05	-43.4
252.-258.	26	M2	47.70		1.1751	.0005	.450	.030	.71	31.7
262.-267.	17	L2	1.31		1.1416	.0122	-.220	.610	.02	-166.7
271.-272.	2	T2	1.26		1.1389	.0202	1.260	1.020	.04	130.6
273.-273.	4	S2	22.25		1.1784	.0012	.730	.060	.45	39.5
274.-277.	12	K2	6.02		1.1710	.0057	.660	.280	.09	51.3
282.-285.	15	ETA2	.32		1.1180	.1348	2.960	6.880	.02	127.1
292.-2X5.	14	2K2	.11		1.5063	.5032	21.370	19.160	.04	66.2
327.-375.	17	M3	.62		1.0609	.0264	-.460	1.430	.01	-127.2

STANDARD DEVIATION D 4.02 SD 1.73 TD 1.05 MICROGAL
O1/K1 1.0151 1-O1/1-K1 1.1341 M2/O1 1.0268

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 K A P G

STATION 1010 SOFIA VERTICAL COMPONENT BULGARIA

42 40 48 N 23 19 48 E H 546 M
GRAVIMETER GD 15/221 INST.GEOPH. AS ARM.SSR SH.OGANISIAN
INSTALLATION V.VOLKOV/S.ZASIMOV/VL.STANCHEV/I.PETKOV
MAINTENANCE V.VOLKOV/S.ZASIMOV/VL.STANCHEV/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY 0.94831
TIME OF THE RECORD CORRECTED BY -19.1 SECONDS

INERTIAL CORRECTION NOT APPLIED

G221	780219/780225	780227.780301	780302/780409	780410/780503	780504/780614
G221	780616/780619	780703/780929	781001/781004	781005/781109	781110/781111
G221	781112/781115	781117/781212	781215/781230	781231/790102	790103/790208

7848 READINGS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL. R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-128.	31	SIG1	1.11	1.1771	.0390	4.480	1.880	.09	81.4
129.-135.	19	Q1	6.78	1.1430	.0073	-.430	.370	.11	-152.6
136.-139.	15	RHO1	1.41	1.2509	.0357	5.790	1.630	.17	56.0
143.-149.	26	O1	35.47	1.1452	.0013	.010	.070	.44	179.2
152.-158.	22	M1	2.68	1.0999	.0142	.710	.740	.15	167.0
161.-162.	3	PI1	.95	1.1257	.0376	1.980	1.900	.04	127.9
163.-163.	7	P1	16.42	1.1389	.0022	-.120	.110	.22	-170.8
164.-164.	3	S1	.36	1.0644	.1168	-65.570	6.070	.41	-126.2
165.-165.	11	K1	49.17	1.1288	.0008	-.010	.040	.38	-178.7
166.-166.	2	PSI1	.50	1.4330	.0925	-7.520	3.700	.09	-46.2
167.-168.	7	PHI1	.69	1.1141	.0499	-.530	2.510	.04	-170.3
172.-177.	22	J1	2.80	1.1515	.0155	-.470	.770	.03	-136.3
181.-186.	18	OO1	1.68	1.2591	.0454	.950	2.060	.13	12.0
207.-22X.	21	EPS2	.37	1.2462	.0880	3.710	4.010	.03	44.0
233.-236.	10	2N2	1.21	1.1768	.0267	.770	1.280	.02	43.6
237.-23X.	10	MU2	1.45	1.1710	.0198	.390	.970	.02	36.2
243.-245.	13	N2	9.15	1.1776	.0032	.290	.150	.14	18.8
246.-248.	11	NU2	1.72	1.1675	.0160	-.300	.790	.01	-39.6
252.-258.	26	M2	47.68	1.1746	.0005	.310	.030	.64	23.7
262.-267.	17	L2	1.31	1.1400	.0122	-.970	.610	.03	-136.4
271.-272.	2	T2	1.21	1.0929	.0202	3.250	1.050	.10	138.1
273.-273.	4	S2	22.01	1.1653	.0012	.290	.060	.15	48.7
274.-277.	12	K2	6.11	1.1892	.0057	-.120	.280	.15	-4.9
282.-285.	15	ETA2	.37	1.2765	.1366	4.630	6.110	.04	42.6
292.-2X5.	14	2K2	.09	1.1809	.5208	27.560	25.270	.04	101.7
327.-375.	17	M3	.61	1.0391	.0294	-1.560	1.630	.02	-135.3

STANDARD DEVIATION D 2.84 SD 1.39 TD 0.93 MICROGAL
O1/K1 1.0145 1-O1/1-K1 1.1273 M2/O1 1.0257

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KARP

STATION 1105 POULKOVO   VERTICAL COMPONENT   U.S.S.R.

59 46 12 N   30 19 12 E   H 65 M
GRAVIMETER BN-07   EOTVOS LORAND GEOPH.INST.,   P.VARGA
INSTALLATION   P.VARGA/V.VOLKOV
MAINTENANCE   V.VOLKOV/S.ZASIMOV/F.GUSEVA/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145   PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY 10.00000

INERTIAL CORRECTION NOT APPLIED

G190 760513/761020

3852 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	5.87		1.1327	.0297	.940	1.490	.17	145.4
143.-149.	26	O1	31.09		1.1488	.0050	-.590	.250	.43	-131.8
152.-158.	22	M1	2.59		1.2161	.0446	-.570	2.080	.12	-11.9
161.-168.	33	K1	43.69		1.1481	.0029	-1.570	.150	1.26	-72.3
172.-177.	22	J1	2.25		1.0586	.0650	1.160	3.500	.22	168.2
181.-1X3.	37	OO1	1.51		1.2919	.1319	5.370	5.830	.20	43.9
207.-23X.	41	2N2	.62		1.2835	.0937	7.220	4.220	.10	54.9
243.-248.	24	N2	4.30		1.1778	.0161	.790	.780	.09	42.7
252.-258.	26	M2	22.63		1.1873	.0027	-1.200	.130	.70	-42.7
262.-267.	27	L2	.61		1.1311	.0648	-8.380	3.280	.09	-104.0
271.-2X5.	47	S2	10.35		1.1668	.0058	-.460	.290	.10	-54.6
327.-375.	17	M3	.29		1.5328	.1840	-5.220	6.850	.09	-16.9

STANDARD DEVIATION D 6.41 SD 2.19 TD 1.27 MICROGAL
O1/K1 1.0006 1-O1/1-K1 1.0048 M2/O1 1.0336

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KARP

STATION 1105 POULKOVO VERTICAL COMPONENT U.S.S.R.

59 46 12 N 30 19 12 E H 65 M
GRAVIMETER GS 11/201 V U G T K, PRAGUE ZD.SIMON
CALIBRATION ELECTROMAGNETIC, SENSIB. APPR. 3.8 MKRGL/MM
INSTALLATION Z.SIMON/J.SIMEK
MAINTENANCE V.VOLKOV/S.ZASIMOV/F.GUSEVA/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

AMPLIT.CORRECTIONS 01 1.0019 K1 1.0024 M2 1.0125 S2 1.0135
PHASE CORRECTIONS 01 4.345 K1 4.686 M2 8.976 S2 9.285

INERTIAL CORRECTION NOT APPLIED

G201 760512/760515 760516/760518 760519/760619 760626/760705 760706/760805
G201 760806/760815 760817/760907 760908/760915 760917/760928 760929/761004
G201 761005/761006 761007/761009

3204 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	5.94		1.1491	.0401	-1.110	1.940	.13	-115.5
143.-149.	26	O1	31.40		1.1626	.0068	-.340	.330	.21	-64.6
152.-158.	22	M1	2.73		1.2852	.0583	-3.310	2.640	.31	-30.8
161.-168.	33	K1	43.49		1.1455	.0041	-.940	.220	.77	-67.6
172.-177.	22	J1	2.79		1.3145	.0868	-2.040	3.750	.34	-17.1
181.-1X3.	37	OO1	1.29		1.1100	.1669	-7.060	8.650	.17	-113.4
207.-23X.	41	2N2	.64		1.3368	.1473	-10.960	6.280	.14	-59.1
243.-248.	24	N2	4.27		1.1849	.0257	1.320	1.260	.13	48.1
252.-258.	26	M2	22.13		1.1754	.0043	-.400	.210	.33	-28.3
262.-267.	17	L2	.62		1.1667	.1055	-1.840	5.240	.02	-80.9
271.-2X5.	47	S2	10.21		1.1673	.0089	-.500	.450	.11	-54.9
327.-375.	17	M3	.16		.8553	.3650	40.970	24.390	.13	126.9

STANDARD DEVIATION D 7.18 SD 3.31 TD 2.34 MICROGAL
O1/K1 1.0150 1-O1/1-K1 1.1180 M2/O1 1.0110

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1105 POULKOVO VERTICAL COMPONENT U.S.S.R.

59 46 12 N 30 19 12 E H 65 M
GRAVIMETER GS-15/220,INST.PHYSICS OF EARTH, AS USSR, V.VOLKOV
CALIBRATION-MICROMETRIC SCREW, SENSIB. 2.026 MKRGL/MM
INSTALLATION V.VOLKOV
MAINTENANCE V.VOLKOV/S.ZASIMOV/F.GUSEVA/M.KUZNETSOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 3/14
B RESIDUES CALCULATED BY ICET

DATA MULTIPLIED BY -1.00000
TIME OF THE RECORD CORRECTED BY -230.4 SECONDS

INERTIAL CORRECTION NOT APPLIED

G220 760525/770118

5724 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.26		1.2079	.0216	-.240	1.040	.25	-6.0
143.-149.	26	O1	31.32		1.1574	.0040	-.120	.200	.08	-128.1
152.-158.	22	M1	2.32		1.0896	.0347	-1.250	1.820	.16	-161.1
161.-168.	33	K1	43.49		1.1427	.0021	-.600	.120	.49	-67.2
172.-177.	22	J1	2.43		1.1398	.0479	.350	2.420	.05	162.1
181.-1X3.	37	OO1	1.42		1.2148	.1108	2.950	5.260	.10	49.9
207.-23X.	41	2N2	.59		1.2170	.0559	.840	2.610	.03	17.4
243.-248.	24	N2	4.32		1.1849	.0114	.730	.550	.11	31.4
252.-258.	26	M2	22.58		1.1844	.0020	-.310	.100	.48	-14.8
262.-267.	17	L2	.61		1.1269	.0438	-3.800	2.240	.04	-115.5
271.-2X5.	47	S2	10.42		1.1752	.0044	1.790	.210	.35	68.4
327.-375.	17	M3	.19		.9996	.1393	-5.990	8.130	.02	-125.1

STANDARD DEVIATION D 6.21 SD 2.41 TD 1.44 MICROGAL
O1/K1 1.0129 1-O1/1-K1 1.1032 M2/O1 1.0233

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1117 OBNINSK VERTICAL COMPONENT USSR

55 10 12 N 36 27 00 E H 130 M
GRAVIMETER BN-07 EOTVOS LORAND GEOPH.INST. P.VARGA
INSTALLATION P.VARGA/V.VOLKOV
MAINTENANCE V.VOLKOV/F.GUSEVA/S.ZASIMOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 4/ 5
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G190 750823/751103 751104/751204 751205/760413

5580 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.50		1.1649	.0306	-.330	1.520	.05	-51.3
143.-149.	26	O1	33.62		1.1531	.0061	-.160	.300	.20	-152.6
152.-158.	22	M1	2.57		1.1230	.0475	.810	2.390	.09	156.1
161.-164.	13	P1	15.37		1.1329	.0109	-1.170	.570	.42	-132.2
165.-168.	20	K1	47.07		1.1480	.0040	.180	.200	.45	19.1
172.-177.	22	J1	2.87		1.2497	.0657	.260	3.000	.20	3.7
181.-1X3.	37	OO1	1.38		1.0963	.1192	12.000	6.220	.31	111.2
207.-23X.	41	2N2	.82		1.3135	.0478	4.690	2.100	.11	35.8
243.-248.	24	N2	5.68		1.2094	.0103	-.650	.490	.24	-15.6
252.-258.	26	M2	29.41		1.1995	.0020	-.310	.100	.98	-9.4
262.-267.	17	L2	.71		1.0308	.0548	2.570	3.040	.10	160.5
271.-273.	6	S2	13.59		1.1915	.0044	.020	.200	.36	.8
274.-2X5.	41	K2	3.64		1.1736	.0186	-.820	.910	.07	-51.5
327.-375.	17	M3	.34		1.2366	.1105	-2.560	5.100	.05	-18.2

STANDARD DEVIATION D 13.79 SD 2.57 TD 1.37 MICROGAL
O1/K1 1.0044 1-O1/1-K1 1.0343 M2/O1 1.0403

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1117 OBNINSK VERTICAL COMPONENT USSR

55 10 12 N 36 27 00 E H 130 M
GRAVIMETER GS 15/220,INST. PHYSICS OF EARTH,AS,USSR, V.VOLKOV
INSTALLATION V.VOLKOV
MAINTENANCE V.VOLKOV/F.GUSEVA/S.ZASIMOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 4/ 5
B RESIDUES CALCULATED BY ICET

TIME OF THE RECORD CORRECTED BY -230.4 SECONDS

INERTIAL CORRECTION NOT APPLIED

G220	770211/770221	770222/770314	770316/770411	770412/770421	770423/770509
G220	770510/770601	770602/770607	770611/770630	770701/770716	770717/770718
G220	770719/770818	770820/770914	770916/770917	770918/770929	770930/771127

6516 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.45		1.1553	.0160	.520	.800	.06	112.1
143.-149.	26	O1	33.54		1.1505	.0029	-.030	.140	.26	-176.1
152.-158.	22	M1	2.54		1.1060	.0276	.330	1.450	.12	173.1
161.-164.	13	P1	15.58		1.1480	.0049	.860	.260	.25	108.5
165.-168.	20	K1	46.53		1.1348	.0018	-.010	.090	.12	-176.0
172.-177.	22	J1	2.72		1.1871	.0355	2.530	1.730	.13	64.8
181.-1X3.	37	OO1	1.58		1.2588	.0884	-2.070	4.060	.13	-25.0
207.-23X.	41	2N2	.70		1.1206	.0348	-1.670	1.780	.03	-140.8
243.-248.	24	N2	5.60		1.1925	.0066	.660	.320	.16	23.0
252.-258.	26	M2	28.87		1.1775	.0011	-.090	.060	.43	-6.1
262.-267.	17	L2	.80		1.1508	.0236	-.110	1.170	.01	-166.6
271.-273.	6	S2	13.35		1.1704	.0026	1.430	.120	.35	71.2
274.-2X5.	41	K2	3.60		1.1608	.0120	.960	.600	.06	88.4
327.-375.	17	M3	.31		1.1315	.0877	-7.280	4.400	.04	-69.0

STANDARD DEVIATION D 5.55 SD 1.87 TD 1.39 MICROGAL
O1/K1 1.0139 1-O1/1-K1 1.1167 M2/O1 1.0235

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1117 OBNINSK VERTICAL COMPONENT USSR

55 10 12 N 36 27 00 E H 130 M
GRAVIMETER GS-15/221 AS ASSR SH.OGANISIAN
INSTALLATION V.VOLKOV
MAINTENANCE V.VOLKOV/F.GUSEVA/S.ZASIMOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 4/ 5
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G221 750830/750910 750911/750911 750912/750913 750914/750914 750915/750917
G221 750919/751008 751009/751023 751027/751027 751024/751026 751027/751119
G221 751120/760126 760131/760418

5256 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.56		1.1743	.0371	4.390	1.850	.51	82.8
143.-149.	26	O1	34.15		1.1713	.0076	-.200	.370	.37	-18.8
152.-158.	22	M1	2.83		1.2331	.0611	1.860	2.800	.19	28.5
161.-164.	13	P1	16.14		1.1896	.0133	-1.390	.660	.62	-39.0
165.-168.	20	K1	47.37		1.1553	.0049	-1.110	.240	1.16	-52.0
172.-177.	22	J1	2.67		1.1664	.0850	-4.370	4.240	.20	-88.9
181.-1X3.	37	OO1	1.60		1.2764	.1484	6.370	6.660	.22	52.7
207.-23X.	41	2N2	.73		1.1833	.1007	9.280	4.800	.12	87.7
243.-248.	24	N2	5.50		1.1714	.0221	.110	1.100	.05	11.3
252.-258.	26	M2	29.39		1.1991	.0042	-.130	.200	.96	-4.0
262.-267.	17	L2	.95		1.3732	.1165	-.360	4.870	.15	-2.3
271.-273.	6	S2	13.89		1.2183	.0089	-1.920	.400	.80	-35.4
274.-2X5.	41	K2	3.51		1.1325	.0377	2.600	1.900	.18	119.2
327.-375.	17	M3	.23		.8514	.1793	-4.070	12.170	.06	-164.5

STANDARD DEVIATION D 25.78 SD 5.92 TD 2.59 MICROGAL
O1.K1 1.0139 1-O1/1-K1 1.1031 M2/O1 1.0238

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1117 OBNINSK VERTICAL COMPONENT USSR

55 10 12 N 36 27 00 E H 130 M
GRAVIMETER GS-15/221 AS ASSR SH.OGANISIAN
INSTALLATION V.VOLKOV
MAINTENANCE V.VOLKOV/F.GUSEVA/S.ZASIMOV

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 4/ 5
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G221	770518/770706	770708/770715	770716/770818	770820/770911	770912/771012
G221	771013/771101	771103/771113	771114/771115	771116/771122	771123/771125
G221	771126/771213	771214/771227	780218/780218	771228/771228	771230/780104
G221	780107/780109	780111/780119	780121/780201		

5760 HOURS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL. R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	PHASE
105.-139.	65	Q1	6.35	1.1371	.0132	.640	.670	.14	150.5
143.-149.	26	O1	33.56	1.1510	.0025	.200	.120	.27	154.2
152.-158.	22	M1	2.50	1.0916	.0245	.720	1.310	.16	168.5
161.-164.	13	P1	15.19	1.1198	.0044	.300	.220	.47	170.2
165.-168.	20	K1	46.79	1.1410	.0017	.100	.080	.16	30.4
172.-177.	22	J1	2.69	1.1744	.0294	-.650	1.440	.04	-45.7
181.-1X3.	37	OO1	1.34	1.0707	.0982	-1.310	5.260	.12	-164.8
207.-23X.	41	2N2	.74	1.1861	.0316	1.410	1.520	.02	48.7
243.-248.	24	N2	5.62	1.1973	.0066	.200	.310	.18	6.4
252.-258.	26	M2	28.98	1.1821	.0012	-.260	.060	.55	-13.7
262.-267.	17	L2	.76	1.0913	.0229	-1.290	1.200	.05	-160.4
271.-273.	6	S2	13.22	1.1593	.0027	.190	.120	.04	101.8
274.-2X5.	41	K2	3.53	1.1370	.0123	-.880	.620	.09	-143.1
327.-375.	17	M3	.30	1.0776	.1033	-14.660	5.490	.08	-95.2

STANDARD DEVIATION D 4.54 SD 1.71 TD 1.48 MICROGAL
O1/K1 1.0087 1-O1/1-K1 1.0706 M2/O1 1.0270

EARTH TIDAL OBSERVATIONS OF THE WORKING GROUP 3.3 KAPG

STATION 1117 OBNINSK VERTICAL COMPONENT USSR

55 10 12 N 36 27 00 E H 130 M
GRAVIMETER GS-15/224, ROLAND EOTVOS UNIVERSITY, B.BODRI
ANALOG RECORD, CALIBRATION ELECTROMAGNETIC, 2.01 MKGL/MM
INSTALLATION V.VOLKOV
MAINTENANCE V.VOLKOV/F.GUSEVA

METHOD VENEDIKOV(1974),FILTERS 1 36 D 3,2 SD 1,2 TD 1,2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID /SKALSKY/
COMPUTING LABORATORY W.G. 3.3 KAPG, GEOPHYSICAL INST.,SOFIA
COMPUTER IBM 370/145 PROCESSED ON 81/ 4/ 5
B RESIDUES CALCULATED BY ICET

INERTIAL CORRECTION NOT APPLIED

G224 761215/770101 770104/770126 770128/770328 770421/770428 770502/770525
G224 770526/770801 770802/770830

5436 HOURS

5436 HOURS 151 INTERVALS FILTERED, WEIGHED, SHIFT 36

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUE AMPL.	RESIDUE PHASE
105.-139.	65	Q1	6.52		1.1682	.0110	.780	.540	.10	61.6
143.-149.	26	O1	34.18		1.1724	.0020	.180	.100	.40	15.7
152.-158.	22	M1	2.67		1.1659	.0199	-1.630	.960	.08	-78.5
161.-164.	13	P1	15.87		1.1699	.0038	-.480	.170	.26	-31.2
165.-168.	20	K1	47.50		1.1585	.0013	.250	.070	.88	13.6
172.-177.	22	J1	2.79		1.2174	.0249	1.170	1.200	.14	24.0
181.-1X3.	37	OO1	1.48		1.1797	.0688	.660	3.360	.03	35.5
207.-23X.	41	2N2	.77		1.2448	.0262	1.510	1.190	.06	21.3
243.-248.	24	N2	5.70		1.2147	.0050	.380	.240	.26	8.4
252.-258.	26	M2	29.54		1.2047	.0008	.000	.040	1.09	.0
262.-267.	17	L2	.82		1.1812	.0179	.010	.870	.01	.6
271.-273.	6	S2	13.68		1.1989	.0020	-.390	.090	.45	-11.9
274.-2X5.	41	K2	3.77		1.2137	.0092	-.770	.440	.17	-17.0
327.-375.	17	M3	.29		1.0402	.0485	2.090	2.710	.01	126.3

STANDARD DEVIATION D 5.15 SD 1.24 TD 0.69 MICROGAL
O1/K1 1.0121 1-O1/1-K1 1.0882 M2/O1 1.0275