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2nd Meeting of the

"Working Group on Data Processing in Tidal Research"

Bonn 20 th - 22th march 1979.

At the 8th International Symposium on Earth Tides in Bonn, 19th-24th September 1977, the President of the Permanent Commission on Earth Tides has appointed the "Working Group on Data Processing in Tidal Research". The Institut für Theoretische Geodäsie, Bonn, has been charged with the organisation of the 2nd meeting in March 1979.

This meeting took place from March 20th to 22th, 1979 at the Institut für Theoretische Geodäsie, 5300 Bonn, Nussallee 17, Federal Republic of Germany.

Present

Baker T.	United Kingdom
Bartha G.	Hungary
Bonatz M.	F. R. Germany
Chojnicki T.	Poland
Ducarme B.	Belgium
Jentsch G.	F. R. Germany
Lecolazet R.	France
Lichtenegger	Austria
Melchior P.	Belgium
Nakai S.	Japan
Schüller K.	F. R. Germany
Sukhwani P.	Spain
Venedikov A.	Bulgaria
Wenzel H.G.	F. R. Germany

Program of the meeting

Subroutine Program for Computing the Tidal Forces for the Practical Use

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1. Introduction.

There are two courses for computing the luni-solar attraction which is a basic procedure not only in the tidal research but also in the tidal correction for the precise gravity survey. First, considering the tidal attraction as a set of many tidal consituents, the tidal forces are obtained by the sum of each constituent. Second, by calculating the positions of the moon and the sun, we can directly get the attraction at any time and place.

According to the first course, as the precise coefficients of each constituent by Cartwright and Tayler are available, we can compute the tidal forces with a sufficient accuracy. This method is especially effective for the harmonic analysis of tidal data, because the amplitudes and phases of each constituent can be got at the same time. However, for the computation of the tidal force itself, more computation time is required as compared with the second method.

In the second method, we can make use of Harrison's program which is called to have an accuracy of 0.1%. But this is not the most convenient, because it contains too complicated parts and the accuracy is not sufficient. It seems that the standardized method in the view of both accuracy and efficiency has not yet been established.

A computer program for the tidal forces, which is written as simple as possible and with a necessary and sufficient accuracy, has been utilized at the International Latitude Observatory of Mizusawa since a few years.

Table 1 List of symbols

Symbol	Explanation	Program
V	tide generating potential	
G	Newtonian gravitational constant	GM,GS
M	mass of moon (sun)	GM,GS
r	geocentric distance of observation point	RR
R	geocentric distance of moon (sun)	DM,DS
z	zenith angle of moon (sun)	BM,BS
ψ	geocentric north latitude of observation point	PS
λ	terrestrial east longitude of observation point	RM
δ	declination of moon (sun)	EM,ES
H	hour angle of moon (sun)	HM,HS
t	Universal Time in hours	UT
$\alpha_{\odot}$	right ascension of mean sun	SA
α	right ascension of moon (sun)	AM,AS
w	tidal acceleration in geocentric coordinate	
g	tidal acceleration in geodetic coordinate	DT
a	equatorial radius of the earth	EE
f	earth's flattening	FL
ξ	height above earth ellipsoid or mean sea level	HI
φ	geodetic north latitude of observation point	PH
γ	difference between geodetic and geocentric latitude	GN
L	astronomical longitude of moon (sun)	SM,SS
β	astronomical latitude of moon (sun)	DC, -
ε	obliquity of the ecliptic	OM
T	Ephemeris Time in Julian centuries from 1900 Jan. 0.5	TI
T'	Universal Time in Julian centuries from 1900 Jan. 0.5	TT
s	mean longitude of moon	WA
h	mean longitude of sun	WB
p	mean longitude of lunar perigee	WC
N	mean longitude of ascending node of moon	WD
p'	mean longitude of perihelion	WE
l	parameter defined by eqn.(27)	SP
l'	mean anomaly of perihelion	HP
F	parameter defined by eqn.(29)	FF
D	parameter defined by eqn.(30)	SH
π	lunar parallax	DD
c	mean distance of sun	CS
e	eccentricity of earth's orbit	EI

2. The outline of the method.

The tidal potential due to the moon or the sun at the Earth's surface can be written by

$$V = \frac{GM}{R}\sum_{n=2}^{\infty}\left(\frac{r}{R}\right)^n P_n(\cos z)$$

$$= \frac{GMr^2}{R^3}\left\{P_2(\cos z) + \frac{r}{R}P_3(\cos z) + \left(\frac{r}{R}\right)^2 P_4(\cos z) + - - - -\right\}. \quad (1)$$

Denoting the suffix m for the moon and s for the sun, we get

$$\frac{r}{R_m} \fallingdotseq 1.6\cdot 10^{-2}, \quad \frac{r}{R_s} \fallingdotseq 4.3\cdot 10^{-5}.$$

Then it is enough if we consider up to the second term of (1) for the moon, and the first term only for the sun. So we have

$$V = V_m + V_s$$

$$= \frac{GM_m r^2}{2R_m^{\ 3}}\left\{(3\cos^2 z_m - 1) + \frac{r}{R_m}(5\cos^2 z_m - 3\cos z_m)\right\}$$

$$+ \frac{GM_s r^2}{2R_s^{\ 3}}\left\{3\cos^2 z_s - 1\right\}, \quad (2)$$

where

$$\cos z = \sin\psi\sin\delta + \cos\psi\cos\delta\cos H \quad (3)$$

and

$$H = t + \lambda + \alpha_{\odot} - \alpha + \pi, \quad (4)$$

Where

$$\alpha_{\odot} = 18^h 38^m 45^s\!.836 + 8640184^s\!.542T' + 0^s\!.093T'^2. \quad (5)$$

Tidal attractions are obtained by differentiating (2) as follows.

$$W_{down} = -\frac{\partial V}{\partial r} = -\frac{GMr}{R^3}\left\{3\cos^2 z - 1 + \frac{3r}{2R}(5\cos^3 z - 3\cos z)\right\} \quad (6)$$

$$W_{south} = -\frac{\partial V}{r\partial\psi} = -\frac{GMr}{R^3}\left\{3\cos z + \frac{3r}{2R}(5\cos^2 z - 1)\right\}\cdot$$

$$(\cos\psi\sin\delta - \sin\psi\cos\delta\cos H) \quad (7)$$

$$W_{west} = -\frac{1}{r\cos\psi}\frac{\partial V}{\partial \lambda} = \frac{GMr}{R^3}\left\{3\cos z + \frac{3r}{2R}(5\cos^2 z - 1)\right\}\cos\delta\sin H, \tag{8}$$

where $r = a(1 - f\sin^2\psi) + \xi,$ (9)

$$\psi = \varphi - f\sin 2\varphi. \tag{10}$$

These components of tidal attraction are referred to the geocentric coordinates. On the other hand, we usually need the component referred to the geoid. Now adopting the suface of the Earth ellipsoid instead of the geoid and putting

$$\gamma = \varphi - \psi = f\sin 2\varphi, \tag{11}$$

$$g_{down} = W_{down}\cos\gamma + W_{south}\sin\gamma, \tag{12}$$

$$g_{south} = W_{south}\cos\gamma - W_{down}\sin\gamma. \tag{13}$$

As γ is small, we write approximately the three components referred to the geoid as follows.

$$g_{down} = W_{up} + W_{south}\gamma, \tag{14}$$

$$g_{south} = W_{south} - W_{down}\gamma, \tag{15}$$

$$g_{west} = W_{west}. \tag{16}$$

Although the computation of the position of the moon and the sun will be mentioned later, general procedures comon to both celestial bodies are referred here. α and δ of the celestial bodies are given by the following expressions after getting the L and β.

$$\left.\begin{aligned} \cos\delta\cos\alpha &= \cos\beta\cos L, \\ \cos\delta\sin\alpha &= \cos\beta\sin L\cos\varepsilon - \sin\beta\sin\varepsilon, \\ \sin\delta &= \cos\beta\sin L\sin\varepsilon + \sin\beta\cos\varepsilon, \end{aligned}\right\} \tag{17}$$

where

$$\varepsilon = 23^\circ\!.45229 - 0^\circ\!.01301\,T. \tag{18}$$

The relation between UT and ET is

$$ET = UT + \Delta T, \tag{19}$$

where ΔT is given in the ephemeris.

The predicted values of ΔT are $+47^s$ for the year 1977, $+48^s$ for 1978 and $+49^s$ for 1979.

For the computation of L and β of the celestial bodies, the following mean orbital elements are necessary.

$$s = 270^\circ.43436 + 481267^\circ.88314\,T - 0^\circ.00113\,T^2 \quad (20)$$

$$h = 279^\circ.69668 + 36000^\circ.76892\,T + 0^\circ.00030\,T^2 \quad (21)$$

$$p = 334^\circ.32944 + 4069^\circ.03403\,T - 0^\circ.01033\,T^2 \quad (22)$$

$$N = 259^\circ.18327 - 1934^\circ.14201\,T + 0^\circ.00208\,T^2 \quad (23)$$

$$p' = 281^\circ.22083 + 1^\circ.71918\,T + 0^\circ.00045\,T^2 \quad (24)$$

Moreover, it is better to take into account the effect of the nutation. The main terms of the nutation are given as

$$\Delta\varepsilon = 9''.21 \cos N, \quad (25)$$

$$\Delta L = -17''.23 \sin N. \quad (26)$$

(25) is to be added to (18) and (26) to (20) $\sim$ (24) respectively.

3. Accuracy.

At the present situation, the finest resolution obtained by tidal observations is 0.3 μgals or so for the gravity data. Therefore, the accuracy of 0.1 μgal in the theoretical tides seems necessary and sufficient. In other words, this is the accuracy of 0.04% in the total amplitude of tidal forces.

As the maximum tidal variations reach roughly 1 μgal/min, 0.1 μgal corresponds to 0.1 min, and in the viewpoint of the reading accuracy in the time scale the above condition seems to be reasonable. 0.1 min in time is 90'' in angle. Then it is necessary to keep the accuracy of 90'' in the α and δ of both celestial bodies.

Concerning the distance to the moon or the sun, the factor of R^{-3} is contained in the formula. Any error in R, therefore, affects the results by the factor of 3. To get the accuracy of 0.04%, it is necessary to obtain the precision of about 0.01% in R.

On the other hand, it is nonsense to wish more accurate positions of the celestial bodies, because

(1) The present accuracy is almost the same as an error by omitting the higher terms of the tide generating potential.

(2) The precision of the constant GMm is also same order as the present accuracy.

(3) The computed tidal components are referred to the Earth's ellipsoid and the vertical deflections are not taken into account .

Thus, the accuracy of 90° in α and δ and 0.1% in R are considered to be necessary and sufficient conditions in the present calculation.

4. Position of the Moon

The Lunar theory by Brown was revised by Eckert et al and summarized in "Improved Lunar Ephemeris 1952 - 1959" (ILE). For the computation of the moon's position, we had better to follow ILE. According to ILE, longitude, latitude and distance of the moon which can be got independently are presented by the many perturbation terms added to their mean positions. The following four parameters are needed to compute these perturbation terms.

$$l = s - p, \tag{27}$$

$$l' = h - p', \tag{28}$$

$$F = s - N, \tag{29}$$

$$D = s - h. \tag{30}$$

Before the computation of these parameters, some additive terms have relatively large amplitudes which should be taken into account to the orbital elements as

$$\Delta S = 14''27 \sin (3.376 - 2.319\,T) + 7''26 \sin (4.524 - 33.757\,T), \tag{31}$$

$$\Delta N = 95.96 \sin (4.524 - 33.757\,T) + 15''58 \sin (3.041 - 33.797\,T). \tag{32}$$

(31) is to be added to (20) and (32) to (23) respectively.

a) moon's longitude

In the present accuracy, the moon's longitude is given by

$$Lm = S + \sum_i k_i \sin (A_i) \tag{33}$$

k_i and A_i for each i are given in Table 3.

The accuracy in the moon's longitude depends on to what extent we take those perturbation terms. For the estimation of the best cutting off, a test has been made. The apparent right ascensions have been computed for 432 epochs at 0^h ET on 1, 6, 11, 16, 21 and 26 in every month during 1974 - 1979 and compared with the given values in the ephemeris. In the calculations, the latitudes necessary to the transformation have been given in the accuracy of 10" and the aberration between the moon and the Earth has been taken into account.

Fig. 1 shows the standard deviation of (O-C) for each i where i = 0 is the case when all perturbation terms have been neglected. To keep the accuracy of 90", it is adequate to take into account up to the term where the standard deviation become to one-third of the accuracy. In Fig. 1, we should take up to the 22nd term. In other words, all perterbation terms having the amplitude more than 18" should be adopted.

b) moon's Latitude

In the previous paragraph, it has been proved that we should take into account the term having the amplitude more than 18". In this accuracy, the formula of the moon's latitude given in ILE can be simplified as lollows

$$\beta_m = 18519''.7 \sin (F + \sum_i m_i \sin B_i) + \sum_j n_j \sin C_j. \qquad (34)$$

Amplitudes and arguments corresponding to each i and j are given in Table 4.

c) moon's distance

The geocentric distance to the moon is given in terms of the sine parallax in ILE. In the present accuracy it is sufficient to write

$$a/R_m = \sin \Pi, \qquad (35)$$

where

$$\Pi = 3422''.700 + \sum_i q_i \cos E_i. \qquad (36)$$

q_i and E_i are given in Table 5. As shown in Table 2, the present adopted value of the constant in (36) is 3422.451. Π should be therefore multiplied by 0.999927. As Π is at most 1° or so, (35) can be replaced by

$$a/R_m = \Pi(\text{rad}).$$

The estimation of the possible error in cutting off the perterbation terms in (36) has been made in the same manner as in longitude and is shown in Fig. 2. In this figure, considering the stoudard deviation of one-third of necessary accuracy in R_m as 0.004%, it is clear that terms up to i = 27 should be taken.

5. Position of the sun

Viewing on the Earth, we can consider that the sun moves on the elliptical orbit. In the present accuracy, the following approximation will be sufficient.

$$L_S = h + 2e \sin l' + \frac{5}{4} e^2 \sin 2l', \tag{38}$$

$$\beta_S = 0, \tag{39}$$

$$C/R_S = 1 + e \cos l' + e^2 \cos 2l', \tag{40}$$

where

$$e = 0.01675104 - 0.00004180\,T. \tag{41}$$

6. Program

A computer program written in FORTRAN and based on the above procedure is shown.

The general precision of the positions of celestial bodies are given in Table 6. The maximum errors for the moon exceed the limit of accuracy but not so much. It can be considered that the total accuracy is kept within 0.1 μgal as a whole, even in the case when one of elements exceeds the temporary error limit.

References

Cartwright, D.E. and R.J. Tayler (1971) :
New Computations of the Tide-generating Potential, Geophys. J.R. astr. Soc. 23, 45-74

Eckert, W.J., Rebecca Jones and H.K. Clark (1954) :
Construction of the Lunar Ephemeris, in " Improved Lunar Ephemeris 1952-1959 ", 283-363 U.S. Govt print. Off, Washington, D.C.

Harrison, J.C. (1971) :
New Computer Programs for the Calculation of Earth Tides, Cooperative Institute for Research in Environmental Sicences, University of Colorado

Table 2 Primary and derived constants

c	149600×10^6 m
a	6378160 m
GE	$398603 \times 10^9\ m^3/s^2$
M/E	1/81.30
f	0.0033529
GS	$132718 \times 10^{15}\ m^3/s^2$
a/R	3422."451

Table 3 Perturbation terms in lunar longitude

No.(i)	Amplitude(k_i)	Argument(A_i)	No.(i)	Amplitude(k_i)	Argument(A_i)
1	+22639".500	l	16	+39".528	l-2F
2	-4586.465	l-2D	17	-38.428	l-4D
3	+2369.912	2D	18	+36.124	3l
4	+769.016	2l	19	-30.773	2l-4D
5	-668.146	l′	20	+28.475	l-l′-2D
6	-411.608	2F	21	-24.420	l′+2D
7	-211.656	2l-2D	22	+18.609	l-D
8	-205.962	l+l′-2D	23	+18.023	l′+D
9	+191.953	l+2D	24	+14.577	l-l′+2D
10	-165.145	l′-2D	25	+14.387	2l+2D
11	+147.687	l-l′	26	+13.902	4D
12	-125.154	D	27	-13.193	3l-2D
13	-109.673	l+l′	28	+9.703	2l-l′
14	-55.173	2F-2D	29	+9.366	l-2F-2D
15	-45.099	l+2F	30	-8.627	2l+l′-2D

Table 4 Perturbation terms in lunar latitude

No.(i)	Amplitude(m_i)	Argument(B_i)	No.(j)	Amplitude(n_j)	Argument(C_j)
1	+22609".07	l	1	-526".069	F-2D
2	-4578.13	l-2D	2	+44.297	F+l-2D
3	+2373.36	2D	3	-30.598	F-l-2D
4	+767.96	2l	4	-24.649	F-2l
			5	-22.571	F+l′-2D
			6	+20.599	F-l

Table 5 Perturbation terms in lunar parallax

No.(i)	Amplitude(q_i)	Argument(E_i)	No.(i)	Amplitude(q_i)	Argument(E_i)
1	+186".540	l	16	-0".304	2l-2D
2	+34.312	l-2D	17	-0.300	l′+2D
3	+28.233	2D	18	+0.283	2l+2D
4	+10.166	2l	19	+0.261	4D
5	+3.086	l+2D	20	+0.230	l-l′+2D
6	+1.918	l′-2D	21	-0.226	l-l′-2D
7	+1.153	l-l′	22	+0.149	l′+D
8	+1.444	l+l′-2D	23	+0.127	2l-l′
9	-0.978	D	24	-0.119	3l-2D
10	-0.949	l+l′	25	-0.109	l+D
11	-0.714	l-2F	26	-0.105	2F-2D
12	+0.622	3l	27	-0.104	2l+l′
13	+0.601	l-4D	28	+0.092	2l′-2D
14	-0.400	l′	29	-0.083	l+2F
15	+0.372	2l-4D	30	+0.067	l+l′-4D

Table 6 Comparisons of the astronomical position by the present calculations with the ephemeris for 432 epochs of approximately every 5 days during 1974-1979.

		mean	SD	max. difference
right ascension (cal-eph)	moon	0".50	28".67	117".37
	sun	5.01	11.64	33.21
declination (cal-eph)	moon	0.43	24.40	-102.07
	sun	1.33	3.37	11.90
distance (cal-eph)/eph	moon	0.04×10^{-5}	3.94×10^{-5}	16.73×10^{-5}
	sun	0.03	3.02	8.12

Fig. 1 Standard deviations in the difference in lunar right ascension between ephemeris and the calculation by successive approximation.

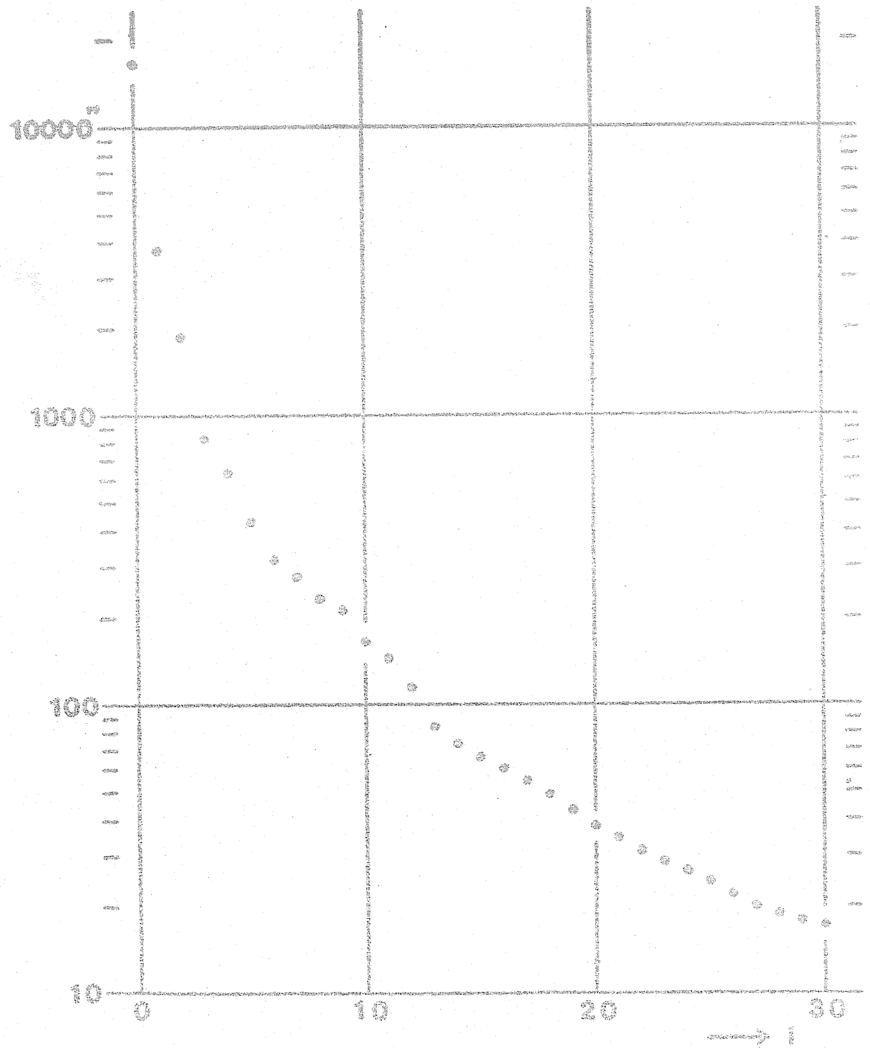
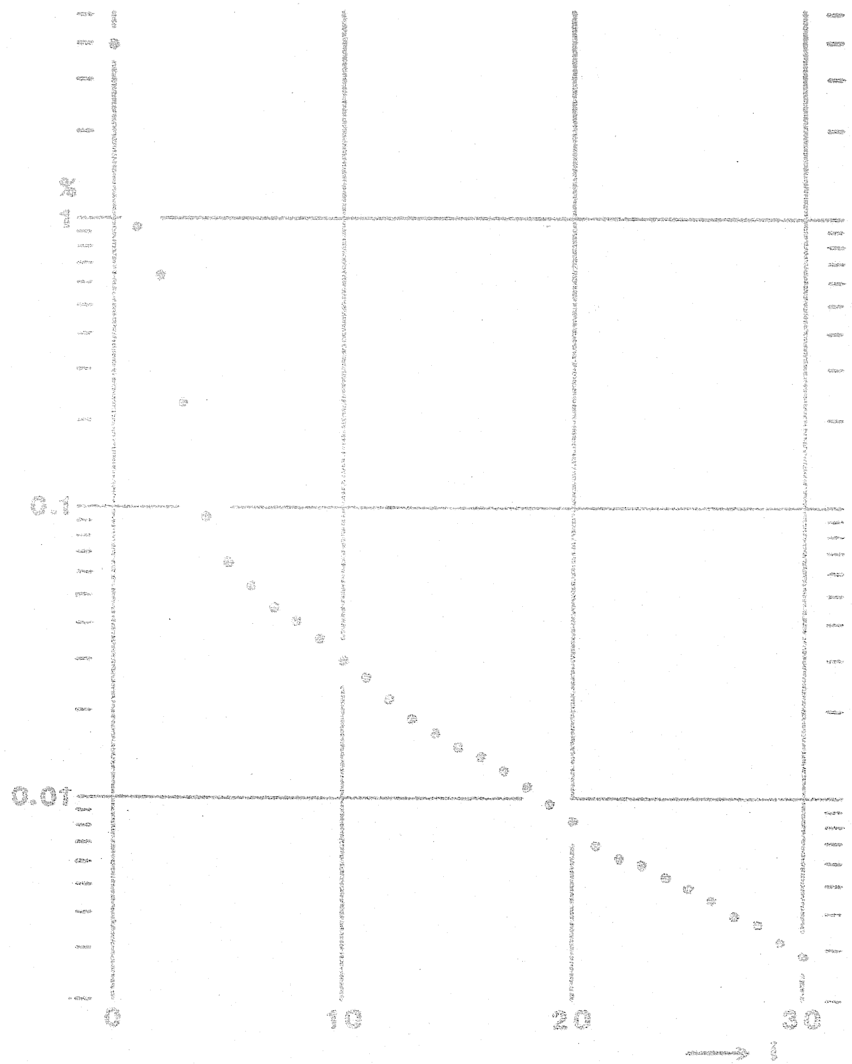


Fig. 2 Standard deviations in lunar parallax.



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      SUBROUTINE TIDE (DT,ST,JA,JB,JC,JD,JE,RM,PH,HI,TL,NN,IC,IH)
C     EXPLANATION OF ARGUMENTS NOT APPEARED IN TABLE 1
C     ST = STEP OR INTERVAL OF CALCULATIONS IN HOURS
C     JA = LAST 2 FIGURES OF YEAR AT THE ORIGIN
C     JB = MONTH
C     JC = DAY
C     JD = HOUR
C     JE = MINUTE
C     TL   ET-UT IN SECONDS
C     NN = NUMBER OF CALCULATIONS
C     IC = IDENTIFICATION OF COMPONENT  IC=1 DOWN, IC=2 SOUTH, IC=3 WEST
C     IH = IDENTIFICATION OF TIME SYSTEM   IH=0 UT, IH=1 JST
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION DT(3000)
      DATA CR/4.848136811D-6/,PI/3.141592654/,FL/3.3529D-3/,CS/1.496D11/
      DATA GM/4.90287D12/,PL/3.422451D3/,EE/6.37816D6/,GS/1.32718D20/
      XT=ST/(36525.*24.)
      XX=ST*PI/12.
      RN=RM*3600.*CR+PI
      GN=FL*SIN((PH+PH)*3600.*CR)
      PS=PH*3600.*CR-GN
      RA=COS(PS)
      RB=SIN(PS)
      RR=EE*(1.-FL*RB**2)+HI
      ZM=RR*GM*1.D8
      ZS=RR*GS*1.D8
      IF (IH.EQ.1) JD=JD-9
      UT=FLOAT(JD)+FLOAT(JE)/60.
      TT=(FLOAT(JA*365+JA/4+JB*31-(JB+3)/2+(JB/9)*MOD(JB,2)+JC+
     A    (3/(JB+1))*(1+(MOD(JA,4)+3)/4))+UT/24.-31.5)/36525.
      TI=TT+TL/(3600.*24.*36525.)
      HD=UT*PI/12.
      CA=14.27*SIN(3.376- 2.319*TI)+ 7.26*SIN(4.524-33.757*TI)
      CB=95.96*SIN(4.524-33.757*TI)+15.58*SIN(3.041-33.797*TI)
      DO 2 MM=1,NN
      WA=( 973563.69+(1732564379.31- 4.08*TI)*TI+CA)*CR
      WB=(1006908.04+( 129602768.13+ 1.09*TI)*TI)*CR
      WC=(1203586.75+(  14648522.52-37.17*TI)*TI+CB)*CR
      WD=( 933059.79-(    6962911.23- 7.48*TI)*TI)*CR
      WE=(1012395.00+(        6189.03+ 1.63*TI)*TI)*CR
      SA=(1006887.54+( 129602768.13+ 1.39*TT)*TT)*CR
      OM=(84428.26-46.85*TI+9.21*COS(WD))*CR
      EI=0.01675104-0.0000418*TI
      OL=17.23*SIN(WD)*CR
      EA=COS(OM)
      EB=SIN(OM)
      SP=WA-WC
      FF=WA-WD
      SH=WA-WB
      HP=WB-WE
      BA=SP+SP
      BB=FF+FF
      BC=SH+SH
      BD=HP+HP
      SS=WB-OL+2.*EI*SIN(HP)+1.25*EI**2*SIN(BD)
      DS=CS/(1.+EI*COS(HP)+EI**2*COS(BD))
      ES=ASIN(EB*SIN(SS))
      AS=ATAN2(EA*SIN(SS),COS(SS))
```

```
      SM=(22639.500*SIN(SP)                  -4586.465*SIN(SP-BC)
     A      +2369.912*SIN(BC)                 +769.016*SIN(BA)
     B      -668.146*SIN(HP)                  -411.608*SIN(BB)
     C      -211.656*SIN(BA-BC)               -205.962*SIN(SP+HP-BC)
     D      +191.953*SIN(SP+BC)               -165.145*SIN(HP-BC)
     E      +147.687*SIN(SP-HP)               -125.154*SIN(SH)
     F      -109.673*SIN(SP+HP)                -55.173*SIN(BB-BC)
     G       -45.099*SIN(SP+BB)                +39.528*SIN(SP-BB)
     H       -38.428*SIN(SP-BC-BC)             +36.124*SIN(SP+BA)
     I       -30.773*SIN(BA-BC-BC)             +28.475*SIN(SP-HP-BC)
     J       -24.420*SIN(HP+BC)                +18.609*SIN(SP-SH)
     K       +13.023*SIN(HP+SH))*CR+WA-OL
      DN=    526.069*SIN(BC-FF)                +44.297*SIN(SP+FF-BC)
     A       +30.598*SIN(SP-FF+BC)             +24.649*SIN(BA-FF)
     B       +22.571*SIN(BC-HP-FF)             +20.599*SIN(FF-SP)
      DF=(22609.07 *SIN(SP)                  -4578.13 *SIN(SP-BC)
     A    +2373.36 *SIN(BC)                   +767.96 *SIN(BA))*CR
      DD=   3422.700                          +186.540*COS(SP)
     A       +34.312*COS(SP-BC)                +28.233*COS(BC)
     B       +10.166*COS(BA)                    +3.086*COS(SP+BC)
     C        +1.918*COS(HP-BC)                 +1.153*COS(SP-HP)
     D        +1.444*COS(SP+HP-BC)              -0.978*COS(SH)
     E        -0.949*COS(SP+HP)                 -0.714*COS(SP-BB)
     F        +0.622*COS(SP+BA)                 +0.601*COS(SP-BC-BC)
     G        -0.400*COS(HP)                    +0.372*COS(BA-BC-BC)
     H        -0.304*COS(BA-BC)                 -0.300*COS(HP+BC)
     I        +0.283*COS(BA+BC)                 +0.261*COS(BC+BC)
     J        +0.230*COS(SP-HP+BC)              -0.226*COS(SP-HP-BC)
     K        +0.149*COS(HP+SH)                 +0.127*COS(BA-HP)
     L        -0.119*COS(BA+SP-BC)              -0.109*COS(SP+SH)
     M        -0.105*COS(BB-BC)                 -0.104*COS(BA+HP)
      DC=(18519.7*SIN(FF+DF)+DN)*CR
      EM=ASIN(EA*SIN(DC)+EB*COS(DC)*SIN(SM))
      AM=ATAN2(EA*COS(DC)*SIN(SM)-EB*SIN(DC),COS(DC)*COS(SM))
      DM=EF/((DD/3422.7)*PL*CR)
      GC=ZM/DM**3
      GD=GC*RR*1.5/DM
      GE=ZS/DS**3
      HH=HD+RN+SA
      HM=HH-AM
      HS=HH-AS
      BM=RB*SIN(EM)+RA*COS(EM)*COS(HM)
      BS=RB*SIN(ES)+RA*COS(ES)*COS(HS)
      IF (IC.EQ.3) DT(MM)=(3.*GC*BM+GD*(5.*BM**2-1.))*COS(EM)*SIN(HM)
     A                      +3.*GE*BS*COS(ES)*SIN(HS)
      IF (IC.EQ.3) GO TO 1
      DA=GC*(1.-3.*BM**2)+GD*(3.*BM-5.*BM**3)+GE*(1.-3.*BS**2)
      DB=(3.*GC*BM+GD*(5.*BM**2-1.))*(RB*COS(EM)*COS(HM)-RA*SIN(EM))
     A    +3.*GE*BS*(RB*COS(ES)*COS(HS)-RA*SIN(ES))
      IF (IC.EQ.1) DT(MM)=DA+GN*DB
      IF (IC.EQ.2) DT(MM)=DB-GN*DA
    1 CONTINUE
      TI=TI+XT
      TT=TT+XT
      HD=HD+XX
    2 CONTINUE
      RETURN
      END
```

A Proposal For Modelling The Body Tide of Gravity And Tilt

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Abstract: Due to the different elastic responses of the Earth with respect to W_2 and W_3 body tide constituents, the assumption of constant tidal admittances δ, γ is not valid, when W_2 and W_3 constituents are included in a frequency band group. Hence, it is proposed to normalize the W_3 constituents relative to the W_2 ones by means of a proper set of Love numbers. The similar problem arises when the π_1,P1,S1,K1,ψ_1,φ_1,θ_1-group cannot be resolved due to the record length. Then, because of the liquid core resonance, the constant admittance assumption does not hold as well. Therefore it is proposed to normalize all constituents of this group to K1 by means of a suitable liquid core Earth model. Following these proposals model errors can be avoided.

1. Tidal admittances for gravity and tilt from Love's theory

According to Love's theory, the body tide admittances for gravity and tilt are dependent from the potential degree and associated Love numbers (MELCHIOR 1978):

$$\delta_n = 1 + \frac{2}{n}h_n - \frac{n+1}{n}k_n \tag{1.1a}$$

$$\gamma_n = 1 + k_n - h_n \tag{1.1b}$$

For the Gutenberg-Bullen A Earth model of FARRELL 1972, one can numerically derive for

$$\begin{aligned} \delta_2 &= 1.1554 \;, \quad \gamma_2 = 0.6926 \\ \delta_3 &= 1.0671 \;, \quad \gamma_3 = 0.8051 \end{aligned} \tag{1.2}$$

Setting up the ratios

$$k_\delta = \frac{\delta_3}{\delta_2} \quad , \quad k_\gamma = \frac{\gamma_3}{\gamma_2} \tag{1.3}$$

we find for the Gutenberg-Bullen A model of (1.2):

$$k_\delta = 0.9236, \; k_\gamma = 1.1624 \tag{1.4}$$

As W_2 and W_3 can be represented both by zonal, tesseral and sectorial sperical harmonics (MELCHIOR 1978) it is clear that a frequency domain evaluation of the associated forces share the same frequency domains. Hence, the assumption of constant admittances δ, γ over the different frequency bands turns out to be not valid, when grouping W_2 and W_3 constituents together.

2. Normalization procedure for taking into account W_2, W_3 interactions

In order to take into account the different elastic responses of the Earth due to W_2, W_3, one has to normalize the theoretical amplitudes of the W_3-constituents with respect to W_2-ones in those frequency bands where interactions occur. This is done by multiplying them with the k_δ, k_γ ratios of (1.3):

$$\bar{A}^T_{\delta_3} = k_\delta A^T_{\delta_3} \quad , \quad \bar{A}^T_{\gamma_3} = k_\gamma A^T_{\gamma_3} \tag{2.1}$$

where k_δ, k_γ may be derived from a suitable set of Love numbers. Consequently, the estimated admittances refer to W_2-origin. As these interactions take place in the long-periodic, diurnal, semidiurnal domain, only W_2-constituents are of interest so that the proposed way of normalization is justified. - The effect on the estimated admittances, when W_2, W_3 interaction is not taken into account, is illustrated in the following table.

There $\delta_2 = 1.160$, $\gamma_2 = 0.687$ are adopted as the true admittances, k-ratios refer to (1.4), calculations have been done for Bonn ($\varphi = 50.33^\circ$, $\lambda = -7.08^\circ$, h = 59 m). The range of variation is due to the time-variant phase relationship between W_2 and W_3 constituents.

Tide	δ	γ_{NS}	γ_{EW}
Q1	1.157 - 1.164	0.675 - 0.697	0.685 - 0.690
O1	1.1596- 1.1604	0.6860- 0.6880	0.6867- 0.6873
M1	1.139 - 1.200	0.382 - 0.734	0.658 - 0.706
K1	1.1599- 1.1601	0.6869- 0.6871	0.6869- 0.6871
2N2	1.145 - 1.183	0.676 - 0.696	0.669 - 0.700
N2	1.1591- 1.1609	0.6820- 0.6916	0.6792- 0.6938
M2	1.1597- 1.1603	0.6869- 0.6871	0.6868- 0.6872
L2	1.126 - 1.302	0.646 - 0.710	0.610 - 0.719

It is to emphazise that especially M1 and L2 are effected due to the relatively big W_3 constituents.

3. Normalization procedure for modelling the liquid core resonance

We meet a similar situation when the π_1, P1, S1, K1, ψ_1, φ_1, θ_1 group cannot be resolved due to insufficient record length. Even if the existing liquid core resonance models are somewhat contradictory with respect to the admittances of the smaller constituents like ψ_1, φ_1 there is no doubt on the significant difference at least between P1 and K1 admittances. By an analogue procedure we can avoid a violation of the constant admittance assumption by normalizing the members of the complete K1 group to the K1 constituent. For this purpose we have to choose an admittance model for the liquid core resonance $\delta_c(\omega_i)$, $\gamma_c(\omega_i)$ and set up the normalization coefficients

$$k_\delta(\omega_i) = \frac{\delta_c(\omega_i)}{\delta_c(K1)} \quad \text{or} \quad k_\gamma(\omega_i) = \frac{\gamma_c(\omega_i)}{\gamma_c(K1)} \qquad (3.1)$$

and multiply the theoretical amplitudes by them.

$$\bar{A}^T(\omega_i) = k_{\delta,\gamma}(\omega_i)A^T(\omega_i) \qquad (3.2)$$

The estimated admittance of this group will then refer to K1 constituent.

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Revised Method of the Pre-processing of Tidal Data

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1. *Introduction*

As some difficulties such as interruptions, instrumental drifts, sensitivity variations or misreadings are usually involved in the original tidal data, it is necessary to correct or adjust them so as to handle uniform and continuous data prior to the harmonic analysis. A pre-processing method which can simultaneously solve these difficulties was already proposed.

This method has been applied to the tidal gravity data in Japan and proved to be effective. However, as the method has been constructed under the assumptions that the tidal factors for every tidal constituent are equal each other and the phase lags in terms of time are small and equivalent, it is valid only for a limited case. The validity of the method can be expanded for a general case when the mutual ratios of tidal factors and the phase lags for at least the main tidal constituents are known in advance.

2. *Method*

The reading value on the record at time t is given by

$$Y_t = T_t + D_t, \qquad (1)$$

where T is the tidal part and D the instrumental drift.
T can be written by

$$T_t = a.R(t - \Delta t), \qquad (2)$$

where a is an unknown parameter having the dimension of the reciprocal of sensitivity, $R(t - \Delta t)$ is a tidal acceleration to the rigid Earth and Δt is a mean time lag.
If Δt is small, $R(t - \Delta t)$ can be expanded by Taylor's theorem,

$$R(t - \Delta t) = R(t) - \Delta t.\frac{dR}{dt} + \frac{\Delta t^2}{2} . \frac{d^2R}{dt^2} - \ldots,$$

where the third and the higher terms are very small and negligible. The instrumental drift can be approximated by a polynomial of the time. Assuming the drift as a polynomial of i-th order, we get

$$Y_t = a.R(t) + b.\frac{dR(t)}{dt} + \sum_{j=o}^{i} k_j \, t^j, \qquad (3)$$

where $b = -a.\Delta t$.

As we can compute the tidal acceleration R and its gradient dR/dt at any time with a sufficient accuracy, all parameters of (2) can be determined by the method of least squares if the order of the polynomial is fixed and the appropriate number of data is available.

In the case when any gap such as zero shift on the record occurs, we can obtain the quantity of this gap by separating k_o of (2) into two terms; one is k_o up to t_o and the other k_o' after t_o. Then, the gap is given by $k_o' - k_o$.

Missing data may be interpolated easily when the parameters are determined.

In the calibration, we can find the displacements on the record corresponding to the artificial change by neglecting the data in which the after-effects are not sufficiently damped and a sensitivity free from the after-effects can be obtained.

By applying the procedure to the original data, we can also find a change in sensitivity. In (2), a is related to the true sensitivity s in the following form,

$$a = f/s,$$

where f is a mean tidal factor. When any change of a is found, we can not directly know the cause: whether the change of sensitivity or that of tidal factor. The true sensitivity, however, can be obtained independently from each calibration. When the change of a and that of sensitivity are consistent, we may consider that the change of a reflects the real change of sensitivity and that the tidal factor remains constant.

In addition, we can easily find misread data by comparing one by one the observed values with the calculated ones.

This procedure is free from the difficulties accompanied by applying the numerical filters to separate the drift. So this pre-processing method is available for every step of procedure prior to the harmonic analysis.

3. The reformation of the method

As seen in the previous paragraph, (2) is implicitly based on the assumptions that the tidal factors for each constituent are equal and the time lags equivalent. In general, these assumptions are not correct.

If the tidal factors and phase lags for each tidal constituent are previously known, (2) can be replaced with

$$T_t = a \sum_i \alpha_i \, k_i \cos(\omega_i t - \chi_i - \beta_i) \qquad (4)$$

where α_i is the tidal factor for i-th constituent, k the theoretical amplitude, ω the frequency, χ the theoretical phase and β the phase lag. In (4), k, ω and χ can be known theoretically but α and β should be derived from the observations.

In practice, α and β are obtained not for every tidal constituent but only for the main constituents in which each of them represents a tidal group with many smaller terms having their frequency close to it. Therefore, (4) can be modified as

$$T_t = a \sum_{i=1}^{m} \sum_{j=1}^{n_m} \alpha_i \, k_{ij} \cos(\omega_{ij} t - \chi_{ij} - \beta_i), \qquad (5)$$

where m is the number of tidal groups and n_m the number of constituents inside the m-th group.

For making use of (5), all values except a should be known in advance. The theoretical values can be got by using the table given by Cartwright and Tayler. When α and β are not available beforehand, they should be derived from the data by the conventional method. Such values are merely approximate ones. We can get better values after substituting them into (5) and doing over again. Even in the case when the correct values of α are not available, it is sufficient if the mutual rations of them can be known. Adopting the normalized α in which the mean weighted with the amplitude of each group becomes 1, a in (5) has the same significance as a in (2). Then, the tidal part of (3) can be replaced by (5). In the modified formula, the parameter related to the time lag as in (5) is no more included. So this new formula will be applicable to any tidal data. After substitution, the pre-processing procedure can be made in the same manner as described in the previous paragraph.

4. An example of application of the new method

The revised formula has been applied to the half-hourly gravimetrical readings with LaCoste & Romberg gravimeter G 305 obtained at Baguio (The Philippines). At first, the old formula was applied to the 108 days data for every day with a 3rd order approximation for the drift, because the correct α and β values were not available. The calculated 1/a, Δt and standard deviations in (O-C) are shown in Fig. 1. In this figure, the large systematic effects corresponding to the high and low tides are recognized in Δt and SD. The cause of these systematics effects may arise from the wrong assumptions stated above. At any rate, the preliminary results based on the previous procedure have been obtained as in Table 1. It is obvious that at Baguio the phase lags and the tidal factors of the main tidal groups are significantly different each other. From Table 1, the normalized α have been calculated as in Table 2.

Substituting α given in Table 2 and β in Table 1 into (5), the pre-processing has been carried out again. The revised 1/a and SD are given in Fig. 2. In Fig.2, it is clear that the systematic effect in SD vanished and SD themselves become very small as a whole. Moreover, the variation of 1/a is smoother than in Fig.1. The calibration values and interpolated data have been also redetermined by the revised formula. New results are shown in Table 3.

From Table 1 and 3, it is obvious that the new results are almost the same as the preliminary ones. From the point of view of accuracy, the new results have not been so much improved. This may be caused by the fact that the assumed variations of sensitivity in both calculations have been virtually the same and the data are somewhat different only for exceptional interruptions.

In the pre-processing, however, the use of (5) instead of (2) would be superior, because (5) is a formula generally applicable.

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Table 1: Preliminary results through the previous pre-processing method.

Station: Baguio - Instrument: LCR G305 - Period of analysis: 21.12.77-3.2.78 - 46 days

Group	Amplitude	Tidal Factor		Phase Lag	
Q1	4.77 μgals	1.300 ±	0.039	-2.95 ±	1.74
O1	16.92	1.225	0.009	-6.29	0.40
M1	0.45	0.969	0.251	-15.83	14.83
K1	31.35	1.139	0.004	-5.16	0.22
J1	1.55	1.150	0.088	2.33	4.38
2N2	4.90	1.224	0.013	-1.21	0.60
N2	18.00	1.173	0.003	-1.35	0.14
M2	84.08	1.177	0.001	-1.63	0.03
L2	3.73	1.222	0.014	-1.19	0.66
S2	34.68	1.167	0.001	-2.00	0.07

Table 2: Normalized Factors

Q1	1.104	2N2	1.040
O1	1.041	N2	0.996
M1	0.823	M2	1.000
K1	0.967	L2	1.038
J1	0.977	S2	0.991

Table 3. Results from the revised method.

Group	Amplitude	Tidal Factor		Phase Lag	
Q1	4.73 µgals	1.290 ±	0.039	-2°83 ±	1°72
O1	16.84	1.220	0.008	-6.21	0.40
M1	0.41	0.888	0.246	-9.10	15.90
K1	31.26	1.136	0.004	-5.19	0.22
J1	1.50	1.116	0.086	1.02	4.44
2N2	4.79	1.198	0.013	0.62	0.64
N2	17.90	1.167	0.003	-0.93	0.14
M2	84.09	1.178	0.001	-1.62	0.03
L2	3.82	1.254	0.014	0.24	0.66
S2	34.68	1.167	0.001	-2.20	0.07

Fig. 1 Relative sensitivities $1/a$, mean time lags Δt and standard deviations in (O-C) obtained by the previous pre-processing method.

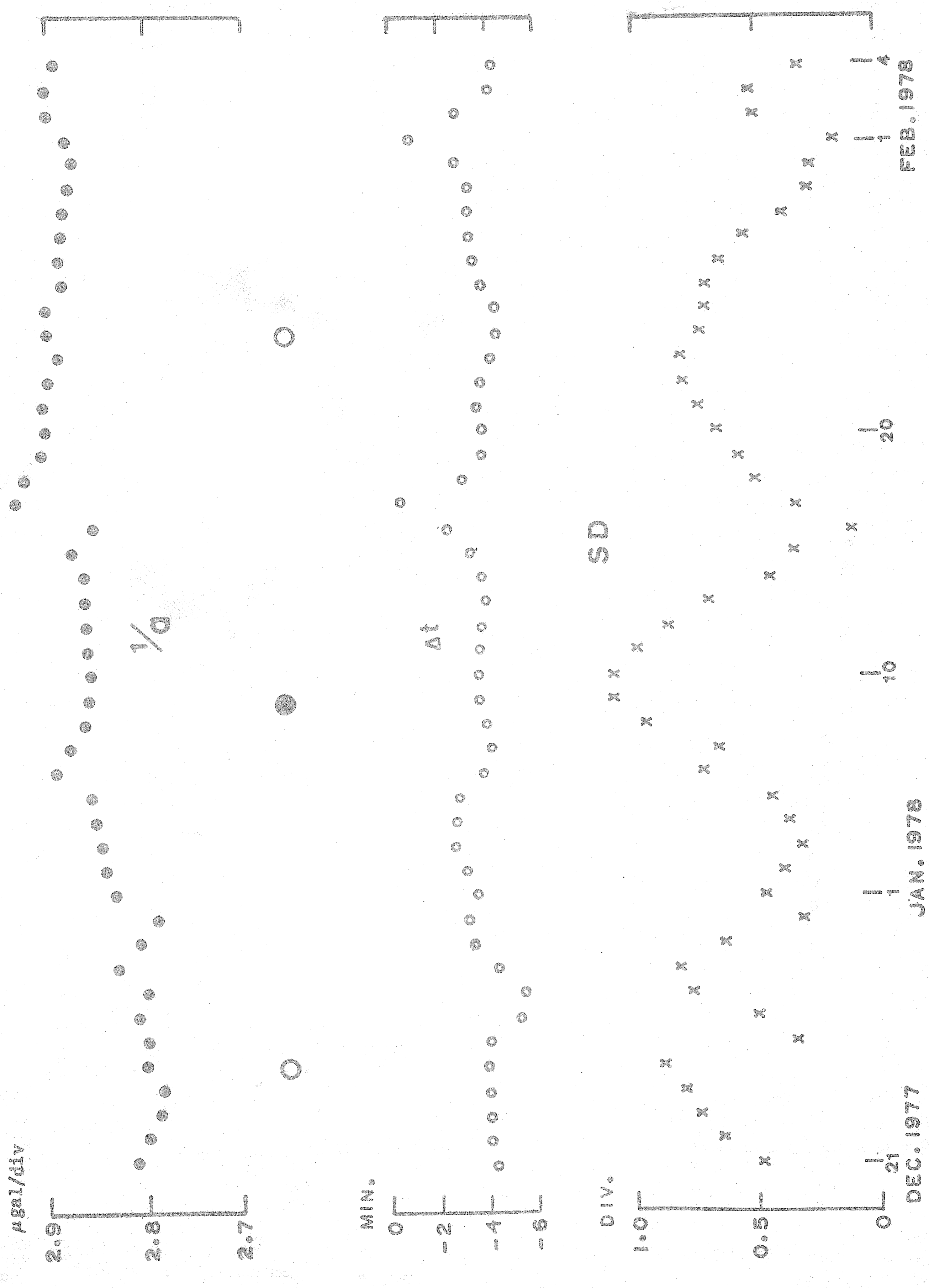
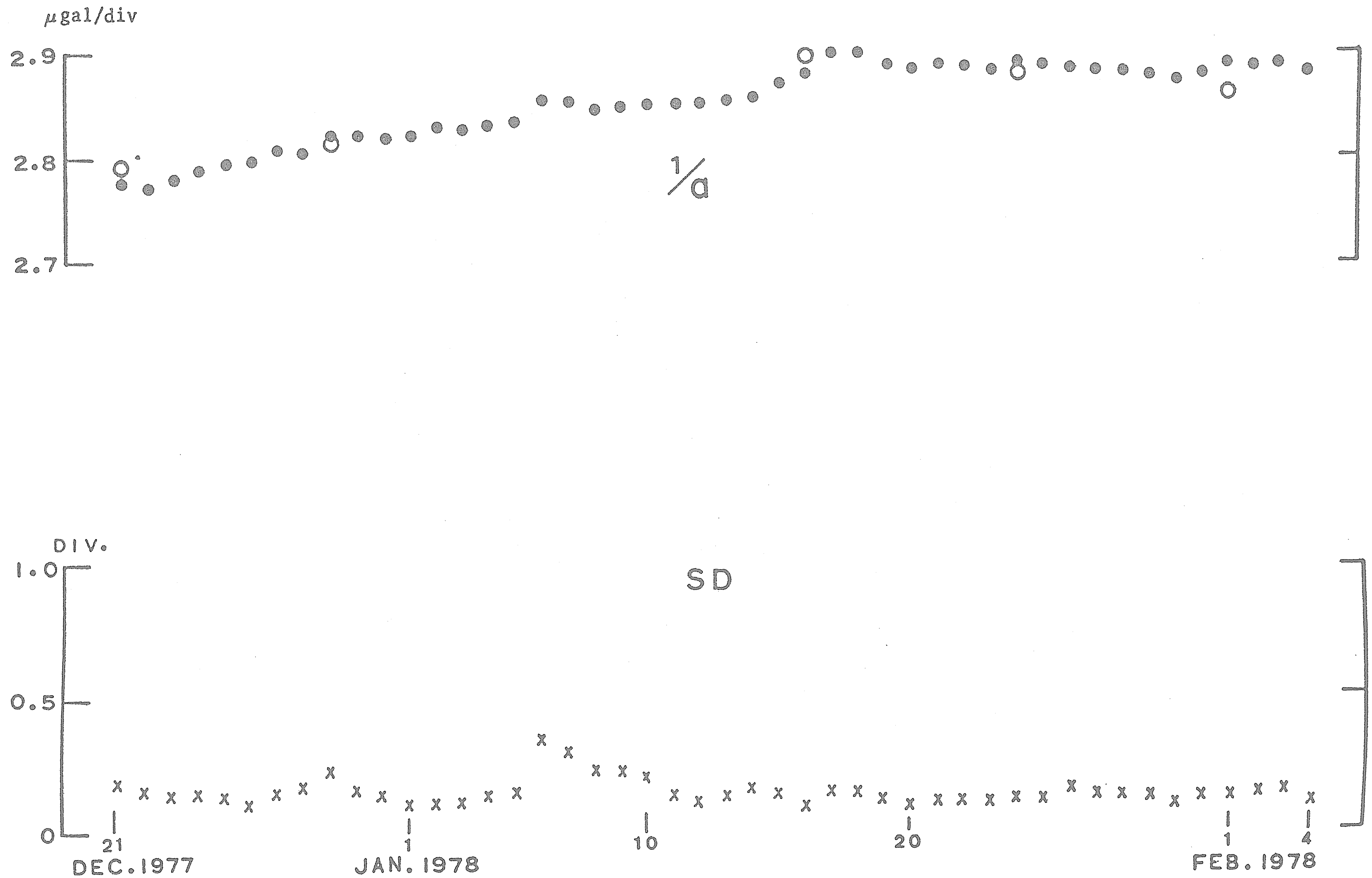


Fig. 2: 1/a and SD obtained by the revised method.



Sensitivity smoothing before the analysis of the tidal data

B. DUCARME*

1. The calibration tables

As previously pointed out the main perturbations to the stationarity of the tidal parameters are the sensitivity errors.

The problem is quite different according to the instrument principle. Static gravimeters and vertical pendulums have a very stable sensitivity. Astaticized instruments (horizontal pendulums and gravimeters) exhibit sensitivity changes due to tilting and their calibration tables are sometimes very difficult to establish.

Some instruments are equipped with automatic calibration devices as dilatable crapaudines for VM pendulums or electrostatic attraction for Geodynamics gravimeters. In that case it is suitable to check the sensitivity twice a week. The resulting sensitivity curve is easy to smooth if necessary (fig. 1).

Other gravimeters are manually calibrated using the micrometric screw. That operation perturbs the curve and should not be repeated more than once a week. The drift corrections are useless as they give systematically higher values of the sensitivity factor.

The trend of the sensitivity between two calibrations is doubtfull: the variations can be very abrupt and even wrong calibrations sometimes appear (fig. 2).

In such a case the only way to know the real variations of sensitivity is to compute a least squares solution on short intervals following for example the Nakai procedure. Such a routine is applied on each 48 hours interval at the International Center for Earth Tides (ICET) as shown in table 1 (program MT32). It provides an apparent amplitude of the tidal phenomenon, a global phase lag expressed in minutes of time, the drift at the central epoch and RMS values of the residuals of the fitting. The jumps appear at a first glimpse. Then it is easy to detect

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the low quality data either from the residuals either from anomalies of the amplitudes and phases. Comparing the amplitudes and the calibration displacements at the same epoch we are able to check the bad calibrations (fig. 2).

The best calibration table is then obtained and a linear interpolation method is used to compute the sensitivity at any epoch required.

2. Possible improvements

As the real accuracy cannot exceed 0.5 per cent for calibration displacements of 10 cm and as the dispersion of successive calibrations is of the order of 1 per cent (table 2) the linear interpolation will introduce a noise in the data.

To improve that situation we can try to smooth the calibration data. This is only possible for the automatic calibrations giving two displacements a week (table 2, fig. 3).

With the other instruments we can smooth the apparent amplitude obtained from the program MT32, find the mean ratio to the available calibration displacements and deduce the equivalent sensitivity.

We can rise a first objection. As the Nakai procedure give a global result for diurnal and semi-diurnal waves and as the relative contribution of both species depends on the Moon and Sun celestial coordinates for any geographical location, we must expect periodic fluctuations of the apparent tidal amplitude (fig. 4). We should thus apply a high degree of smoothing.

3. First Experiments

Two programs have been designed

MT 41 - Smoothing of a time serie applying the Vondrak procedure.

MT 42 - Interpolation inside of a smoothed serie and comparison between several series.

A first complete experimentation has been performed on a very coherent serie of observations performed at Istanbul with the gravimeter Geodynamics Geo 783 equipped with two independant electrostatic calibration voltages called OC and NC. The corresponding calibration displacements are proportional to the square of the voltages.

$$V_{OC} = 54.9 \text{ V}$$

$$V_{NC} = 50.0 \text{ V}$$

and we have thus

$$A_{OC}/A_{NC} = 1.2056$$

We first checked if this ratio is well observed through the sensitivity table. We smoothed independently the two series of sensitivity factors through the program MT 41 and compared the results with the program MT42 (table 4). For the same smoothing parameter $\varepsilon = 10^{-5}$ the OC data (25 points) show a dispersion of .008 and the NC data (23 points) of .006.

The mean ratio between the two series is 0.996 ± 0.007 and no systematic error is suspected. Unhappily the distribution of the residuals is not random. During the first month of registration the NC sensitivity factor is systematically one per cent higher than the OC factor. In practice it corresponds to the beginning of the station characterized by electrical power troubles. During that period the calibration voltages were

$$V_{OC} = 55.4 \text{ V}$$

$$V_{NC} = 50.5 \text{ V}$$

For the following tests this period has been neglected. As a next step we smoothed the apparent sensitivity data from MT32 (table 3). The three anomalous periods shown in table 1 are eliminated by applying a very low weight. The resulting dispersion is one per cent. We smoothed also the amplitude of the calibration displacements independently for the OC and NC series.

By comparison of the smoothed data we have a mean amplitude ratio (table 5, fig. 5)

$$A_{OC}/A_{NC} = 1.204 \pm 0.008$$

Comparing the smoothed serie MT32 to the OC and NC series we find ratios (table 6, fig. 6)

$$0.966 \pm 0.008$$

$$1.162 \pm 0.007$$

We are now able to compute a calibration table from the smoothed OC + NC table and also from the smoothed MT32 serie.

4. Analysis Results

We applied a standard Venedikov computation using the three available calibration tables

1- individual calibrations

2- smoothed calibrations

3- smoothed MT32 sensitivities

The results of the global analysis are listed below.

The smoothed calibrations produce systematically lower δ factors with respect to the standard procedure but do agree perfectly between themselves.

The discrepancy is probably due to the perturbation in the calibration voltage during the first month, neglected in the smoothing procedure.

The noise slightly decreases for the semi-diurnal waves and is constant for the diurnal ones. The RMS errors on the δ factors remain constant.

The $\delta(O_1)/\delta(K_1)$ factor slightly decreases.

The comparison of the 5 successive monthly analysis show that the improved calibration table did not reduce the dispersion. It seems that this dispersion results from instrumental errors (table 6).

The complete agreement between the smoothed calibration tables obtained from the calibration data and from the MT32 apparent amplitude is very encouraging.

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TABLE 1

Station Istanbul

Successive Applications of a least squares fitting on 48 hours.

(Nakai Procedure)

78320004346677111190	9.84821	-1.61	1109.17	1.22	
78320004346877111210	9.71199	-1.87	1108.50	1.12	
78320004347077111230	9.72615	-2.34	1110.06	1.07	
78320004347277111250	9.84461	-3.36	1110.60	1.35	
78320004347477111270	9.88779	-2.56	1117.26	1.85	
78320004347677111290	10.04246	-2.66	1122.83	2.27	
783200043480 7712 22	9.83424	-1.75	1118.99	1.49	
783200043482 7712 42	10.13448	-2.83	1122.01	1.87	
783200043484 7712 62	9.75894	-1.35	1123.36	1.07	
783200043486 7712 82	9.83059	-1.73	1125.18	1.29	
78320004349077712122	9.86077	-2.95	1173.09	2.31	
78320004349277712142	9.95260	-2.47	1180.03	1.10	
78320004349477712162	9.70900	-.25	1179.59	1.80	
78320004349677712182	9.78194	-2.33	1181.02	1.26	
78320004349877712202	9.29599	57.94	1193.30	18.33	9
78320004350077712222	9.86949	-2.63	1130.55	1.08	
78320004350277712242	9.85125	-2.63	1128.98	1.14	
78320004350477712262	9.90748	-3.20	1134.79	1.22	
78320004350677712282	9.96799	-2.77	1132.27	1.37	
78320004350877712302	9.06827	41.15	1131.40	20.85	9
783200043518781 92	10.01012	-1.91	1122.12	1.62	
78320004352178 1122	10.07728	-1.18	1111.02	.92	
78320004352378 1142	9.96962	-.19	1105.51	.90	
78320004352578 1162	9.88423	.01	1101.83	.56	
78320004352778 1182	9.91700	-.41	1099.92	.84	
78320004353078 1220	10.01232	-1.28	1096.63	.95	
78320004353278 1240	.9.99908	-2.24	1093.78	1.37	
78320004353478 1260	10.10934	-.82	1095.75	.70	
78320004353678 1280	10.11773	-.72	1089.26	.59	
78320004353878 1300	9.97333	-.44	1083.38	.90	
78320004354078 2 10	10.05397	-1.20	1081.80	.63	
78320004354278 2 30	10.03638	-1.53	1081.95	1.03	
78320004354478 2 50	10.12718	-.88	1077.52	1.47	
78320004354678 2 70	10.18380	-.81	1081.77	1.06	
78320004354878 2 90	10.19811	-1.18	1082.59	.73	
78320004355078 2110	10.13598	-.80	1072.45	.49	
78320004355278 2130	10.03995	-.01	1071.64	.73	
78320004355478 2150	9.93699	-1.44	1073.15	.66	
78320004355678 2170	10.03411	-1.12	1069.21	.79	
78320004355878 2190	10.22103	-1.20	1063.72	1.45	
78320004356078 2210	10.18730	-.84	1057.94	1.14	
78320004356278 2230	10.16168	-1.29	1049.23	.69	
78320004356478 2250	10.19548	-1.13	1043.26	.58	
78320004356678 2270	10.08135	.05	1045.14	1.09	
78320004357078 3 30	10.03000	-1.08	1133.56	1.17	
78320004357278 3 50	10.19323	-1.61	1123.80	1.24	
78320004357478 3 70	10.25484	-1.09	1115.24	1.38	
78320004357678 3 90	10.35036	-.33	1110.46	1.37	
78320004357878 3110	10.24973	-.24	1104.27	.71	
78320004358078 3130	5.88446	54.94	1096.28	27.45	9
78320004358878 3210	10.26748	-1.22	1117.63	1.41	
78320004359378 3260	10.24836	.81	1116.25	.90	
78320004359678 3290	10.09872	.79	1104.13	.92	
78320004359878 3310	9.98292	-1.53	1102.09	.89	
78320004360078 4 20	10.13368	-.40	1101.28	1.48	

78320004360278 4 40	10.28659	.06	1098.22	1.46
78320004360478 4 60	10.26580	-.33	1099.07	.77
78320004360678 4 80	10.28549	-.06	1089.85	.62
78320004361378 4142	9.90570	-.97	1134.94	.60
78320004361878 4200	10.35207	-.15	1101.05	1.11
78320004362078 4220	10.22127	-.99	1097.42	.96
78320004362278 4240	10.15821	.68	1096.52	1.45
78320004362478 4260	10.09188	.93	1088.86	1.19
78320004362678 4280	9.94479	.20	1084.95	1.00
78320004362878 4300	10.05628	-.86	1080.28	.94
78320004363078 5 20	10.37206	.14	1076.08	1.32
78320004363278 5 40	10.35710	-.23	1077.88	1.30
78320004363478 5 60	10.17164	.77	1076.06	.88
78320004363678 5 80	10.18514	1.35	1075.58	1.00
78320004363878 5100	10.03407	.32	1072.99	1.07
78320004364078 5120	10.07240	-.65	1070.94	.85
78320004364278 5140	9.89771	-.79	1065.71	.79
78320004364478 5160	10.17635	-1.71	1064.15	1.18
78320004364678 5180	10.20064	-.33	1057.05	1.13
78320004364878 5200	10.14489	-.26	1054.94	1.06
78320004365078 5220	10.17440	.16	1049.28	1.82
78320004365278 5240	10.02419	.51	1048.40	1.46
78320004365478 5260	9.99373	-.48	1046.22	1.04
78320004365678 5280	9.94470	-1.42	1041.83	1.22
78320004365878 5300	10.22276	-.68	1041.35	1.22

A: Apparent amplitude

PHI: Global Phase Lag (minutes)

DRIFT: Drift of the mean position

[illegible] mean residual after adjustment

TABLE 2
STATION ISTANBUL

CALIBRATION TABLE

INST	STATION		EPOCH				JULIAN DATE	DISPLACEMENT	SENSITIVITY FACTOR		
0	783	2000	1977	11	19	17	43467.208	10.400	1.17577	0.00340	OC
0	783	2000	1977	11	22	14	43470.083	8.465	1.20024	0.00071	NC
0	783	2000	1977	11	26	15	43474.125	10.290	1.18834	0.00464	OC
0	783	2000	1977	11	29	8	43476.833	8.480	1.19811	0.00283	NC
0	783	2000	1977	12	2	9	43479.875	10.280	1.18949	0.00465	OC
0	783	2000	1977	12	6	10	43483.917	8.465	1.20024	0.00213	NC
0	783	2000	1977	12	9	14	43487.083	10.270	1.16943	-0.00114	OC
0	783	2000	1977	12	13	8	43490.833	8.470	1.18064	0.00000	NC
0	783	2000	1977	12	16	11	43493.958	10.370	1.15815	0.00561	OC
0	783	2000	1977	12	20	13	43498.042	8.500	1.17647	0.00277	NC
0	783	2000	1977	12	23	13	43501.042	10.490	1.14490	-0.02977	OC
0	783	2000	1977	12	27	7	43504.792	8.470	1.18064	0.00279	NC
0	783	2000	1977	12	30	8	43507.833	10.240	1.17285	0.00691	OC
0	783	2000	1978	1	13	8	43521.833	8.735	1.14482	0.00197	NC
0	783	2000	1978	1	17	10	43525.917	10.440	1.15038	0.00665	OC
0	783	2000	1978	1	20	12	43529.000	8.675	1.15274	0.00200	NC
0	783	2000	1978	1	24	14	43533.083	10.375	1.15759	0.00504	OC
0	783	2000	1978	1	27	16	43536.167	8.685	1.15141	0.00199	NC
0	783	2000	1978	1	31	8	43539.833	10.360	1.15927	0.00449	OC
0	783	2000	1978	2	3	12	43543.000	8.645	1.15674	0.00067	NC
0	783	2000	1978	2	7	14	43547.083	10.375	1.15759	0.00392	OC
0	783	2000	1978	2	10	16	43550.167	8.645	1.15674	0.00067	NC
0	783	2000	1978	2	14	8	43553.833	10.450	1.14928	0.00553	OC
0	783	2000	1978	2	17	13	43557.042	8.770	1.14025	0.00130	NC
0	783	2000	1978	2	21	14	43561.083	10.370	1.15815	0.00336	OC
0	783	2000	1978	2	24	14	43564.083	8.650	1.15607	0.00402	NC
0	783	2000	1978	3	1	7	43568.792	10.510	1.14272	0.01209	OC
0	783	2000	1978	3	5	12	43573.000	10.300	1.16602	0.00000	OC
0	783	2000	1978	3	7	14	43575.083	8.660	1.15473	0.00536	NC
0	783	2000	1988	3	10	7	47230.792	10.525	1.14109	0.01372	OC
0	783	2000	1978	3	27	7	43594.792	8.705	1.14877	0.00066	NC
0	783	2000	1978	3	30	7	43597.792	10.460	1.14818	-0.00655	OC
0	783	2000	1978	4	4	13	43603.042	8.750	1.14286	0.00000	NC
0	783	2000	1978	4	7	6	43605.750	10.500	1.14381		OC
0	783	2000	1978	4	10	6	43608.750	10.520	1.14163		OC
0	783	2000	1978	4	20	14	43619.083	8.685	1.15141	0.00332	NC
0	783	2000	1978	4	25	17	43624.208	10.360	1.15927	0.00675	OC
0	783	2000	1978	4	28	6	43626.750	8.740	1.14416	0.00526	NC
0	783	2000	1978	5	2	13	43631.042	10.390	1.15592	0.00671	OC
0	783	2000	1978	5	5	15	43634.125	8.690	1.15075	0.00399	NC
0	783	2000	1978	5	9	6	43637.750	10.650	1.12770	0.00000	OC
0	783	2000	1978	5	12	6	43640.750	8.755	1.14220	0.00196	NC
0	783	2000	1978	5	16	12	43645.000	10.585	1.13462	0.00376	OC
0	783	2000	1978	5	20	15	43649.125	8.625	1.15942	0.00744	NC
0	783	2000	1978	5	22	15	43651.125	10.470	1.14709	-0.00109	OC
0	783	2000	1978	5	27	7	43655.792	8.665	1.15407	0.00602	NC
0	783	2000	1978	5	30	11	43658.958	10.525	1.14109	0.00054	OC
0	783	2000	1978	6	2	11	43661.958	8.850	1.12994	0.00256	NC

TABLE 3

Smoothing of the apparent tidal amplitudes obtained by the Nakai Procedure

		E1 = .001000 ◆		E2 = .000100 X		E3 = .000010 •	
TJULIEN	OBS	LIS	RES	LIS	RES	LIS	RES
43466.50	9.848	9.762	-.086	9.755	-.093	9.792	-.056
43468.50	9.712	9.783	.071	9.796	.084	9.814	.102
43470.50	9.726	9.814	.087	9.832	.105	9.833	.107
43472.50	9.845	9.850	.006	9.861	.016	9.848	.004
43474.50	9.888	9.887	-.001	9.884	-.004	9.861	-.027
43476.50	10.042	9.917	-.125	9.899	-.143	9.870	-.173
43480.00	9.834	9.935	.101	9.908	.073	9.878	.044
43482.00	10.134	9.926	-.209	9.903	-.232	9.880	-.255
43484.00	9.759	9.906	.147	9.893	.134	9.879	.120
43486.00	9.831	9.882	.051	9.879	.049	9.877	.046
43490.00	9.861	9.839	-.021	9.854	-.006	9.871	.010
43492.00	9.953	9.823	-.130	9.845	-.108	9.869	-.084
43494.00	9.709	9.812	.103	9.839	.130	9.867	.158
43496.00	9.782	9.811	.029	9.839	.057	9.867	.085
43498.00	9.296	9.821	.525 ◆	9.844	.548 X	9.869	.573 •
43500.00	9.869	9.842	-.028	9.855	-.015	9.872	.003
43502.00	9.851	9.870	.019	9.869	.018	9.877	.026
43504.00	9.907	9.904	-.003	9.888	-.020	9.884	-.023
43506.00	9.968	9.940	-.028	9.908	-.060	9.893	-.075
43508.00	9.068	9.977	.908 ◆	9.929	.860 X	9.902	.834 •
43518.00	10.010	10.021	.011	9.983	-.027	9.953	-.057
43521.00	10.077	9.992	-.085	9.983	-.095	9.969	-.109
43523.00	9.970	9.974	.005	9.983	.013	9.979	.009
43525.00	9.884	9.964	.080	9.985	.101	9.989	.105
43527.00	9.917	9.964	.047	9.990	.073	9.999	.082
43530.50	10.012	9.988	-.025	10.006	-.006	10.017	.005
43532.50	9.999	10.010	.011	10.019	.020	10.027	.028
43534.50	10.109	10.032	-.078	10.033	-.076	10.037	-.072
43536.50	10.118	10.051	-.067	10.047	-.071	10.047	-.071
43538.50	9.973	10.068	.094	10.061	.088	10.056	.083
43540.50	10.054	10.083	.029	10.073	.019	10.065	.011
43542.50	10.036	10.097	.061	10.084	.048	10.073	.037
43544.50	10.127	10.109	-.019	10.093	-.034	10.081	-.046
43546.50	10.184	10.114	-.070	10.099	-.085	10.088	-.095
43548.50	10.198	10.111	-.087	10.102	-.096	10.095	-.103
43550.50	10.136	10.103	-.032	10.104	-.032	10.102	-.034
43552.50	10.040	10.096	.056	10.105	.065	10.109	.069
43554.50	9.937	10.094	.157	10.107	.170	10.115	.178
43556.50	10.034	10.101	.067	10.111	.077	10.123	.089
43558.50	10.221	10.113	-.108	10.116	-.105	10.130	-.091
43560.50	10.187	10.125	-.062	10.124	-.064	10.138	-.049
43562.50	10.162	10.133	-.028	10.132	-.029	10.147	-.015
43564.50	10.195	10.137	-.059	10.142	-.053	10.155	-.040
43566.50	10.081	10.139	.058	10.154	.072	10.164	.083
43570.50	10.030	10.164	.134	10.182	.152	10.181	.151
43572.50	10.193	10.191	-.002	10.197	.004	10.189	-.004
43574.50	10.255	10.219	-.035	10.212	-.043	10.196	-.058
43576.50	10.350	10.245	-.106	10.224	-.126	10.202	-.148
43578.50	10.250	10.263	.013	10.233	-.016	10.207	-.043
43580.50	5.884	10.273	4.388 ◆	10.239	4.354 X	10.210	4.325 •
43588.50	10.267	10.243	-.025	10.224	-.044	10.208	-.060
43593.50	10.248	10.174	-.075	10.195	-.054	10.197	-.052
43596.50	10.099	10.151	.052	10.181	.082	10.190	.091
43598.50	9.983	10.152	.169	10.175	.192	10.185	.202
43600.50	10.134	10.165	.031	10.171	.038	10.181	.048
43602.50	10.287	10.181	-.105	10.170	-.117	10.178	-.109
43604.50	10.266	10.194	-.072	10.169	-.097	10.175	-.091
43606.50	10.285	10.196	-.090	10.167	-.118	10.172	-.113
43613.00	9.906	10.140	.234	10.158	.252	10.166	.260
43618.50	10.352	10.163	-.189	10.162	-.190	10.164	-.188
43620.50	10.221	10.159	-.052	10.163	-.059	10.164	-.058
43622.50	10.158	10.153	-.005	10.163	.005	10.163	.005
43624.50	10.092	10.150	.058	10.164	.073	10.162	.070
43626.50	9.945	10.156	.211	10.166	.221	10.160	.215
43628.50	10.056	10.168	.112	10.166	.110	10.157	.101
43630.50	10.372	10.181	-.191	10.166	-.206	10.154	-.218
43632.50	10.357	10.185	-.172	10.162	-.195	10.150	-.207
43634.50	10.172	10.174	.003	10.155	-.016	10.145	-.027
43636.50	10.185	10.153	-.032	10.146	-.039	10.139	-.046
43638.50	10.034	10.129	.095	10.134	.100	10.133	.098
43640.50	10.072	10.110	.038	10.123	.050	10.126	.053
43642.50	9.898	10.100	.202	10.112	.214	10.118	.221
43644.50	10.176	10.097	-.079	10.103	-.074	10.111	-.065
43646.50	10.201	10.096	-.104	10.094	-.106	10.104	-.096
43648.50	10.145	10.092	-.053	10.087	-.058	10.097	-.048
43650.50	10.174	10.082	-.093	10.081	-.093	10.091	-.083
43652.50	10.024	10.071	.047	10.078	.053	10.085	.061
43654.50	9.994	10.067	.073	10.077	.083	10.080	.086
43656.50	9.945	10.077	.132	10.080	.136	10.075	.130
43658.50	10.223	10.104	-.118	10.088	-.134	10.071	-.152
	SIG	.10894429		.11550008		.11839742	

T JULIEN Julian Date

OBS Observed value

LIS Smoothed value

RES Difference (observed-smoothed)

E_1, E_2, E_3 Smoothing parameter (Vondrak method)

Table 4

Comparison of the sensitivity factors deduced from the OC and NC pulses

	NC	OC	OC/NC	Discrepancy
43470.00	1.20157	1.18272	.98431	-.01154
43477.00	1.19861	1.18058	.98496	-.01088
43484.00	1.19365	1.17449	.98395	-.01190
43491.00	1.18692	1.16728	.98345	-.01239
43498.00	1.17920	1.16131	.98482	-.01102
43505.00	1.17102	1.15828	.98912	-.00673
43522.00	1.15448	1.15572	1.00108	.00523
43529.00	1.15197	1.15556	1.00312	.00728
43536.00	1.15123	1.15614	1.00426	.00842
43543.00	1.15137	1.15625	1.00424	.00840
43550.00	1.15159	1.15574	1.00360	.00776
43557.00	1.15178	1.15469	1.00253	.00668
43564.00	1.15229	1.15313	1.00073	.00489
43575.00	1.15261	1.14957	.99736	.00152
43595.00	1.14803	1.14581	.99806	.00222
43603.00	1.14587	1.14635	1.00042	.00458
43619.00	1.14624	1.14879	1.00222	.00638
43627.00	1.14801	1.14818	1.00015	.00430
43634.00	1.15004	1.14460	.99527	-.00057
43641.00	1.15160	1.14123	.99100	-.00485
43649.00	1.15091	1.13979	.99034	-.00551
43656.00	1.14592	1.14075	.99549	-.00036
43662.00	1.13758	1.14205	1.00393	.00809

RAPPORT = .99584 DISPERSION = .00743

TABLE 5

Direct Comparison of the Smoothed OC and NC Amplitudes

JULIAN DATE	NC AMPLITUDE	OC AMPLITUDE	RATIO	DISCREPANCY
43491.00	8.450	10.334	1.223	0.019
43498.00	8.493	10.370	1.221	0.017
43505.00	8.542	10.374	1.215	0.011
43522.00	8.657	10.381	1.199	-.005
43529.00	8.678	10.384	1.197	-.007
43536.00	8.685	10.383	1.196	-.008
43543.00	8.686	10.386	1.196	-.008
43550.00	8.684	10.392	1.197	-.007
43557.00	8.683	10.402	1.198	-.006
43564.00	8.679	10.416	1.200	-.004
43575.00	8.676	10.448	1.204	0.000
43595.00	8.710	10.486	1.204	0.000
43603.00	8.727	10.478	1.201	-.003
43619.00	8.724	10.444	1.197	-.007
43627.00	8.711	10.461	1.201	-.003
43634.00	8.695	10.494	1.207	0.003
43641.00	8.683	10.525	1.212	0.008
43649.00	8.689	10.539	1.213	0.009
43656.00	8.727	10.530	1.207	0.003
43662.00	8.791	10.509	1.195	-.009

Mean Ratio: 1.204 Dispersion: 0.008

TABLE 6

Comparison between the apparent tidal amplitudes A and the calibration displacements of OC and NC

JULIAN DATE	OC	A	RATIO	DISCRE-PANCY
43487.00	10.30000	9.87575	.95881	-.00734
43494.00	10.35300	9.86700	.95306	-.01309
43501.00	10.37600	9.87425	.95164	-.01451
43508.00	10.37400	9.90000	.95450	-.01165
43526.00	10.38400	9.99400	.96244	-.00371
43533.00	10.38300	10.02950	.96595	-.00020
43540.00	10.38400	10.06284	.96907	.00292
43547.00	10.38900	10.08975	.97120	.00505
43554.00	10.39800	10.11331	.97262	.00647
43561.00	10.40900	10.14016	.97417	.00802
43569.00	10.42900	10.17478	.97562	.00947
43573.00	10.44100	10.19084	.97604	.00989
43578.00	10.45800	10.20594	.97590	.00975
43598.00	10.48500	10.18616	.97150	.00535
43606.00	10.47100	10.17275	.97152	.00537
43609.00	10.46200	10.16901	.97200	.00584
43624.00	10.45100	10.16225	.97237	.00622
43631.00	10.48000	10.15309	.96881	.00266
43638.00	10.51400	10.13459	.96391	-.00224
43645.00	10.53500	10.10925	.95959	-.00656
43651.00	10.53800	10.08950	.95744	-.00871
43659.00	10.52100	10.07016	.95715	-.00900

RAPPORT = .96615 DISPERSION = .00783

JULIAN DATE	NC	A	RATIO	DISCRE-PANCY
43491.00	8.45000	9.86992	1.16804	.00567
43498.00	8.49300	9.86900	1.16202	-.00035
43505.00	8.54200	9.88825	1.15760	-.00477
43522.00	8.65700	9.97407	1.15214	-.01023
43529.00	8.67600	10.00936	1.15342	-.00895
43536.00	8.68500	10.04459	1.15655	-.00583
43543.00	8.68600	10.07500	1.15991	-.00246
43550.00	8.68400	10.10025	1.16309	.00072
43557.00	8.68300	10.12484	1.16605	.00368
43564.00	8.67900	10.15291	1.16982	.00745
43575.00	8.67600	10.19759	1.17538	.01301
43595.00	8.71000	10.19354	1.17033	.00796
43603.00	8.72700	10.17725	1.16618	.00381
43619.00	8.72400	10.16400	1.16506	.00269
43627.00	8.71100	10.15925	1.16626	.00388
43634.00	8.69500	10.14634	1.16692	.00455
43641.00	8.68300	10.12409	1.16597	.00360
43649.00	8.68900	10.09541	1.16186	-.00051
43656.00	8.72700	10.07616	1.15460	-.00778
43662.00	8.79100	10.07656	1.14624	-.01614

RAPPORT = 1.16237 DISPERSION = .00698

TABLE 7

SUCCESSIVE MONTHLY ANALYSIS

A. LINEAR INTERPOLATION

	δO_1	δM_2	$\delta M_2/\delta O_1$
1	1.1666	1.1743	1.007
2	1.1654	1.1664	1.001
3	1.1610	1.1786	1.015
4	1.1625	1.1874	1.021
5	1.1552	1.1844	1.025
MEAN	1.1621	1.1782	1.014
	± 0.0020	± 0.0037	.
GLOBAL	1.1588	1.1811	1.019
	± 0.0036	± 0.0013	.
R.M.S.	D 3.33	SD 2.22	.

B. SMOOTHED CALIBRATION CURVE

	δO_1	δM_2	$\delta M_2/\delta O_1$
1	1.1704	1.1750	1.004
2	1.1582	1.1674	1.008
3	1.1589	1.1771	1.016
4	1.1545	1.1793	1.022
5	1.1463	1.1755	1.026
MEAN	1.1577	1.1750	1.015
	± 0.0039	±0.0021	.
GLOBAL	1.1547	1.1767	1.019
R.M.S.	D 3.41	SD 1.79	.

C. APPARENT SENSITIVITY CURVE

	δO_1	δM_2	$\delta M_2/\delta O_1$
1	1.1667	1.1706	1.003
2	1.1655	1.1754	1.009
3	1.1523	1.1711	1.016
4	1.1503	1.1738	1.020
5	1.1513	1.1790	1.024
MEAN	1.1573	1.1740	1.014
	±0.0035	±0.0015	.
GLOBAL	1.1541	1.1762	1.019
	±0.0035	±0.0011	.
R.M.S.	D 3.22	1.83	.

TRANS WORLD PROFILE TURQUIE - ASIE STATION KANDILLI-ISTANBUL
STATION 2000 KANDILLI-ISTANBUL VERTICAL COMPONENT TURQUIE - ASIE

41 04 N 29 03 30 E H 130 M P 0 M D 10 KM
OBSERVATOIRE DE KANDILLI / KANDILLI RASATHANESI ISTANBUL
SERVICE DES MAREES TERRESTRES - YER MARESI BOLUMU D.TANER
CAVE GRAVIMETRIQUE - PILIER ANCRE SUR LA ROCHE
OROGENESE CALEDONIENNE ET HERCYNIENNE DANS LE MASSIF PALEOZOIQUE APPARTENANT
A L UNITE DES PONDITES ET DES CHAINES DE MONTAGNES NORD ANATOLIENNES
GRAVIMETRE GEODYNAMICS 783 J.T.KUO TRANS WORLD PROFILES
CALIBRATION BRUXELLES-FUNDAMENTAL STATION
INSTALLATION P.MELCHIOR
MAINTENANCE E.KASNAK/K.ALTINSAPAN
GRANT AFOSR-73-2557A PROJECT-TASK 8607-02

LEAST SQUARE ANALYSIS / VENEDIKOV FILTERS ON 48 HOURS / PROGRAMMING B.DUCARME
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPUTING CENTER INTERNATIONAL CENTER FOR EARTH TIDES/FAGS/ BRUSSELS
COMPUTER UNIVAC 1100/40 PROCESSED ON 79/ 3/19

INERTIAL CORRECTION PROPORTIONAL TO THE SQUARE OF ANGULAR SPEEDS
NORMALISATION FACTOR .94863
PHASE LAG O1 .40 M2 .60 O1/M2 .67
CORRECTION FOR DIFFERENTIAL ATTENUATION M2/O1 1.00538 /MODEL 2/

G783 771120/771130 7712 3/7712 9 771213/771219 771223/771229 78 110/78 110
G783 78 113/78 119 78 123/78 228 78 3 4/78 312 78 322/78 322 78 327/78 327
G783 78 330/78 4 9 78 415/78 415 78 421/78 531

TIME INTERVAL 194.0 DAYS 3696 READINGS 13 BLOKS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
133.-136.	20	Q1	6.72	.11	1.1410	.0194	-.31	.98	.12	-161.6
143.-145.	16	O1	35.66	.11	1.1588	.0036	-.29	.18	.18	-95.2
152.-155.	15	NO1	2.79	.11	1.1515	.0451	.38	2.24	.03	133.2
161.-163.	10	P1	16.70	.09	1.1656	.0060	-1.71	.29	.53	-71.9
164.-168.	23	S1K1	49.35	.10	1.1401	.0023	-.09	.12	.13	-34.7
175.-177.	14	J1	2.99	.11	1.2341	.0468	5.09	2.18	.31	58.2
184.-186.	11	OO1	1.76	.23	1.3301	.1766	-2.79	7.64	.24	-21.1
233.-23X.	20	2N2	1.51	.05	1.1557	.0378	.37	1.88	.01	120.8
243.-248.	24	N2	9.64	.06	1.1798	.0075	.27	.36	.17	16.0
252.-258.	26	M2	50.42	.06	1.1811	.0013	.34	.07	.94	18.4
265.-265.	9	L2	1.37	.04	1.1390	.0294	-.03	1.48	.03	-178.2
267.-273.	9	S2	23.53	.06	1.1846	.0029	.30	.14	.50	14.2
274.-277.	12	K2	6.61	.08	1.2227	.0141	-.56	.67	.34	-10.8
335.-375.	16	M3	.74	.04	1.1732	.0616	-1.57	3.01	.11	-10.2

STANDARD DEVIATION D 3.33 SD 2.22 TD 1.56 MICROGAL
STUDENT FACTOR T¤S#95%,M, 138*#1.96

O1/K1 1.0164 1-O1/1-K1 1.1332 M2/O1 1.0193
CENTRAL EPOCH TJJ# 2443563.0

TRANS WORLD PROFILE   TURQUIE - ASIE   STATION KANDILLI-ISTANBUL
STATION 2000 KANDILLI-ISTANBUL   VERTICAL COMPONENT   TURQUIE - ASIE

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NORMALISATION FACTOR   .94863
PHASE LAG   O1   .40   M2   .60   O1/M2   .67
CORRECTION FOR DIFFERENTIAL ATTENUATION   M2/O1 1.00538   /MODEL 2/

G783   771120/771130   7712 3/7712 9   771213/771219   771223/771229   78 110/78 110
G783   78 113/78 119   78 123/78 228   78 3 4/78 312   78 322/78 322   78 327/78 327
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TIME INTERVAL   194.0 DAYS   3696 READINGS   13 BLOKS

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPL. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
133.-136.	20	Q1	6.69	.12	1.1346	.0199	.18	1.01	.15	171.8
143.-145.	16	O1	35.54	.11	1.1547	.0037	-.26	.18	.22	-130.9
152.-155.	15	NO1	2.68	.11	1.1094	.0462	1.41	2.38	.14	151.1
161.-163.	10	P1	16.61	.09	1.1598	.0061	-1.24	.30	.37	-76.7
164.-168.	23	S1K1	49.31	.10	1.1391	.0024	-.11	.12	.11	-54.3
175.-177.	14	J1	2.86	.12	1.1820	.0479	4.92	2.33	.25	80.9
184.-186.	11	OO1	1.64	.24	1.2348	.1809	-.21	8.43	.10	-3.4
233.-23X.	20	2N2	1.51	.04	1.1560	.0304	-.75	1.51	.02	-105.4
243.-248.	24	N2	9.61	.05	1.1755	.0060	.89	.29	.19	50.2
252.-258.	26	M2	50.23	.05	1.1767	.0011	.31	.05	.76	20.9
265.-265.	9	L2	1.38	.03	1.1473	.0237	.14	1.19	.02	167.8
267.-273.	9	S2	23.45	.05	1.1805	.0023	.28	.11	.42	16.0
274.-277.	12	K2	6.56	.06	1.2140	.0114	-.40	.54	.29	-9.0
335.-375.	16	M3	.73	.04	1.1572	.0607	-1.26	3.01	.10	-8.9

STANDARD DEVIATION   D   3.41   SD   1.79   TD   1.54 MICROGAL
STUDENT FACTOR   T¤S#95%.M, 138*#1.96

O1/K1 1.0137   1-O1/1-K1 1.1118   M2/O1 1.0190
CENTRAL EPOCH TJJ# 2443563.0

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133.-136.	20	Q1	6.68	.11	1.1342	.0188	.24	.96	.15	169.2
143.-145.	16	O1	35.52	.11	1.1541	.0035	-.21	.17	.21	-141.4
152.-155.	15	NO1	2.69	.11	1.1104	.0437	2.08	2.25	.15	140.6
161.-163.	10	P1	16.69	.08	1.1652	.0058	-1.24	.28	.40	-65.9
164.-168.	23	S1K1	49.32	.10	1.1396	.0022	-.13	.11	.14	-53.4
175.-177.	14	J1	2.85	.11	1.1791	.0454	4.54	2.21	.23	81.5
184.-186.	11	OO1	1.63	.23	1.2291	.1713	2.22	8.02	.11	35.1
233.-23X.	20	2N2	1.51	.04	1.1551	.0310	.96	1.54	.03	104.9
243.-248.	24	N2	9.60	.05	1.1750	.0061	1.07	.30	.22	56.2
252.-258.	26	M2	50.21	.05	1.1762	.0011	.30	.05	.74	20.9
265.-265.	9	L2	1.39	.03	1.1525	.0241	-.00	1.20	.01	-179.9
267.-273.	9	S2	23.40	.05	1.1784	.0024	.24	.12	.38	15.3
274.-277.	12	K2	6.48	.06	1.1984	.0116	-.01	.56	.21	-.3
335.-375.	16	M3	.73	.04	1.1572	.0606	-1.29	3.01	.10	-9.1

STANDARD DEVIATION D 3.23 SD 1.83 TD 1.54 MICROGAL
STUDENT FACTOR T□S#95%,M, 138*#1.96

O1/K1 1.0127 1-O1/1-K1 1.1041 M2/O1 1.0192
CENTRAL EPOCH TJJ# 2443563.0

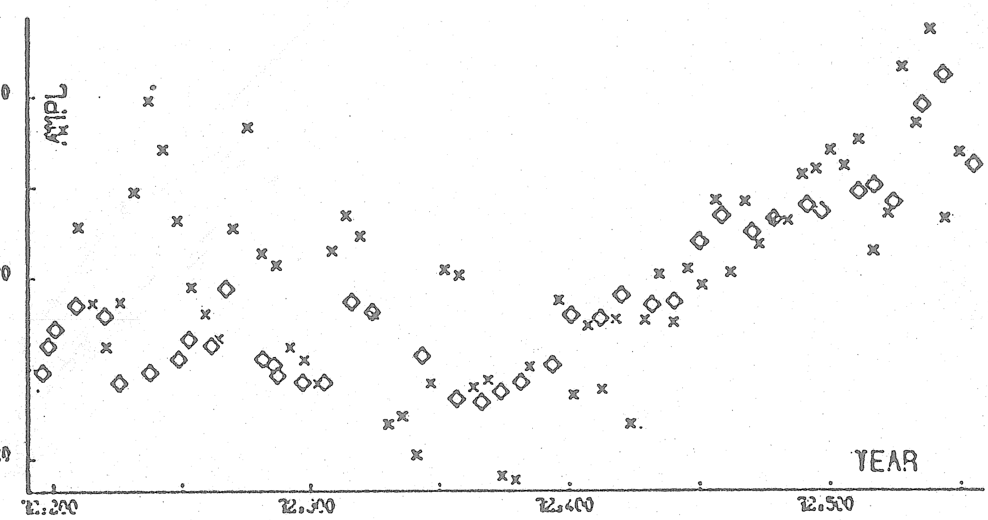

Figure 1: Station Chur - Gravimeter Geo 804

◇ amplitude of the calibration

x apparent tidal amplitudes from Nakai adjustment

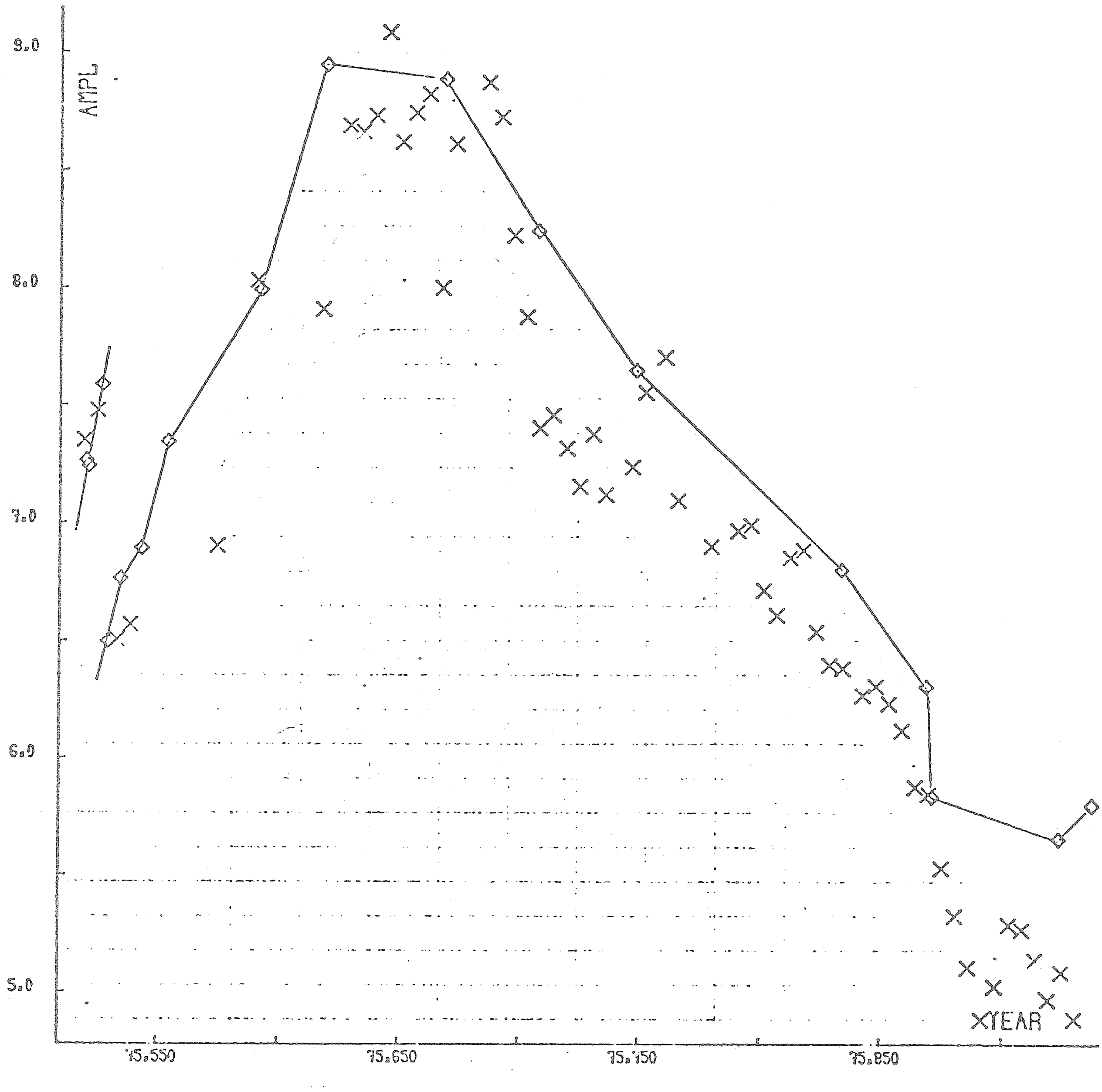

Figure 2: Station Broken Hill - Gravimeter LCR 3

amplitude of the calibrations

x apparent tidal amplitude from Nakai adjustment

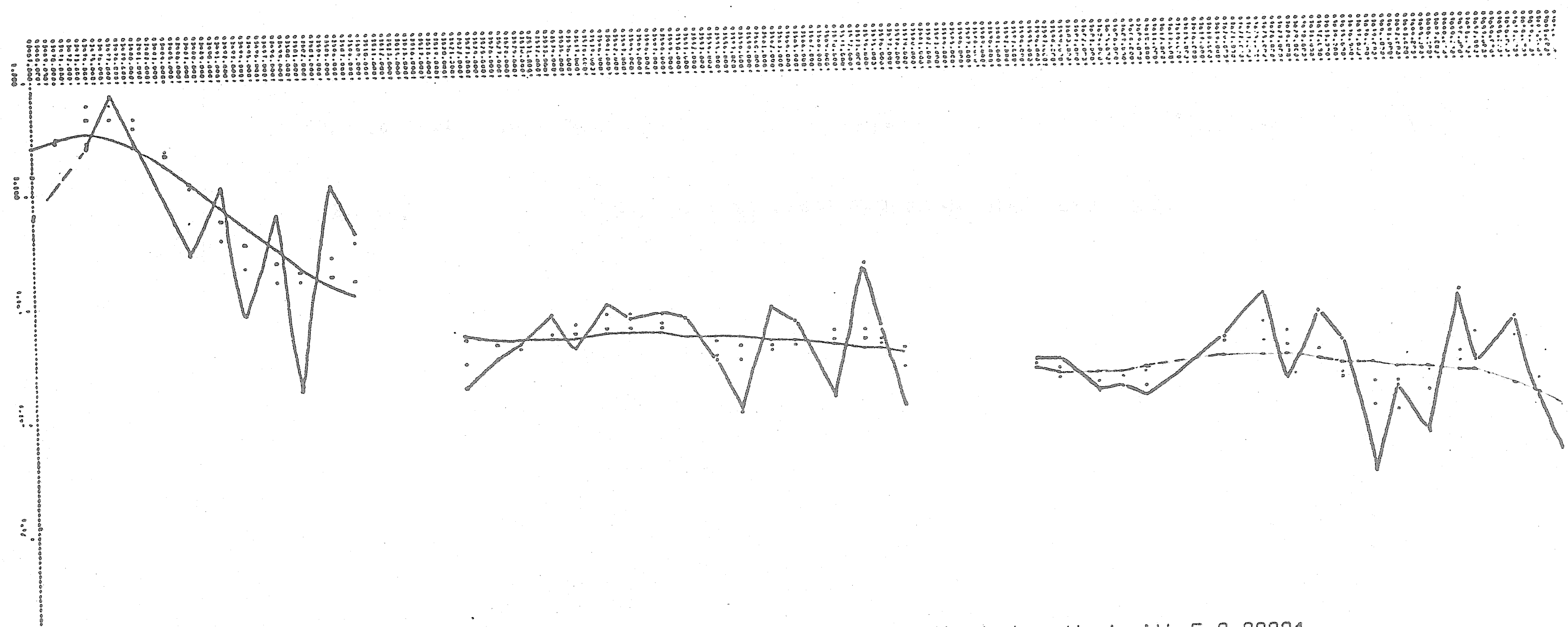

Figure 3 - Smoothed calibration table for using Vondrak method with E=0.00001

Figure 4: Smoothing of the apparent tidal amplitude with E=0.00001

note the periodic fluctuations of the raw data effectively suppressed by the smoothing

NOMBRE DE POINTS DOUBLES = 129

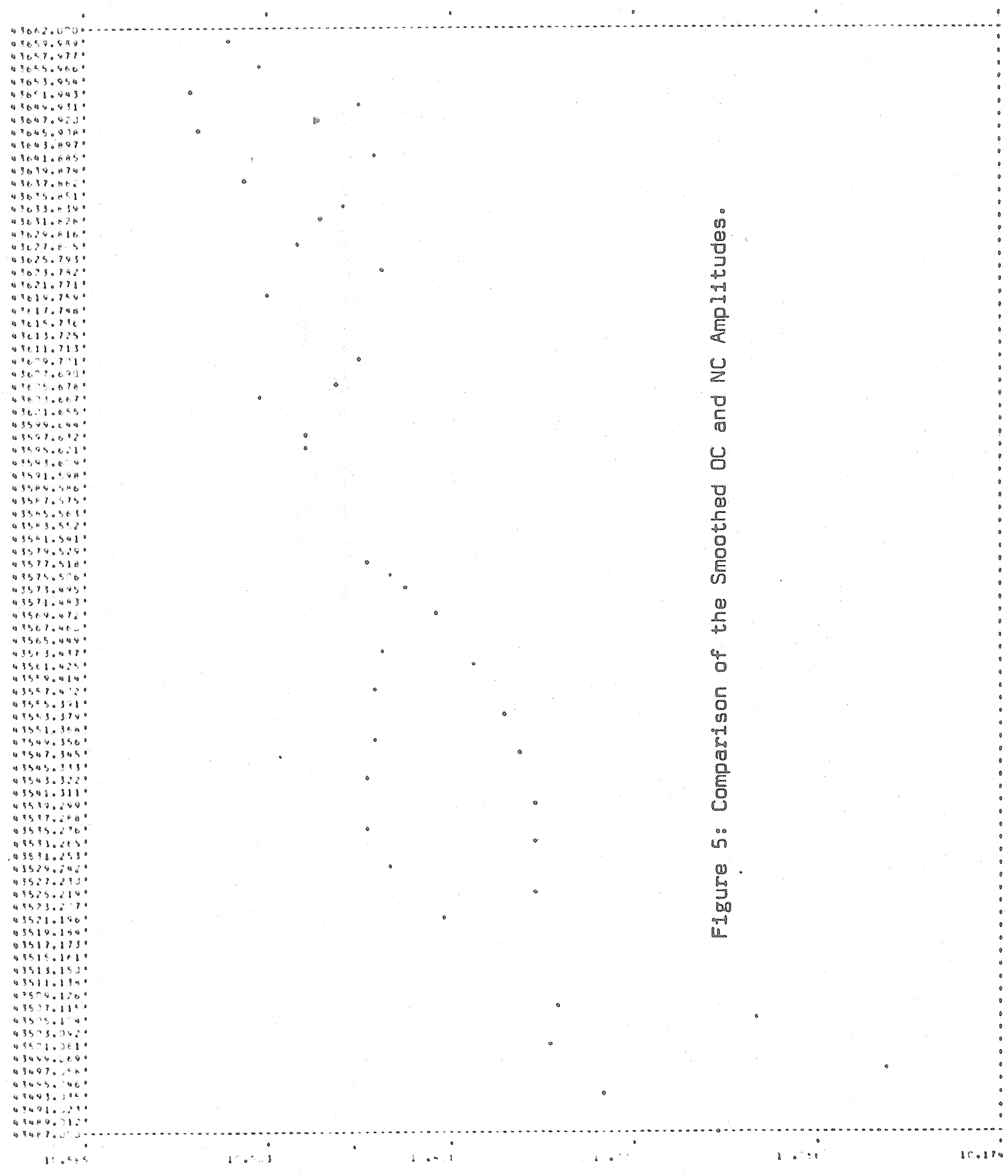

Figure 5: Comparison of the Smoothed OC and NC Amplitudes.

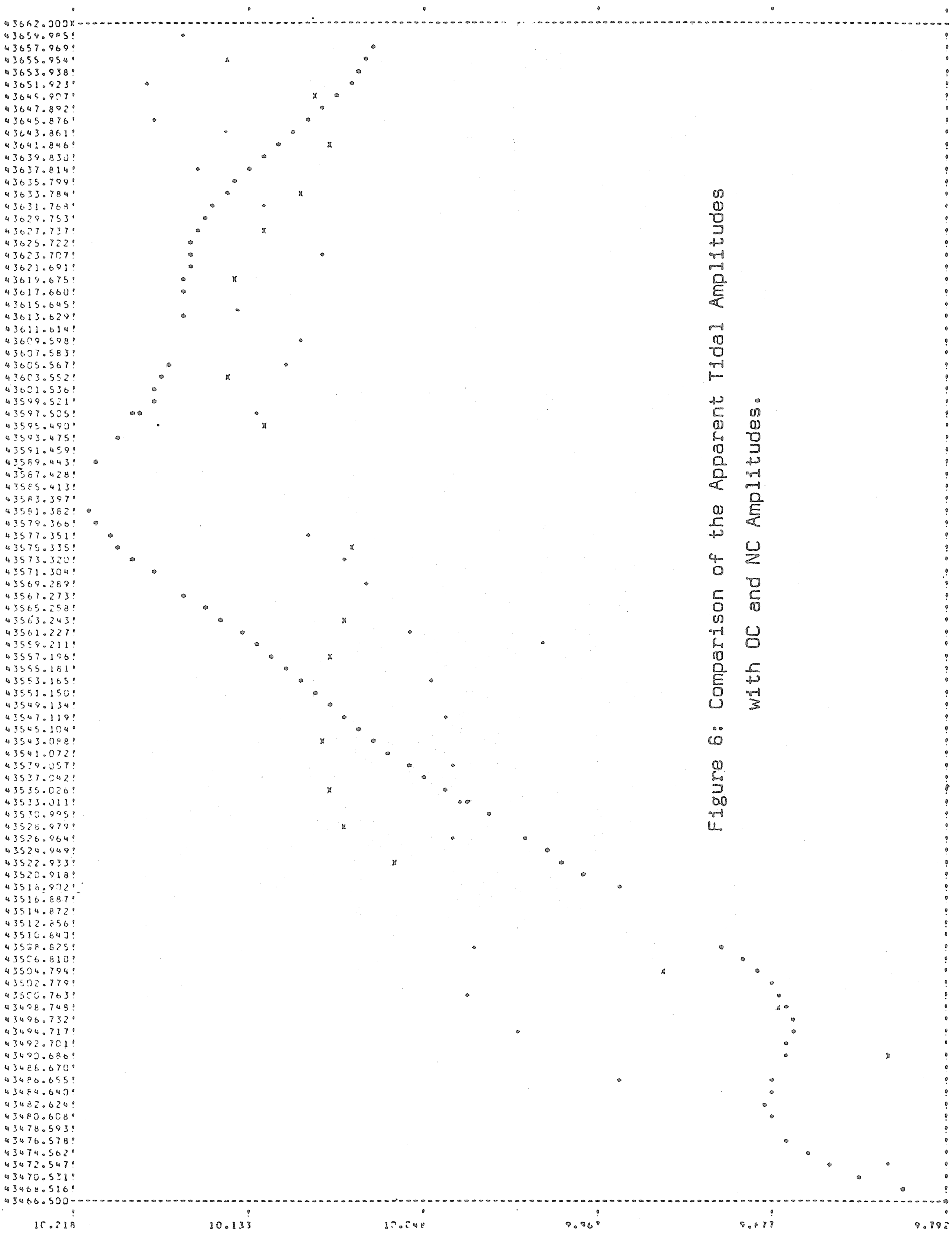

Figure 6: Comparison of the Apparent Tidal Amplitudes with OC and NC Amplitudes.

NOMBRE DE POINTS DOUBLES = 1

A METHOD FOR EVALUATION OF LOCAL TILT RECORDS

G. BARTHA

In this paper I should like to call attention to some questions of the evaluation of local tilt records. It is true that this area is not directly connected to the Earth tides research, but according to my opinion this interesting topic will become more important in the future. So, it is worth while dealing with such questions from the point of view of evaluation process.

The first question : What is the local tilt ? The Earth tides records contain three components :

$$l(t) = L(t) + R(t) + D(t) \tag{1}$$

The L(t) is the lunisolar effect, the R(t) is a non-lunisolar <u>real</u> effect and D(t) is the instrumental drift. In the normal case :

$$\frac{\Delta L(t)}{\Delta t} >> \frac{\Delta R(t)}{\Delta t} \tag{2}$$

In practice we can find a reverse situation, when :

$$\frac{\Delta L(t)}{\Delta t} << \frac{\Delta R(t)}{\Delta t} \tag{3}$$

This is the result of local movements which are induced by natural effects or artificial activities. Mainly the horizontal pendulums are "sensitive" to these effects. So, we call local tilt those which are caused by local movements.

The second question : What can we do if we find such a recording place, where the inverse relation is true ? Of course if we want to record the Earth tides effects, it is necessary to stop the recording in this place and to seek for another place. However, perhaps the local tilt is very important information from another point of view. For example, if this place is a coal mine, the local tilt records can give an important information for the mine engineers. In this case it is worth while to continue to record.

Now we reach the third question : Which information is important for us and how can we get it from the records ? In the case of the horizontal pendulum records this information can be the following : Let function $\alpha(t)$ represent the local tilt. Then :

$$\Delta\alpha(t) = \alpha(t) - \alpha(t_o) \tag{4}$$

where $\Delta\alpha$ is a tilt in the time interval $\{t, t_o\}$. In practice the determination of the function $\Delta\alpha$ is important. If t and t_o are epochs in the past, it seems that this is a very simple task. The difference of the ordinates $\alpha(t)$ and $\alpha(t_o)$ from the record gives $\Delta\alpha(t)$. However, in practice this process is not always so simple. Generally, the records have many gaps and as well, we can find unknown shifts in the records, too (figure 1). Usually we do not know the tilt, therefore

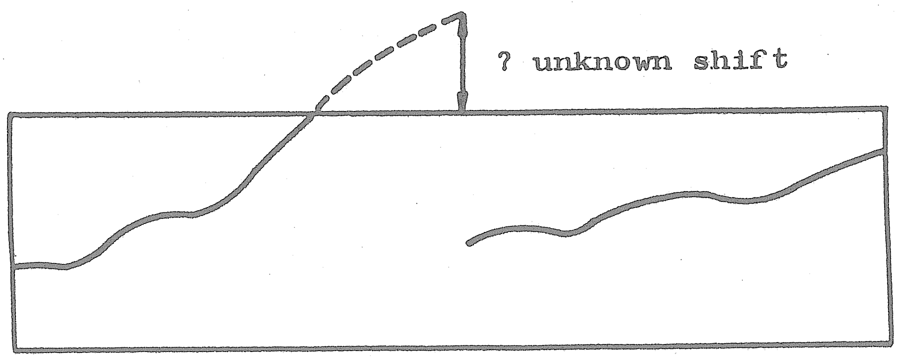

Figure 1.

the signal runs many times out from the recording paper. Of course, in this case the simple difference of the ordinates does not give the value $\Delta\alpha(t)$.

The difference coordinates can not be formed, if t is an epoch in the future, that is when we should like to make a prediction.

The solution of these problems is to find an analytical form for the function $\alpha(t)$. The Fourier analysis is not suitable for this purpose, because the time series has many gaps. It seems that the following process is suitable to determine an analytical form : Let $\alpha(t)$ be represented in the following form :

$$\alpha(t) - \alpha(t+1) = a_i \left[\cos(\omega_i t + \phi_i) - \cos(\omega_i (t+1) + \phi_i)\right] \tag{5}$$

Then

$$\alpha(t) - \alpha(t+1) = x_i \left[\cos \omega_i t(1-\cos \omega_i) + \sin \omega_i t \sin \omega_i\right] +$$

$$+ y_i \left[\sin \omega_i t(1-\cos \omega_i) - \cos \omega_i t \sin \omega_i\right] =$$

$$= c_i x_i + s_i y_i$$

$$x_i^2 + y_i^2 = a_i^2 \qquad -\frac{y_i}{x_i} = \text{tg } \phi_i \tag{6}$$

In matrix form :

$$\underline{\alpha} = \begin{bmatrix} \underline{C}_i , \underline{S}_i \end{bmatrix} \begin{bmatrix} x_i \\ y_i \end{bmatrix} \qquad (7)$$

From the solutions of the system of linear equations we can get the amplitude a_i which belongs to ω_i frequency.

Choosing a set of ω_i we can compute the power spectrum of the time series (figure 2.).

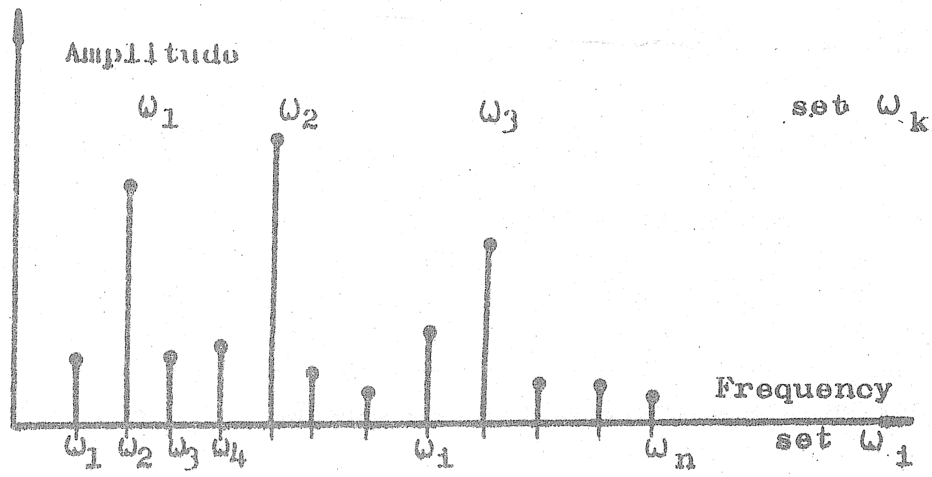

Figure 2.

From this spectrum we can choose the characteristic frequencies. Let ω_k represent this set. Then :

$$\alpha(t) - \alpha(t+1) = a_k \left[\cos(\omega_k t + \phi_k) - \cos(\omega_k(t+1) + \phi_k) \right] - $$

$$- p_1 - (2t-1)\, p_2 \qquad (8)$$

where p_1 and p_2 are the coefficients of a first and second order polinomial, respectively. Solving the equation system (8) we can get the parameters of the function $\alpha(t)$.

A POSSIBILITY OF CHARACTERIZING EVALUATION METHODS

G. BARTHA

In the methods, based on the least squares technique, the determination of the Earth tides factors are traced back to solve a system of linear equations. The system of linear equations, which must be solved is :

$$\underset{(n,1)}{\underline{L}} + \underset{(n,1)}{\underline{V}} = \underset{(n,m)}{\underline{\underline{A}}} \; \underset{(n,1)}{\underline{X}} \qquad (1)$$

From the principle of least squares technique :

$$\underline{X} = (\underline{\underline{A}}^T \underline{\underline{A}})^{-1} \underline{\underline{A}}^T \underline{L} = \underline{\underline{Q}} \, \underline{\underline{A}}^T \underline{L} \qquad (2)$$

The mean square error for an observation of unit weight :

$$\sigma^2 = \frac{\underline{V}^T \underline{V}}{n-m} \qquad (3)$$

The root mean square errors of the Earth tides factors :

$$\mu_{x_i} = \sigma \sqrt{Q_{ii}} \qquad (4)$$

The root mean square errors of the unknowns contain two parts. The first part is the factor σ, which is determined by the discrepancies between the time series and the functional model. The functional model is given by the matrix $\underline{\underline{A}}$. If the choice of the functional model is good, the discrepancies are small. In such a case, the distribution of these discrepancies is a normal one and its standard deviation is just the factor σ. So, the factor σ characterizes the "quality" of the time series.

The second part of the r.m.sq.e. μ_{x_i} is $\sqrt{Q_{ii}}$ which is a diagonal element of the inverse matrix. The factor $\sqrt{Q_{ii}}$ is only determined by the functional model.

On the basis of the foregoing, the factor σ is "data factor" and the factor $\sqrt{Q_{ii}}$ is a "model factor".

If the choice of the functional model is good, the data factor σ is independent of the length of the data series. However, the model factor $\sqrt{Q_{ii}}$ is changing with increasing length of the time series.

Let n denote the number of data in a time series. The functions $\mu_{x_i}(n)$ give an important feature of the evaluating methods, and give a possibility of characterize the method itself.

Let us find the function $\mu_{x_i}(n)$ in the following form :

$$\mu_{x_i} = \sigma \cdot c \cdot n^a \tag{5}$$

In logarithm form :

$$\lg \mu_{x_i} = \lg \sigma + \lg c + a \lg n \tag{6}$$

The functions of $\lg \mu_{x_i}$ (lg n) are linear functions which we can call "model lines".

The model lines were determined for tides O1, P1S1K1, M2, S2K2 by the "old" Venedikov method, in that case when the tides were classified in 11 groups (Figure 1).

We can see that the greater direction tangent belongs to the greater amplitude. Similarly the greater value lg c belongs to the greater amplitude.

If we change the group classification of the tides, the functional model will be changed. In this case the parameters of model lines will be changed, too. We can see in the Figure 2. the model lines of the tide P1S1K1 in the case of a classification into 11 groups, and the model lines of the tides P1, S1K1 in the case of a classification into 12 groups.

On the Figure 3 we can see the model lines of the tides P1S1K1, and M2 from another evaluating method. In this method a differential filter with two elements was applied. If we compare these model lines with the model lines of the Venedikov method, differences can be seen, so, these lines are suitable for characterizing the evaluation methods.

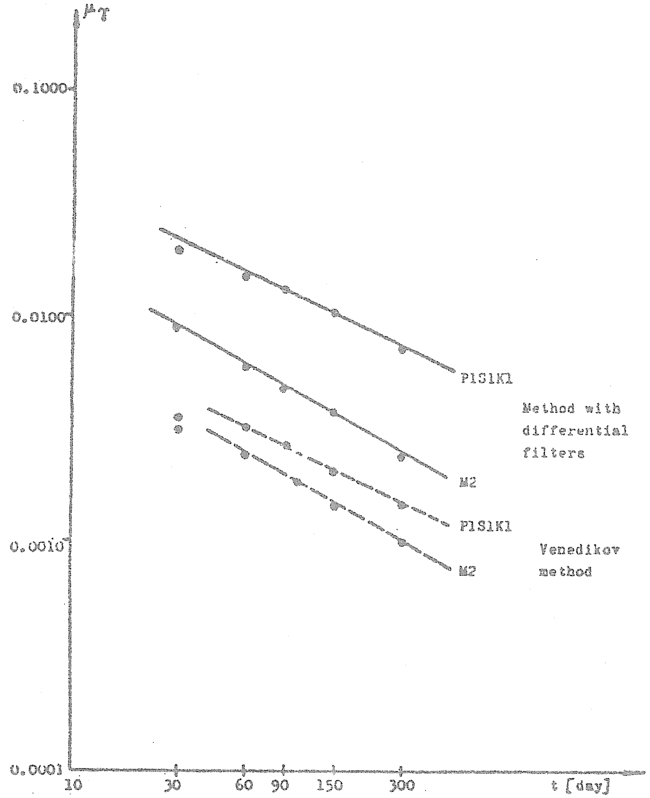

Fig. 3.

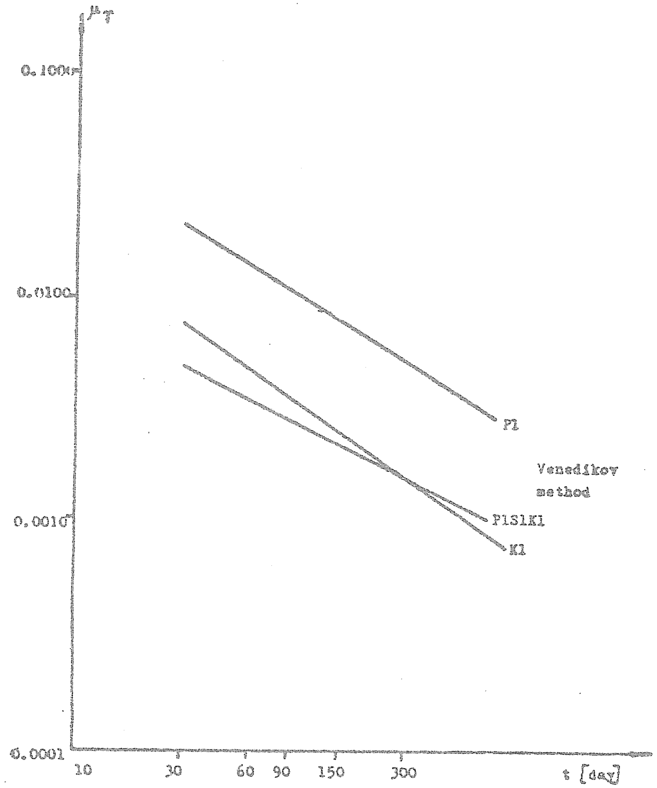

Fig. 2.

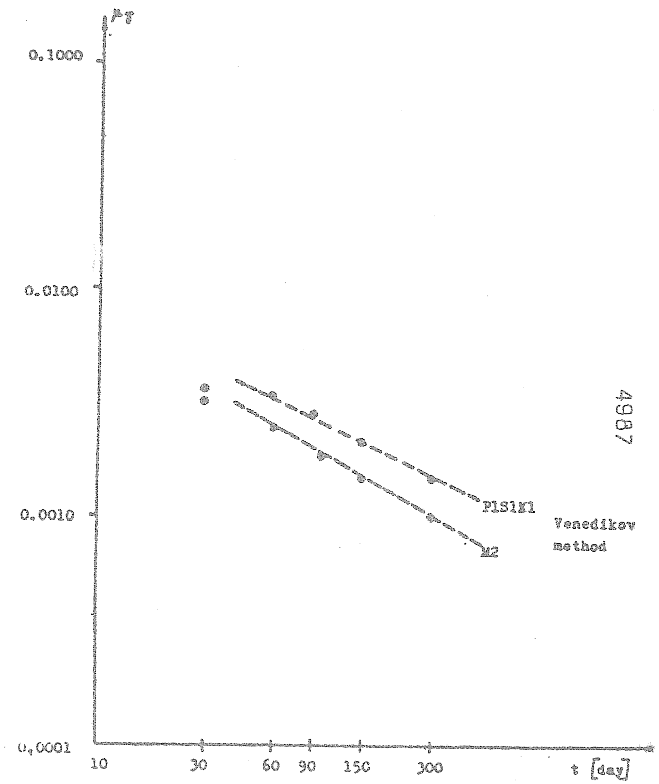

Fig. 1.

TESTING OF THE GROUPING OF THE WAVES IN THE ANALYSIS OF THE EARTH TIDAL RECORDS

A.P. VENEDIKOV

Geophysical Institute
Bulgarian Academy of Sciences

1. INTRODUCTION.

The resolution of an analysis is determined by the length of the record. As the length is limited and we have quite a lot of very close waves we must have a kind of a grouping of waves whatever be the method of analysis. One group is formed by waves with close frequencies for which we accept that the tidal parameters, δ and ϕ, do not change.

In {1} we have the important suggestion that even for tides with close frequencies that are normaly included into one same group we have to consider a difference or a variation of the parameters. In any case such a detailed variation may be taken into account through a suitable affection of the theoretical spectrum while the estimates of the parameters should be inevitably derived under the assumption of their constancy. Thus from the point of view of the processing of the records this suggestion does not modify the conception here given of the grouping.

In the method of Lecolazet {2} the groups have been introduced through the homologous numbers. In the methods of Doodson-Lennon {3} and of Pertsev {4} the constancy of the parameters for some groups was used through some corrections.

In {5} the grouping was explicitly used through the application of the unknowns ξ and η, directly related to δ and ϕ. 3 variants of grouping were proposed for records of length greater than 1 year, less than 1 year but greater than 6 months and less than 6 months but greater than 1 month. These groupings are the variants N° 2, 3 and 4 in the table 1. The difference between these variants are only in the groups P1, S1 and K1 and in S2 and K2. Several less important groups were associated with some other more important groups, having in mind the small differences in the parameters and the limits of the precision.

In the ICET {6} for longer data with high quality a detailed grouping is applied (variant 0 in table 1) in which practically all groups that can be separated are separated. It is called also "fine structure".

In our opinion the choice of the groups has not a priori an unique solution, though it generally depends from the length of the records. The reasons are : (i) there are cases in which we cannot be certain that there are real differences in the parameters between the groups, (ii) the precision may be not sufficient to check the differences between some groups, (iii) when the differences are not important a better precision will be realized if a group associates more waves even if they are separable, (iv) when the length of a record is under a given limit but quite close to it, it may be still possible to apply the separation corresponding to that limit and (v) when the total length corresponds to a limit but there are too great lacks inside the record it may be more reasonable to apply a separation corresponding to a lower limit.

In any way it seems to be usefull to check the significance of the grouping used in the analysis through a comparison of different variants and this is the aim of the present paper. In some cases we suggest to process an analysis with the simultaneous application of several variants of grouping and to compare them by the method of analysis of variance (AV).

II. SIMULTANEOUS APPLICATION OF DIFFERENT VARIANTS OF GROUPS.

Let $\underline{U}$ be the vector column of all observed values in a record. For the methods {5,7} $\underline{U}$ is composed by the filtered values (both even and odd filtering) but relative to one of the principal groups - diurnal, semidiurnal, terdiurnal or long period waves.

Let $\underline{X}_1$ be the vector column of all unknowns ξ and η relative to the most detailed grouping, for instance the variants 0 or 1 in table 1. If m_1 is the number of the elements of $\underline{X}_1$ then m_1 is equal to twice the number of all possible groups. By $\underline{X}_i$ we shall denote the analogous vector relative to an i-th variant and by m_i the number of the elements in $\underline{X}_i$. We shall suppose that the variants are so arranged that for a greater i we have a rougher grouping i.e. a smaller m_i, as in the table 1. The number of all variants we want to study we shall denote by v.

Whatever the length of the record is we may constitute the following v variants of observational equations

$$\underline{U} = \underline{\underline{A}}_i \cdot \underline{X}_i + \underline{e}_i \qquad (i = 1, \ldots v) \qquad (1)$$

where $\underline{\underline{A}}_i$ is an $(n \times m_i)$ - dimensional matrix, $\underline{e}_i$ is the n - dimensional vector of the errors of the equations and n is the number of the observations in $\underline{U}$.

From now we may compose v variants of normal equations

$$\underline{\underline{A}}_i^* \underline{U} = \underline{\underline{A}}_i^* \underline{\underline{A}}_i \cdot \underline{X}_i \qquad (i = 1, \ldots v) \qquad (2)$$

For the practice it is important to notice that all variants may be considered as obtained from the first variant (i = 1). If a sequence of groups in the variant 1 is associated in a single group in the variant i this means that the corresponding sequence of unknowns in $\underline{X}_1$ is replaced by a single unknown in $\underline{X}_i$. In fact as we have a pair of unknowns for each group we shall have a pair of sequences replaced by a pair of unknowns. This complication may disappear in the presentation in considering complex numbers but it remains in the practical application.

The columns in $\underline{\underline{A}}_1$ corresponding to the replaced unknowns are also replaced by a single column in $\underline{\underline{A}}_i$ which is the sum of the replaced columns. And the corresponding columns and rows in the matrix $\underline{\underline{A}}_1^* \underline{\underline{A}}_1$ are replaced by a single column and a single row obtained by the summation of the replaced columns and rows.

The transformation of the matrices may be expressed through a matrix $\underline{\underline{T}}$ with elements T_{jk}, $j = 1, \ldots m_1$, $k = 1, \ldots m_i$. We set up

$$T_{jk} = 1 \qquad (3)$$

if the group k in the variant i incorporates the group j from the variant 1 and

$$T_{jk} = 0 \qquad \text{otherwise.}$$

Then we have

$$A_i = A_1 \cdot T \qquad \text{and} \qquad \underline{\underline{A}}_i^* \underline{\underline{A}}_i = \underline{\underline{T}}^* \underline{\underline{A}}_1^* \underline{\underline{A}}_1 \underline{\underline{T}} \qquad (5)$$

$$\underline{\underline{A}}_i^* \underline{U} = \underline{\underline{T}}^* \underline{\underline{A}}_1^* \underline{U}$$

It is interesting that $\underline{X}_i$ may be perceived as

$$\underline{X}_i = (\underline{\underline{T}}^* \underline{\underline{T}})^{-1} \underline{\underline{T}}^* \underline{X}_1 \qquad (6)$$

In such a way we have the possibility to simultaneously realize several different variants of grouping for the analysis of a record. We have to make the composition of the observational equation and the accumulation of the elements of the normal equations, which is the hard and time-consuming job, once - for the detailed grouping. Once the normal equations for this variant are composed there is no problem for the computer with a very little waste of time to compose the normal equations for any variant. It needs however quite a lot of care in the programming.

III. ANALYSIS OF VARIANCE.

The use of one or another variant of grouping has the meaning that we make one or another hypothesis about the tidal parameters. Thus if $j > i$ and in the variant j we have a fewer number of groups in that variant we make the hypothesis that some of the unknowns used in the variant i are equal to each other. On the contrary the variant i is free from that hypothesis. To test such a kind of hypothesis we may apply the AV, i,e. to test a given variant of grouping.

Descriptions of the AV may be found in many books of the mathematical statistics, for instance {8}.

Let R_1 be the sum of squares of the residuals for the variant j ($j > i$), it is when a hypothesis about the unknowns in $\underline{X}_j$ in relation with the unknowns $\underline{X}_i$ is assumed to be true. Let R_o be the sum of squares when the conditions implied in the hypothesis that reduces the number of the groups from the variant i to the variant j are not imposed. So R_o is the sum of squares when the variant i is realized.

The degrees of freedom are :

$$R_1 \quad : \quad n - m_j$$

$$R_o \quad : \quad n - m_i$$

$$R_1 - R_o \quad : \quad (n - m_j) - (n - m_i) = m_i - m_j \qquad (7)$$

The quantity

$$F_{ji} = \frac{R_1 - R_o}{m_i - m_j} \Big/ \frac{R_o}{n - m_i} \qquad (8)$$

when the hypothesis is true must have a Snedecor distribution, known also as F - distribution (in honour of R. Fisher).

We shall again be concerned by the meaning of the hypothesis. If it is true it means that it is indeed reasonable to associate several of the groups from the variants i in greater groups in the variant j. It is reasonable because in that case greater groups must give higher precision of the estimates of the parameters. It means also that the more detailed grouping does not provide greater information.

Let $F_c = F_c(P, m_i - m_j, n - m_i)$ is the value of the F distribution for a fiducial probability P, for instance P = 95 % and degrees of freedom $m_i - m_j$ and $n - m_i$. When the hypothesis is not true we may expect in general small values of F_{ji}, namely it will be smaller than F_c with a probability P. It may happen to be greater than F_c with a probability only a = 1 - P or a = 5 % when P = 95 %.

Upon these considerations if it happens that the estimate F_{ji} derived from the simultaneous analysis with the variants i and j of grouping is

$$F_{ji} > F_c \tag{9}$$

we may conclude that the hypothesis is not true with a risk to make an error equal to a. In that case we may consider the grouping i as reasonable and reject the rougher grouping j.

If on the contrary it happens that

$$F_{ji} < F_c \tag{10}$$

it means simply that the hypothesis cannot be rejected on the basis of our data. It is still not sufficient to accepte the hypothesis i.e. we cannot pretend that the two variants of grouping are equivallent and thus to recomend the replacement of the variant i by the variant j in general. However the appearence of (10) in the analysis of a given record is quite enough to decide that its precision is not sufficient for the revealing of the differences between these groups in the variant i that are associated in greater groups in the variant j. Thus on the basis of (10) it may be recomended for the analysis of that record to prefer the less detailed variant j.

IV. PRACTICAL APPLICATION AND SOME RESULTS.

In the program SVETLA we use for the application of (7) it is possible to apply up to 7 variants of grouping which are the variants 1 to 7 in the table 1. In its variant developed in ICET with Dr Ducarme the variant 1 is replaced by the variant 0. Though there is not a great difference between these two variants, according to a suggestion of Prof. Melchior, we have the intention to replace the variant 1 by the variant 0.

The variants 0 and 1 correspond to the fine structure and they provide a complete separation or so. The variants 2, 3 and 4 correspond to the standard separation for lengths of 1 year, 6 months and 1 months. The variants 5 and 6 are rather arbitrary and may be used to check the significance of some groups. The last variant 7 associates all tides from one principal group in one group. The simultaneous analysis with the first four variants or with anyone of them may check whether there are significant differences at all within each of the principal groups.

It may be seen that we have a very poor study of the high frequency tides. For the ter-diurnal tides we have only two groups in the variant 0 while there is a single group in all other variants. It will be interesting to include a supplementary wave S3 and even S4 in order to check the presence of meteorological subharmonics as well as to study an eventual influence of the oceans.

In SVETLA it is possible to apply simultaneously up to 5 variants - whichever combination of the 7 variants. When a record is processed the observational equations and the normal equations are composed for the detailed (fine structure) grouping, i.e. the matrix $\underline{\underline{A}}_1^* \underline{\underline{A}}_1$ is obtained. From that matrix, which is stored we obtain the matrix of the normal equations for any variant. The indices i of the variants we want to study are an input of the processing.

When more than one variant is applied then the number or the F_{ji} for $i = 1, \ldots j-1$ are determined and printed. The degrees of freedom are not printed as it is easy to find them.

The aim of the present paper is to demonstrate the technics we apply for testing the grouping. It has not the pretention to make definitive conclusions for which a broad study would be necessary. For that reason we give here only a few results only as illustrations. The conclusions that one can derive may only demonstrate how they can be done.

In the tables 2 and 3 are given the results from the analysis of 4 variants of grouping of a long record from Frankfurt of a very high internal precision. The data are not corrected by a drift of the amplitudes revealed by Usandivaras and Ducarme.

In the lower part of the tables is made the AV. In table 2 there are given F_{j1} i.e. a comparison of the variants j = 2,3 and 7 with the variant 1, F_{j2} - a comparison of the variants 3 and 7 with the variant 2 and $F_{j3} = F_{73}$ - a comparison of the variants 7 with 3. In the table 3 there are given F_{j1} for j = 2 and 7 and $F_{j2} = F_{72}$. Here the variant 3 is omitted because it is identical to the variant 2.

Together with the values F_{ji} there are given the corresponding pairs of degrees of freedom and the critical values F_c taken from a table of the F-distribution for a level of significance a = 5 %.

In all cases we have $F_{ij} > F_c$. This means that in all cases the more detailed groups are to be prefered. This conclusion is confirmed by the fact that in general the mean square errors are not improved when the groups are greater. The variant 7 is not an exception though the mean square error is only 3. In that case the group that associates all tides is only named S2. The low error 3 is to be compared with the error of M2 which is also 3.

The most interesting point seems to be the comparison of the variants 1 and 2, i.e. the "fine structure" and the grouping usually applied on records of one year or greater. In that case the value derived F_{21} is slightly greater than F_c but, nevertheless, it is greater. This is enough, according to the statistical theory and practice, to reject the variant 2 in favor of the fine structure - the variant 1. On the basis of such a conclusion we may consider reasonable the estimates obtained for the litle groups like PY1, PSI1, PHI1, ignored in the variant 2.

TABLE 1. Variants of groups of the tidal waves - Diurnal tides

Var. 0	SIGQ	2Q1	SIG1	Q1	RHO1	O1	TAU1	NO1	KI1	PY1	P1	S1	K1	PSI1	PHI1	TET1	J1	SO1	OO1	NU1
Var. 1			SIG1	Q1	RHO1			M1		PY1	P1	S1	K1	PSI1	PHI1		J1		OO1	NU1
Var. 2				Q1	O1			M1			P1	S1	K1				J1		OO1	
Var. 3				Q1	O1			M1			P1		K1				J1		OO1	
Var. 4				Q1	O1			M1					K1				J1		OO1	
Var. 5					O1								K1				J1			
Var. 6					O1								K1							
Var. 7													K1 (all D tides)							

Semidiurnal tides

Var. 0	EPS2	2N2	MU2	N2	NU2	M2	LMB2	L2	T2	S2	K2	ETA2	2K2
Var. 1	EPS2	2N2	MU2	N2	NU2	M2		L2	T2	S2	K2	ETA2	2K2
Var. 2 & 3		2N2		N2		M2		L2		S2	K2		
Var. 4		2N2		N2		M2		L2		S2			
Var. 5				N2		M2				S2			
Var. 6						M2				S2			
Var. 7										S2 (all SD tides)			

Ter-diurnal tides

Var. 0	MO3	M3
Var. 1 to 7		M3

TABLE 2. Frankfurt, LCR 098, 24.11.67-15.01.75, R. Brein, D tides.

Group	Var. 1	Var. 2	Var. 3	Var. 7
SIG1	1.1388 115			
Q1	1.1463 23	1.1466 22	1.1466 22	
RHO1	1.1618 115			
O1	1.1509 4	1.1510 4	1.1511 4	
M1	1.1487 46	1.1483 46	1.1478 47	
PY1	1.1181 169			
P1	1.1522 10	1.1520 10	1.1519 10	
S1	0.8126 609	0.7987 592		
K1	1.1380 3	1.1381 3	1.1379 3	1.1430 3
PSI1	1.1622 405			
PHI1	1.1970 239			
J1	1.1606 52	1.1600 53	1.1599 53	
OO1	1.1708 63	1.1732 62	1.1738 63	
F_{j1}		2.5	4.8	37.6
Deg.fr.		12/1106	14/1106	26/1106
F_c(a=0.05)		1.75	1.69	1.51
F_{j2}			18.2	67.2
Deg.fr.			2/1118	14/1118
F_c(a=0.05)			3.00	1.69
F_{j3}				74.2
Deg.fr.				12/1120
F_c(a=0.05)				1.75

TABLE 3. Frankfurt. LCR 098, 24.11.67-15.01.75, R. Brein, SD tides.

Group	Var. 1	Var. 2	Var. 7
EPS2	1.1040 510		
2N2	1.1734 153	1.1551 96	
MU2	1.1437 120		
N2	1.1753 19	1.1747 19	
NU2	1.1535 95		
M2	1.1839 3	1.1838 3	
L2	1.1358 74	1.1349 74	
T2	1.1939 113		
S2	1.1859 6	1.1859 6	1.1842 3
K2	1.1908 20	1.1910 20	
ETA2	1.2286 347		
2K2	1.2815 753		
F_{j1}		2.4	44.3
Deg.fr.		12/1112	28/1112
$F_c(a=0.05)$		1.75	1.51
F_{j2}			93.9
Deg.fr.			10/1124
$F_c(a=0.05)$			1.83

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INFLUENCES OF DIFFERENT FILTERS ON RESULTS OF TIDAL OBSERVATION ANALYSES

Tadeusz CHOJNICKI

Contemporary methods of tidal observation analyses based on a least squares method differ in two basic points :

1. Shift of a filter during filtering is equal a/ to filter length or b/ to 1 hour, that is it filters a/ without covering or b/ with covering.
2. Adjustment of basic groups of waves, i.e. diurnal, semidiurnal and terdiurnal is realized a/ separately or b/ altogether.

The use of the way a/ and b/ affects the obtained results according to the used filter as shown in the presented diagrams. The Venedikov's method of replacing observation was used {7}, {8} employing the way a/, and the classical method {1} employing the way b/. In the first case results were examined for 33 groups of Venedikov's filters /M65 and M74/, and in the second case for 2 Pertsev filters {6}, 6 Malkowski's filters {5} and 1 De Meyer's filter {4}.

The examination was based upon analysis of four six-week series of model observations, the characteristics of which are given in Table I. Construction of model observations is in principle identical as the one described in {2}. Considering, however, the remarks in the Venedikov's paper {9}, the possibility of generation of observational errors with abnormal distribution due to a given residual spectrum was introduced into the programme of model construction. It allowed also for assumption of mean errors in particular frequency bands.

In comparisons results obtained by the mentioned methods were used that is errors of a single observation with weight 1, mean square errors in basic frequency bands as well as values of unknowns and their errors. To make a comparison of results easier, the so called indicator of quality IQ was computed for every analysis, showing error of a tidal value calculated on the basis of resultant errors obtained after adjustment. These errors were obtained from differences between values of amplitude factors and phase differences assumed in models and obtained from analysis. The indicator of quality was calculated with a formuls :

$$IQ = \sqrt{\frac{1}{2} \sum_{i=1}^{n} R_i^2 \left(m_{d_i}^2 + d_i^2\, m_{f_i}^2\right)} \, , \qquad (1)$$

TABLE I

N° of model	Number of days	Station	Wave groups				Drift	Data of MSE				Remarks
			0	1	2	3		m_0	m_1	m_2	m_3	
42	42	Strasbourg	x	x	x	x	typic	1	4	2	1	
35	42	Warsaw	x	x	x	x	—	1	—	—	—	Inconstancy of unknows $0.993 < \phi < 1.007$ $-0.7 < \Delta\phi < +0.7$
34	42	Warsaw	x	x	x	x	linear	1	—	—	—	
32	42	Warsaw	—	x	x	x	—	1	—	—	—	

where : m_d and m_f - resultant errors of amplitude factors and phase differences, d - amplitude factors, R - amplitudes of tidal waves, n - number of waves for which parameters were determined. The above formula was derived for the moment in which phases of all waves are equal to 45°.

From a sum of squares of resultant deviations of drift and a tide after drift elimination an error of drift m_d and pure tide m_p was calculated for the classical method. These errors cannot be calculated for the Venedikov's method because it gives neither drift nor pure tide.

Figures 1 - 4 present results of analysis of the Venedikov method. Results for particular filters are arranged according to increase of a mean square error m_o. A mean square error of a single observation, mean square errors in a diurnal and semidiurnal bands, and indicator of quality IQ are marked. The broken line presents results of modifications of this method which depends on adjustment of all three basic groups of waves together.

The following conclusions may be drawn from analysis of the diagrams 1 - 4 :

1. The estimation of accuracy in majority of filters disagrees with the one assumed in the model and is a function of the used filter. The discrepancy, sometimes up to 300 %, grows with complication of a drift and with variability of unknowns during observations. The estimation of accuracy may be both overestimated and underestimated.

2. The analysis results depend upon the used filter, at the same time there is no correlation between estimation of accuracy by mean square errors and indicator of quality. Thus a choice of optimal results according to the criterium of a minimal mean square error as in the method M74 seems to be very doubtful.

3. A modification of the Venedikov method consisting in joint adjustment of three basic wave groups improves results considerably and estimation of accuracy in great part. It should be noticed that the method M74 partly takes this modification into account but insufficiently.

4. Some filters give decidedly bad results, for example 33/34, 5/4, 303/304, 305/304.

Figures 5 - 8 show diagrams of the same elements for the classical method. Before the discussion of conclusions following the analysis of these diagrams it should be noticed that filters MP and 41/399 are worse, and filter 25/902 is positively bad. They have been included into analysis with the purpose to emphasize some conclusions mentioned below.

The analysis of figures 5 - 8 results in the following conclusions :

1. The kind of a filter used practically does not affect final results of analysis.

2. The estimation of accuracy agrees with an assumed one within 25 % for good filters, and even for bad ones it does not exceed 80 %.

3. In the case of a bad filter we obtain a false image of the drift. But even in this case a deformation can be eliminated by using two adjustment with the use of a filter for a tidal residual between these adjustments. Results for such a case were represented in figures 5 - 8 with the dashed line.

The comparison of the figures 1 - 4 and 5 - 8 shows that the classical method gives smaller values of the indicator of quality IQ, i.e. results of analysis of this method are more consistent with the data in the model.

An interesting fact resulting from a comparison of results obtained from model 35 and the others is worth mentioning. In model 42 in main frequency bands mean square errors equal to 4, 2 and 1 µgal were generated whereas in model 34 and 32 m_o = 1 µgal in all bands. Similar results were obtained from the analysis. In model 35, however, mean square errors equal to 1 µgal were generated in all frequency bands but amplitude factors were made variable (from 0.993 to 1.007) as well as phase differences (from -0°.7 to 0°.7). From the analysis different accuracies were obtained in particular bands which, comparing with results for the other models points that variation of tidal parameters during observations is the main reason of different accuracies obtained in bands. Therefore accuracy difference in particular frequency bands may be considered the measure of calibration imperfection.

Completing comments on a new way of accuracy estimation {3} in the newest version of the classical method we give below the effect of a used filter on computation of a mean square error of a single observation and mean errors in particular frequency bands, taken into consideration in this version too.

Values of drift after filtering of observation set A equals :

$$D = A_{-n}F_{-n} + \dots + A_oF_o + \dots + A_nF_n \qquad (2)$$

The value of observation A_F after filtering will be equal to :

$$A_F = A_o - D , \qquad (3)$$

that is :

$$A_F = A_o(1 - F_o) - A_{-n}F_{-n} - \dots A_{-1}F_{-1} - A_1F_1 - \dots A_nF_n . \qquad (4)$$

An error of a raw observation A is equal to m_o, and an error of a filtered observation A_F is denoted by m_{oF}. In the analysis we adjust filtered observations, thus after adjustment we obtain m_{oF}. However, in the final estimation of accuracy we are interested in m_o. From the dependence resulting from equation (4) we obtain :

$$m_o = \frac{m_{oF}}{\sqrt{1 - 2F_o + \sum_{-n}^{n} F^2}} \qquad (5)$$

A mean square error of a single observation calculated from expansion of a residual in a Fourier series in band p,q {3} is equal to :

$$M_{o_{pq}} = \frac{w}{\sqrt{2}} \sqrt{\frac{k+1}{m} \sum_{i=p}^{q} a_i^2} \qquad (6)$$

where : k is the number of all components of the Fourier expansion, m the number of expansions components in band p,q, and a the amplitude of expansion components.

The amplitudes a in the expansion of the residual which results from the adjustment of filtered observations, are multiplied by the appropriate amplification coefficients f of the used filter. Therefore M_{oF} calculated from such values will be equal to :

$$M_{oF_{pq}} = \frac{w}{\sqrt{2}} \sqrt{\frac{k+1}{m} \sum_{i=p}^{q} a_i^2 f_i^2} . \qquad (7)$$

Dividing squares of (6) and (7) by themselves and assuming that within one band amplitudes are approximately equal, we obtain :

$$\frac{M^2_{oF_{pq}}}{M^2_{o_{pq}}} = \frac{a_i^2 \sum_{i=p}^{q} f_i^2}{m\, a_i^2} \quad , \qquad (8)$$

and then :

$$M_{o_{pq}} = M_{oF_{pq}} \sqrt{F_{pq}} \quad , \qquad (9)$$

where F_{pq} denotes :

$$F_{pq} = \frac{m}{\sum^{m} f^2_{pq}} \qquad (10)$$

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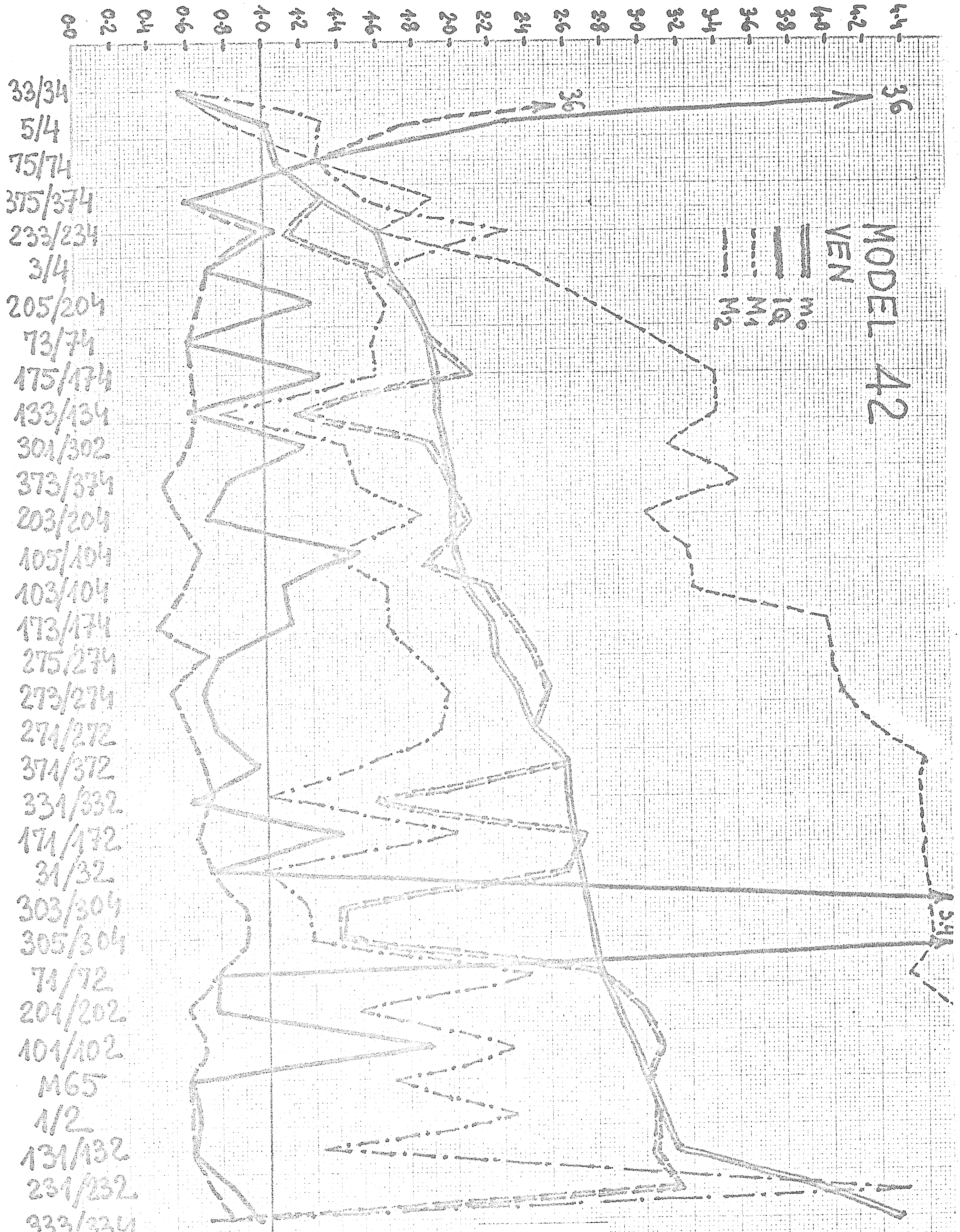
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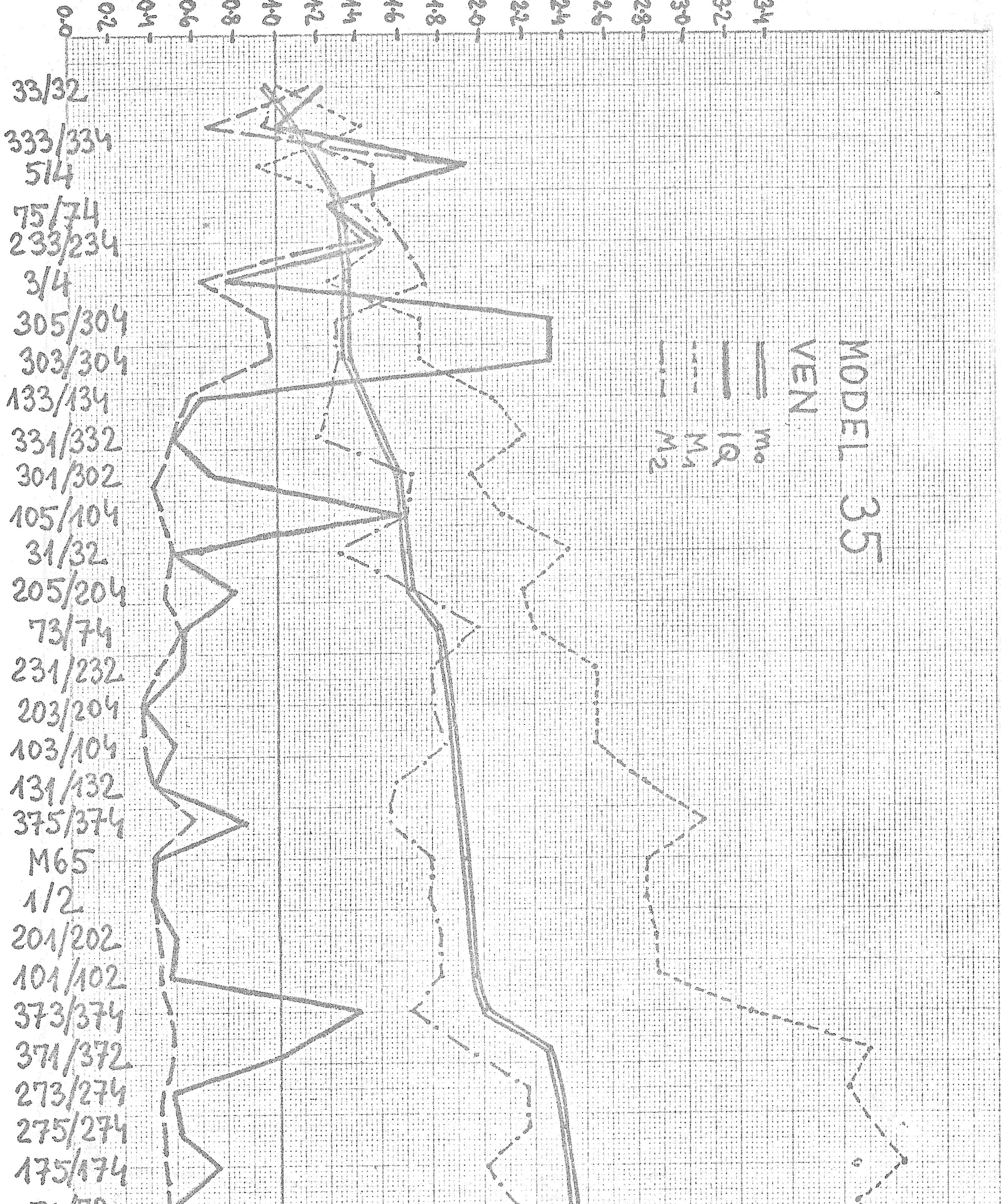
175/174
133/134
301/302
373/374
203/204
105/104
103/104
173/174
275/274
273/274
271/272
371/372
331/332
171/172
31/32
303/304
305/304
71/72
201/202
101/102
MG5
1/2
131/132
231/232
333/334
36
36
34
34
MODEL 42
VEN
m_0
m_1
M_2

Fig. 1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1.6
1.8
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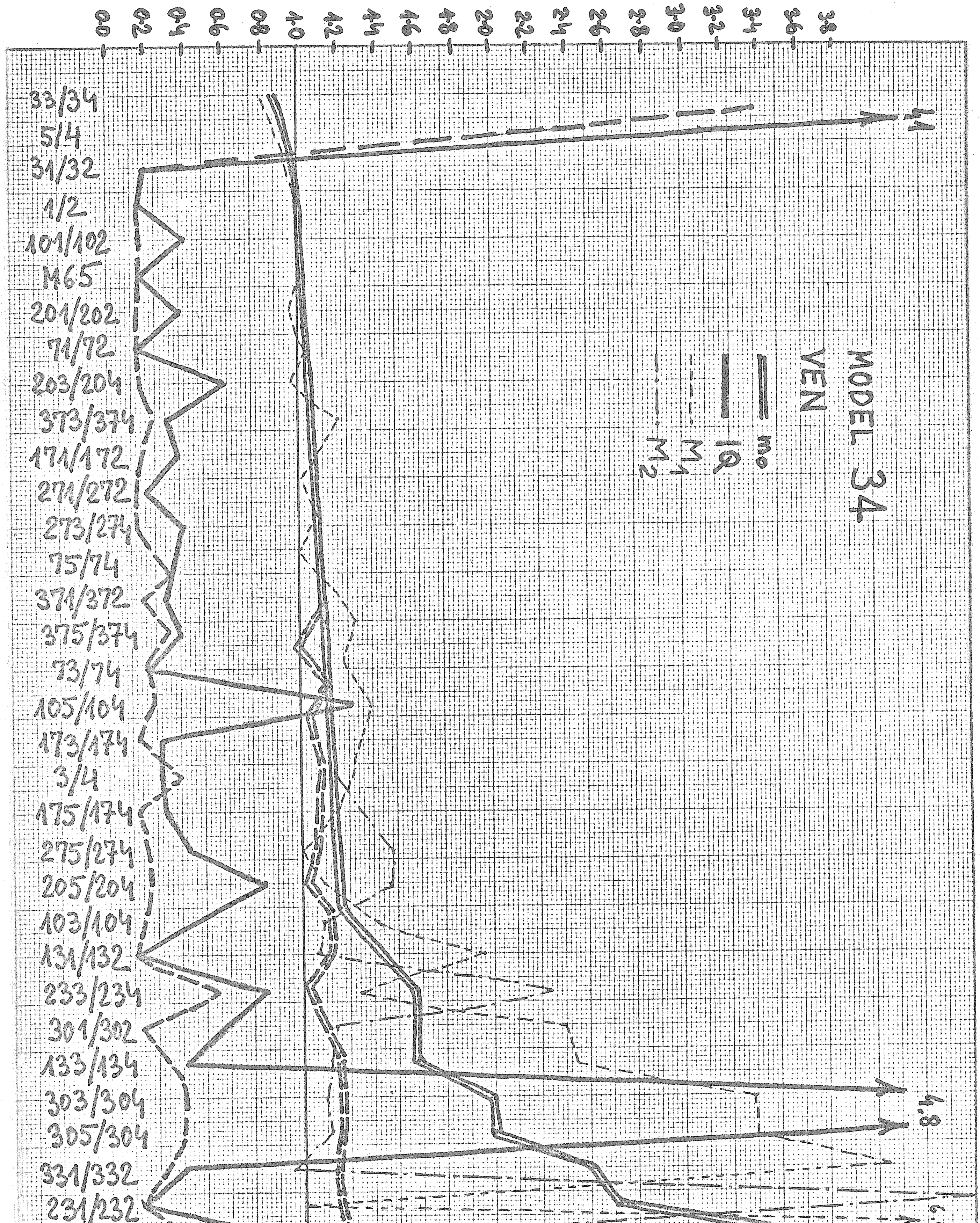
2.2
2.4
2.6
2.8
3.0
3.2
3.4
33/32
333/334
5/4
75/74
233/234
3/4
305/304
303/304
133/134
331/332
301/302
105/104
31/32
205/204
73/74
231/232
203/204
103/104
131/132
375/374
M65
1/2
201/202
101/102
373/374
371/372
273/274
275/274
175/174
71/72
171/172
271/272
173/174

Fig.2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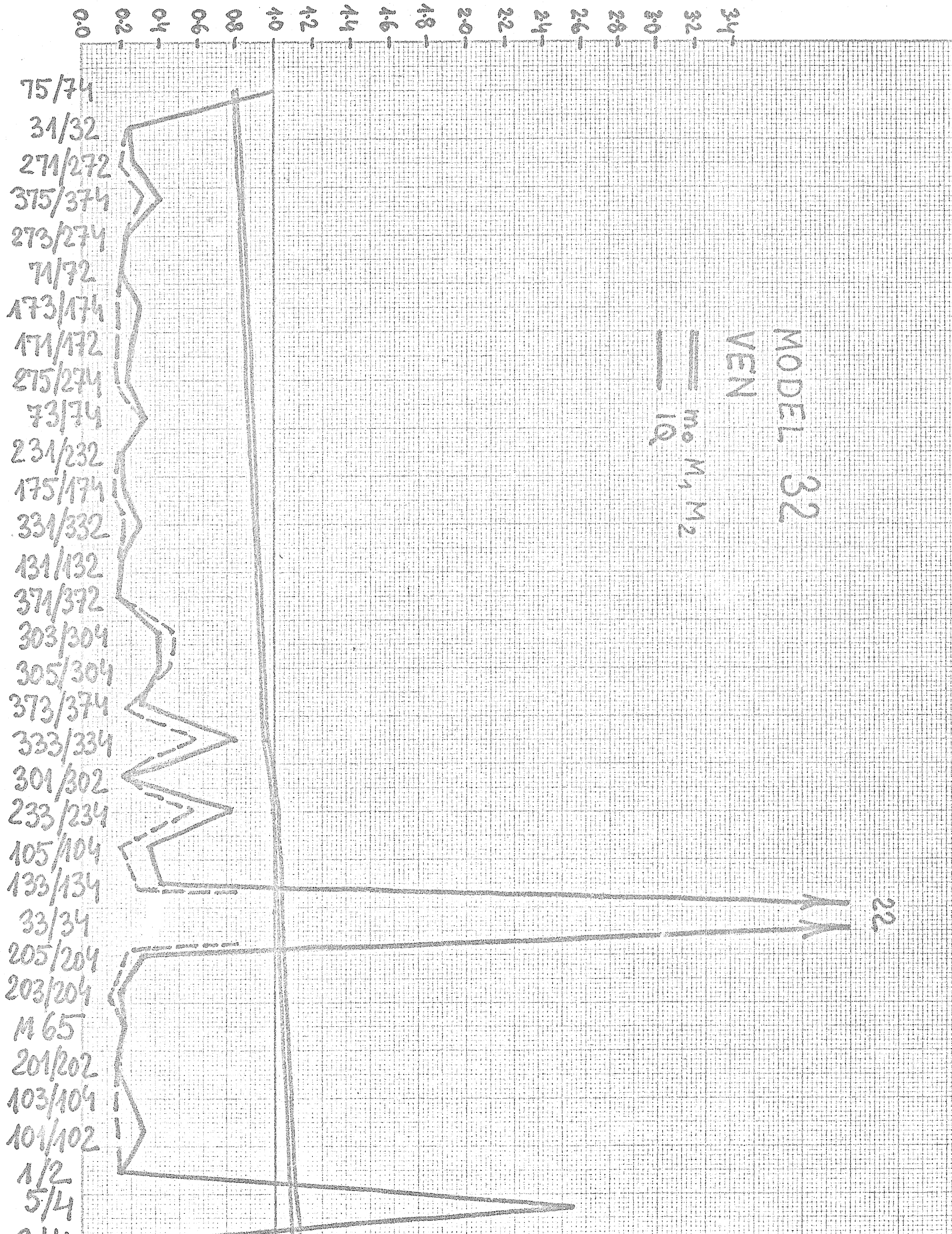
2·6
2·8
3·0
3·2
3·4
3·6
3·8
33/34
5/4
31/32
1/2
101/102
M65
201/202
71/72
203/204
373/374
171/172
271/272
273/274
75/74
371/372
375/374
73/74
105/104
173/174
3/4
175/174
275/274
205/204
103/104
131/132
233/234
301/302
133/134
303/304
305/304
331/332
231/232
333/334
MODEL 34
VEN
m0
IQ
M1
M2
41
4.8
6.58

Fig. 3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2.4
2.6
2.8
3.0
3.2
3.4
75/74
31/32
271/272
375/374
273/274
71/72
173/174
171/172
275/274
73/74
231/232
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331/332
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303/304
305/304
373/374
333/334
301/302
233/234
105/104
133/134
33/34
205/204
203/204
M 65
201/202
103/104
101/102
1/2
5/4
3/4
22
MODEL 32
VEN
m0 M1 M2
IQ

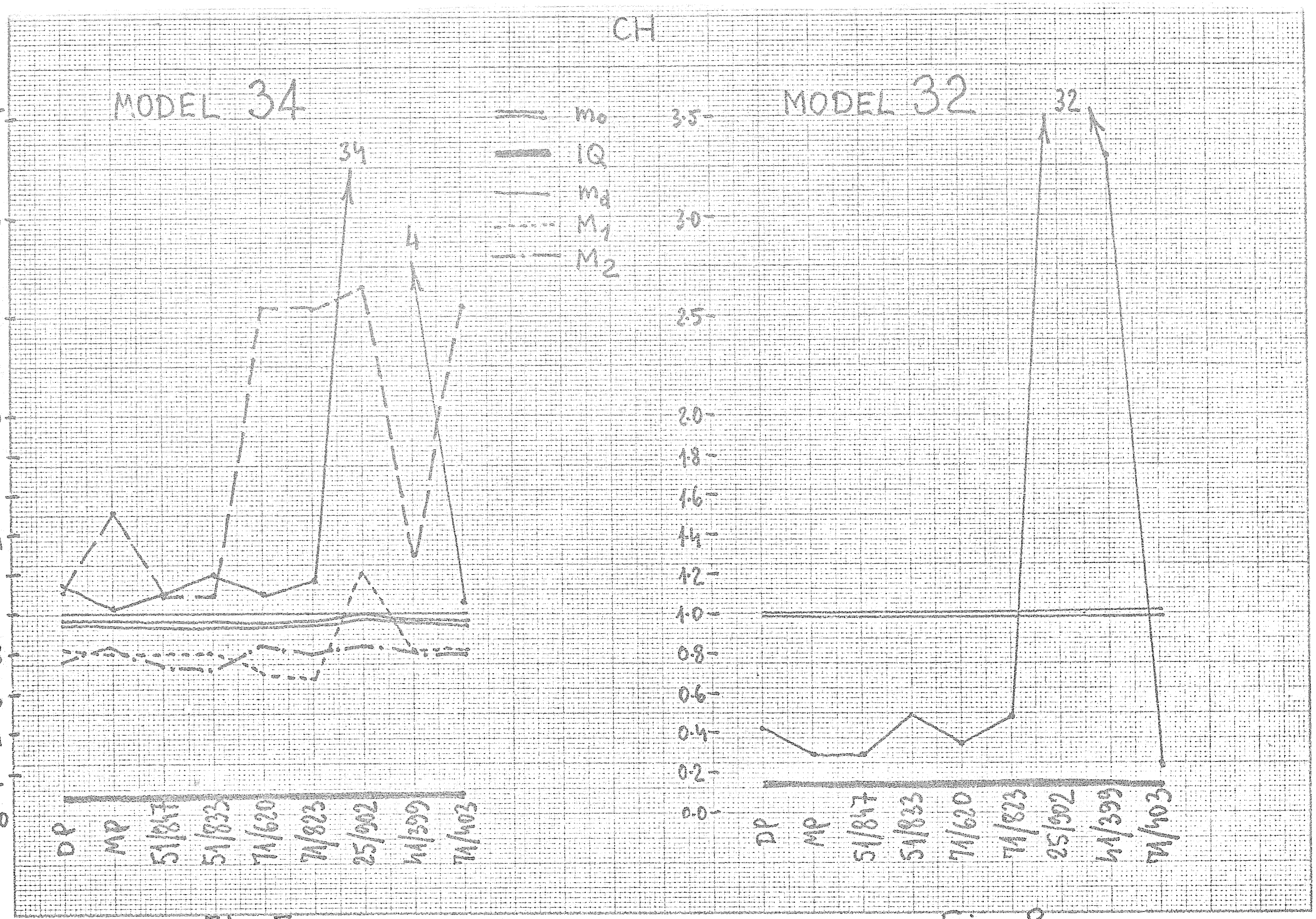
Fig.4

5009

CH

Fig. 5.

Fig. 6.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MODEL 32
34
4
32
mo
IQ
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M2
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1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DP
MP
51/847
51/833
71/620
71/823
25/902
41/399
71/403

Fig. 7.

Fig. 8

THE NYQUIST FREQUENCY AND THE SUBSTITUTION OF THE HOURLY ORDINATES BY FILTERED VALUES IN THE EARTH TIDAL ANALYSIS

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I. INTRODUCTION.

In (1,2) it is suggested to replaced the hourly ordinates of the records by some filtered values. The filters are applied on intervals with length say N hours and with a shift equal to N or greater than N if there is an interruption in the record.

In that way the Nyquist frequency becomes q = 1/2 N which is a very small number. For some values of N the tidal frequencies may be equal to a multiple of q. Thus for N = 48 we have $2\pi q = 3^\circ\!.75$ while the angular velocities of the principal tides S1 and S2 are $w_{S1} = 15°$ and $w_{S2} = 30°$ and the angular velocities of the other diurnal and semidiurnal tides are near these numbers. A worry about that circumstance was expressed in a personal discussion by Dr Zürn.

Another phenomenon related to the low value of the Nyquist frequency was discussed by Dr Schüller (3). If w_i is the angular velocity of a tide i there may be a leakage from a wave with angular velocity

$$w = w_i + 2\pi \cdot 2q \cdot k = 2\pi / N \cdot k + w_i \qquad (1)$$

where k is an integer. It has been demonstrated in (3) that artificial tides with $w = 21^\circ\!.44$ and $6^\circ\!.44$ may affect the diurnal tides, especially the tide O1. This phenomena is known as the shift of the spectrum.

Here we shall try to show that the use of a pair of filters i.e. the analysis of a pair of filtered values makes possible the determination of the Nyquist frequency and of its multiples. The preliminary use of the filters affect the leakage frequencies. There is no problem to construct them in a manner to eliminate them so that the criticism of Dr Schüller does not concern the principles of our methods. On an exemple we shall demonstrate that their elimination seems useless.

II. DETERMINATION AT THE NYQUIST FREQUENCY AND THEIR MULTIPLES THROUGH PAIRS OF FILTERED VALUES.

First of all we shall give an interpretation of the Nyquist frequency when the method of the least squares is applied.

Let us have an uninterrupted record from which we have taken, in one or another way, $n = 2\ell + 1$ equidistant ordinates, U_t $(t = -\ell, -\ell+1, \ldots \ell)$. Here t is the time measured in units of N hours, where N is the distance in hours between the consecutive ordinates. For simplicity we shall consider ℓ as an integer and n as an odd number.

We shall consider the observational equations of the form

$$U_t = \sum_{i=1}^{m} (X_i \cos w_i t + Y_i \sin w_i t) \qquad (2)$$

where each term in the parenthesis is related to a tide with angular velocity w_i and X_i and Y_i are unknowns. It is supposed that all m tides taken into account in (2) can be separated in dependance of the length of the record.

The normal equations will be of the form

$$\sum_{j=1}^{m} A_{ij} X_j = C_j \quad \text{and} \quad \sum_{j=1}^{m} B_{ij} Y_j = D_j \qquad (3)$$

$$(i = 1, 2, \ldots m)$$

where

$$A_{ij} = \sum_{t=-\ell}^{+\ell} \cos w_i t \cos w_j t = a_{ij} + b_{ij} ,$$

$$B_{ij} = \sum_{t=-\ell}^{+\ell} \sin w_i t \sin w_j t = a_{ij} - b_{ij} . \qquad (4)$$

Here

$$a_{ij} = \frac{\sin \frac{n}{2} (w_i - w_j)}{2 \sin \frac{1}{2} (w_i - w_j)} , \quad a_{ii} = n/2 \qquad (5)$$

and

$$b_{ij} = \frac{\sin \frac{n}{2} (w_i + w_j)}{2 \sin \frac{1}{2} (w_i + w_j)} \qquad (6)$$

The Nyquist frequency at the unity of time used is $q = 1/2$ and the corresponding angular velocity is $w = \pi$. When a tide has a frequency equal to a multiple of q, i.e. an angular velocity

$$w_i = k\,\pi \quad , \quad \text{then} \quad b_{ii} = n/2 = a_{ii} \tag{7}$$

and

$$B_{ii} = 0 \quad .$$

Thus the second part of the system (3) cannot be resolved and the term Y_i of the tide i remains undetermined. That is one meaning of the Nyquist frequency when the method of the least squares is used.

Let us suppose that there is another sequence V_t $(t = -\ell \ldots \ell)$ derived from the same record and function of the same waves as U_t but shifted on $\pi/2$.

The observational equations for V_t will be

$$V_t = \sum_{i=1}^{m} (-X_i \sin w_i t + Y_i \cos w_i t) \tag{9}$$

The application of the least squares method on both U_t and V_t, that is on the equations (2) and (9), will give the normal equations

$$\sum_{j=1}^{m} A'_{ij} X_j = E_j \quad \text{and} \quad \sum_{j=1}^{m} B'_{ij} Y_j = F_j \tag{10}$$

where

$$A'_{ij} = B'_{ij} = A_{ij} + B_{ij} = A_{ij} \tag{11}$$

and

$$A'_{ii} = B'_{ii} = a_{ii} = n/2$$

independently from the frequency and its relation with the Nyquist frequency.

The sequence of the filtered values is similar to U_t and V_t considered. The even filter does not modifies the phases while the odd filter shifts the phases by $\pi/2$. The difference with the equations (2) and (9) is that the amplifying factors must be included. Thus if we use the same notations for the filtered values they will be

$$U_t = \sum_{i=1}^{m} c_i (X_i \cos w_i t + Y_i \sin w_i t)$$

$$V_t = \sum_{i=1}^{m} s_i(-X_i \sin w_i t + Y_i \cos w_i t) \tag{12}$$

where c_i and s_i are the amplifying factors. As c_i and s_i are not very different the equation (11) will be satisfied with an approximation and thus practically we have an independance from the Nyquist frequency.

III. THE LEAKAGE EFFECT.

Let the angular velocity w_j be

$$w_j = w_i + 2k\pi \tag{13}$$

Then

$$\cos w_j t = \cos w_i t \quad \text{and} \quad \sin w_j t = \sin w_i t \;, \tag{14}$$

or the coefficients at X_i and X_j as well as at Y_i and Y_j in (2) and (9) are identical. Thus the separate determination of the two waves is impossible. If the wave i only remains in the equations then there will be a leakage of the wave j.

It is not just the same the case when we consider these two waves in the equations (12) of the filtered values because of the amplifying factors.

The elements corresponding to these two waves in the normal equations, with the use of the notations (4) and the equations (13) and (14), will be (considering only X_i and X_j) :

$$\begin{matrix} c_i^2 A_{ii} + s_i^2 B_{ii} & c_i c_j A_{ii} + s_i s_j B_{ii} \\ c_i c_j A_{ii} + s_i s_j B_{ii} & c_j^2 A_{ii} + s_j^2 B_{ii} \end{matrix} \tag{15}$$

The value of the determinant of these four coefficients (arranged as in (15)) is

$$A_{ii} B_{ii} (c_i s_j - s_i c_j)^2 \approx A_{ii} B_{ii} c_i (s_j - c_j)^2 \;, \tag{16}$$

as $c_i \approx s_i$. Or, when $s_j \neq c_j$, i.e. the reaction of the even filter is different from that of the odd filter to the wave j, there is not a linear dependance between the unknowns X_i and X_j. This means (i) that there is a possibility for their separation and (ii) when one of the wave is omitted in the equations (12) a certain reduction of its influence upon the other wave may be expected.

This result explains why it is possible, in the application of the method {2}, to determine the diurnal waves without a complete elimination of the semidiurnal waves. In that case a group associating all semidiurnal waves is determined together with the diurnal waves.

IV. ELIMINATION AND STUDY OF THE PRESENCE OF LEAKAGE WAVES.

Now we shall consider the effect of leakage according to Dr Schüller {3} and his conclusions.

In the previous part of the paper we have agreed with (3) that there is a danger of a leakage when the data analysed are taken over interval of N hours where N is the length of the filtered intervals. It has been shown that when these data are the filtered values a separation of the leakage waves may be possible as well as it is possible to expect a reduction of their influence. Nevertheless a leakage may exist and it must deserve our attention.

First of all we shall consider the possibilities for its elimination.

The filters used are built so that they amplify the waves of a given principal group. The waves that may cause a leakage are in relation with the amplified waves given approximately by (13) where the angular velocities are expressed in degrees per N hours. Thus the amplified waves and the leakage waves are orthogonal or nearly orthogonal. Then it must be not very difficult to slightly modify the filters so that they eliminate the leakage waves. Thus we reach a first conclusion about {3}.

1. The criticism in {3} does not concern the principles of the methods {1,2}. It simply demonstrates are effect which can be easily suppressed if it will be proved to be necessary.

It may be added that the effect of the artificial waves in {3} does not mean at all that such waves really exist in our records. Why shall we consider a wave with $w = 21^\circ.44$ and not directly a supplementary parasite wave with $w = 28^\circ.94$? In our opinion it is more constructive first to find if a perturbation really exists and then to study how it is affecting the results.

Let V be a tidal wave with angular velocity w_V. We shall denote by LV the leakage wave with angular velocity $w_V + 2\pi/N$ (these velocities are expressed in hours). We shall consider the case N = 48 which is discussed in {3} and which seems to be most sensible to a leakage. Thus the wave LO1 has an angular velocity $w_{LO1} = 13^\circ.94 + 7^\circ.5 = 21^\circ.44$ - just one of the waves in {3}.

We have modified the filters number 1 {2} for N = 48 into the filters number 13, 14, 15 and 16 that eliminates respectively LK1, LO1, LQ1 and LS2. The analysis using these filters together with the filters 1 must testify the presence or the lack of the special waves considered.

The analysis has been applied on a record of one year from the station Potsdam, gravimeter Askania GS 15/222, realized by Dr Dittfeld. In the record there are some interruptions. In order to amplify an eventual presence of the leakage waves, i.e., sooner, in order to avoid a reduction of the leakage effect from the random lengths of the interruptions, we have dropped away a small amount of data. This has been done so that each interruption is a multiple of 48 hours.

The results are presented in the tables 1 and 2. Nothing can be seen but small differences that can be perfectly explained by the mean square errors. Thus we get a second conclusion.

2. Up to now there is no evidence for the existance of any wave that may cause a leakage in the application of the methods {1,2}.

It may be objected that the analysis of one record is far not enough to make general conclusions. For that reason we begin the conclusion by the words "up to now". In addition we hope that it is understandable that we do not want to waste efforts and machine time for the study of an effect unless its presence is proved.

In conclusion we want to thank Dr Zürn for its discussion, Dr Schüller for its work upon our methods which we consider as very valuable despite the discrepancies with its conclusions and to Dr Dittfeld who provided us his high quality data.

TABLE 1

Potsdam, GS 15/222, 1.07.76 - 1.07.77, H. Dittfeld (original data modified)

Filters on 48 hours, filtered values weighed.

filters N° :	1		13		14		15		16	
tide	δ	κ	δ	κ	δ	κ	δ	κ	δ	κ
Q1	1.1640	-0.42	1.1648	-0.37	1.1650	-0.35	1.1651	-0.33	1.1654	-0.40
	66	32	67	33	69	34	70	35	67	33
O1	1.1505	-0.04	1.1507	-0.07	1.1505	-0.08	1.1503	-0.09	1.1508	-0.06
	12	6	13	6	13	6	13	7	12	6
M1	1.1153	0.33	1.1198	0.39	1.1201	0.31	1.1204	0.26	1.1199	0.42
	118	60	122	62	128	66	133	68	120	61
P1	1.1560	0.16	1.1546	0.19	1.1543	0.17	1.1541	0.16	1.1547	0.19
	22	11	23	11	25	12	26	13	23	11
S1	0.4054	135.	0.3983	142.	0.3897	149.	0.3822	154.	0.4009	141.
	1256	76.	1308	19.	1384	21.	1458	22.	1286	19.
K1	1.1387	0.06	1.1384	0.04	1.1385	0.04	1.1386	0.03	1.1384	0.05
	8	4	9	4	9	5	10	5	8	4
J1	1.1607	1.36	1.1501	0.88	1.1468	0.98	1.1447	1.04	1.1535	0.90
	165	81	173	86	188	94	199	1.00	169	84
OO1	1.1645	3.47	1.1673	3.52	1.1641	3.93	1.1622	4.22	1.1660	3.19
	385	1.94	417	2.05	462	2.27	496	2.44	404	1.98
2N2	1.2226	2.37	1.2499	2.75	1.2372	2.61	1.2322	2.56	1.2193	2.66
	184	86	247	1.14	211	98	198	93	187	88
N2	1.1776	1.95	1.1785	2.00	1.1790	2.03	1.1792	2.05	1.1789	2.07
	36	17	45	22	39	19	37	18	36	17
M2	1.1863	1.16	1.1870	1.10	1.1873	1.11	1.1874	1.12	1.1871	1.14
	6	3	7	4	7	3	6	3	6	3
L2	1.1510	2.58	1.1648	2.82	1.1629	2.76	1.1620	2.74	1.1485	2.86
	132	66	162	80	144	71	137	68	137	68
S2	1.1910	0.36	1.1920	0.35	1.1919	0.35	1.1918	0.35	1.1915	0.33
	13	6	15	8	13	7	13	7	13	7
K2	1.1852	0.11	1.1853	-0.06	1.1861	-0.07	1.1865	-0.07	1.1823	0.09
	60	29	71	35	64	31	61	30	62	30

TABLE 2

Potsdam, GS 15/222, 1.07.76 - 1.07.77, H. Dittfeld (original data modified)

Filters on 48 hours, filtered values unweighed

filters N° :	1		13		14		15		16	
tide	δ	κ	δ	κ	δ	κ	δ	κ	δ	κ
Q1	1.1667	-0.25	1.1666	-0.24	1.1669	-0.23	1.1670	-0.22	1.1668	-0.25
	74	36	74	36	76	37	78	38	74	36
O1	1.1512	0.03	1.1512	0.02	1.1511	0.00	1.1510	-0.01	1.1512	0.03
	14	7	14	7	15	7	15	7	14	7
M1	1.1219	-0.32	1.1223	-0.36	1.1222	-0.44	1.1221	-0.48	1.1213	-0.31
	134	68	136	69	143	73	148	75	134	68
P1	1.1562	0.04	1.1562	0.03	1.1561	0.01	1.1561	-0.00	1.1563	0.04
	25	12	25	13	27	13	28	14	25	12
S1	0.5951	140.	0.5950	139.	0.5775	145.	0.5598	149.	0.5946	140.
	1446	14.	1473	14.	1554	16.	1632	17.	1452	14.
K1	1.1393	0.10	1.1393	0.09	1.2394	0.09	1.1394	0.08	1.1393	0.10
	9	5	9	5	10	5	10	5	9	5
J1	1.1581	0.42	1.1558	0.41	1.1524	0.42	1.1502	0.41	1.1580	0.45
	185	92	191	95	207	1.03	219	1.09	186	92
OO1	1.1653	4.10	1.1617	4.20	1.1534	4.65	1.1482	4.96	1.1664	4.06
	448	2.20	465	2.29	514	2.55	551	2.75	451	2.22
2N2	1.2331	2.05	1.2505	1.51	1.2390	1.67	1.2345	1.74	1.2321	2.08
	212	98	266	1.22	230	1.06	217	1.01	212	98
N2	1.1770	2.15	1.1754	2.07	1.1761	2.12	1.1764	2.15	1.1770	2.14
	41	20	50	24	44	21	42	20	42	20
M2	1.1871	1.12	1.1869	1.10	1.1871	1.11	1.1872	1.12	1.1872	1.12
	7	3	8	4	7	4	7	3	7	3
L2	1.1552	2.81	1.1601	2.97	1.1604	2.91	1.1605	2.88	1.1536	2.76
	158	78	179	89	161	80	154	76	160	80
S2	1.1916	0.39	1.1918	0.43	1.1917	0.42	1.1916	0.42	1.1917	0.40
	15	8	16	9	15	8	14	8	15	8
K2	1.1891	0.09	1.1894	0.07	1.1892	0.05	1.1891	0.04	1.1891	0.09
	72	35	79	38	72	35	69	33	73	35

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SIMULTANEOUS ANALYSIS OF DIFFEFENT EARTH TIDAL RECORDS

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I. INTRODUCTION

For the geophysical interpretation we have to deal with different instruments, in different epochs, in different stations and any possible combination of these cases. Among them the case "different stations" is the most important for the geophysical purposes.

Such a situation which in fact must be the usual situation raises two problems of the data processing : (i) to get global estimates of the tidal parameters for all records and (ii) to study the differences between the estimates relative to each individual record.

The solution now used is : (i) to take a mean of the individual estimates and (ii) to test the differences of each couple of records and of each individual estimate with the mean. A disadvantage is that the mean is based upon a small number of observations as one record is only one observation and that its estimation of precision is based upon a few degrees of freedom.

We suggest here (i) to process a simultaneous analysis (SA) of all records as if it is a single record and (ii) to apply the method of analysis of variance (AV) which can reveal the significance of the differences in a set of records.

On that occasion we would like to underline once again the great practical advantages of the use of the method of the least squares in addition to its deep theoretical ground. The realization of a SA and of an AV for our purpose is a simple question of a suitable choice of the unknowns in one or another variant. In addition the AV in principle is based upon the method of the least squares.

In our opinion we have here once again a demonstration that the power spectrum analysis, an excellent method when the spectrum is unknown, is not convenient for us. For its application we shall have to look for solutions of the problems : gaps between the records, partial overlaps, variations of the amplitudes and the phases in the different stations. We shall have still to search the equivalent notions of the sum of squares, the degrees of freedom and of the statistical criteria used in the AV.

II. SIMULTANEOUS ANALYSIS.

For a SA we must set up that the tidal parameters, say δ and κ are the same for all record. For that purpose the classical unknowns related to amplitudes and phases are not suitable, as they are different in the different stations.

On the contrary the unknowns

$$\xi = \delta \cos \phi \qquad \text{and} \qquad \eta = -\delta \sin \phi, \tag{1}$$

suggested in {1,2}, make no problem for the practical realization of such a condition.

In the program {3} for the application of {2} we have presumed the option of a SA based upon the use of (1). However this option was a quite limited one from the restricted computing facilities at the time. It seems that it has not been used.

The use of (1) and the method of the least squares reduces the SA to an addition of the normal equations relative to the individual records and to the resolution of the new system of normal equations so obtained. In such a way we may process simultaneously the individual analysis of each record as well as the SA of all records. The only problem is that the lengths of the individual records may be different between them and different with the length of the global record realized through the addition of the records. Thus we may have different variants of grouping of the waves. We shall see that this is a simple practical problem.

In the program SVETLA we apply at Sofia as well as in its variant we have developed at ICET, Bruxelles with Dr. Ducarme we have a much more flexible option for the SA than in {3}.

A part S_1 of the storage of the computer is used for the composition and the resolution of the normal equations of each record. When the analysis of a record is over, the normal equations are transfered into another part S_2 of the storage, together with a sum of squares and the degrees of freedom necessary for the AV. The results from S_1 are printed and then it is used for the analysis of the next record.

In S_2 we have an accumulation so that after the last record we have the normal equations for the SA together with the elements necessary for the determination of the mean square errors and for the AV. Then the information from S_2 is transfered to S_1 where the analysis is processed just as of the individual records. A few additional computations are realized and the results are printed with a convenient modification of the format.

The problem of the difference of the grouping between the records and between them and the global record is overgone in the following manner.

In SVETLA the observational equations as well as the normal equations are initially composed relatively to the most detailed grouping. Thus these equations may be linearily dependent if the record is somewhat short. However this is not an obstacle for their composition but for their solution. For the resolution the normal equations are compressed {4} through a convenient addition of the rows and of the columns. The transfer from S_1 in S_2 is realized before the compression as well as the transfer of S_2 into S_1. Thus we may process the analysis of each record as well as the SA under a whatever grouping we want.

SVETLA is designed for the application of the method {5} in which a weighing of the observations, i.e. of the filtered values is presumed. This does not implies difficulties for the computation. In the same time the weights used are not correct having in mind the rigorous definition. They reflect the variation of the level of the white noise as well as the appearence of some errors but not entirely the real noise. For that reason they may be used for the analysis of a record obtained by one instrument and of records obtained by similar instruments. When records obtained by very different instruments are used it is dangerous that the weights will not reflect the real relation of their quality. That is why in SVETLA we have the option when transfering from S_1 to S_2 the equations to be divided by a mean value of the weights as well as an analysis of unweighed filtered values.

The proof that the equations for the SA are the sum of the equations for the individual analysis is a rather trivial one. However we shall give it in order to introduce the designations necessary for the AV. For a simplification we shall use here a unification of the designations though it is not very practical for programming.

We shall denote by a vector column $\underline{X}$ the set of all unknowns ξ and η relative to the grouping for the SA. We shall accept that this grouping is coinciding with the most detailed grouping in the program and this simplification does not affect the generality. By m we shall denote the number of all unknowns in $\underline{X}$, i.e. m is equal to twice the number of the groups in the SA.

Let us have R records and let $\underline{U}_r$ be the vector column composed of all observations in the r-th record, i.e. of all filtered values obtained through both the even and odd filters. We have in mind only the set of observations relative to one of the principal groups of waves, i.e. diurnal, semi-diurnal, terdiurnal or long period waves. We shall denote by N_r the number of the observations in $\underline{U}_r$, i.e. N_r is equal to twice the number of the filtered intervals.

The more general assumption about the unknowns $\underline{X}$ is that they are different for the different records. If $\underline{X}_r$ are their values for the r-th record in the general case we have

$$\underline{X}_1 \neq \underline{X}_2 \neq \dots X_R \qquad (2)$$

For that assumption we have to compose the equations of observations $\underline{U}_r$ separately for each r. Let these equations have the following general form

$$\underline{U}_r = \underline{\underline{A}}_r \cdot \underline{X}_r \qquad (r = 1, 2, \dots R) \qquad (3)$$

where $\underline{\underline{A}}_r$ is an $N_r \times m$ matrix. The normal equations will be

$$\underline{\underline{A}}_r^* \underline{U}_r = \underline{\underline{A}}_r^* \underline{\underline{A}}_r \cdot \underline{X}_r \qquad (r = 1, 2, \dots R) \qquad (4)$$

where * means the transposition of a matrix. Still in the general case the grouping of the record r may be different from the grouping in the SA, i.e. the number of the unknowns may be $m_r \neq m$. Then the vector $\underline{X}_r$ in the observational equations may be replaced by a vector $\underline{Y}_r$ composed of m_r unknowns, and the matrix $\underline{\underline{A}}_r$ by a matrix $\underline{\underline{B}}_r$ with dimensions $N_r \times m_r$. Thus the observational equations will be

$$\underline{U}_r = \underline{\underline{B}} \cdot \underline{Y}_r \qquad (5)$$

and the normal equations will be

$$\underline{\underline{B}}_r^* \underline{U}_r = \underline{\underline{B}}_r^* \underline{\underline{B}}_r \cdot \underline{Y}_r \qquad (6)$$

For our practical aim it is important that the vector $\underline{\underline{B}}_r^* \underline{U}_r$ and the matrix $\underline{\underline{B}}_r^* \underline{\underline{B}}_r$ may be easily obtained from the corresponding elements of the equations (4).

A less general assumption about the unknowns than (2) is to suppose that they do not change with the records i.e. to make the hypothesis that

$$\underline{X}_1 = \underline{X}_2 = \ldots\ldots \underline{X}_R = \underline{X} \qquad (7)$$

Then instead of R different sets of observational equations (3) we shall have one single set unifying all equations i.e.

$$\underline{U}_r = \underline{\underline{A}}_r \cdot \underline{X} \qquad (r = 1, 2, \ldots R) \quad . \qquad (8)$$

The essential difference between (8) and (3) is that in (8) $\underline{X}$ is the same for all records and the solution of all equations should be realised simultaneously. If we denote

$$N = \sum_{r=1}^{R} N_r \qquad (9)$$

and by $\underline{U}$ an N x 1 vector column and by $\underline{\underline{A}}$ an N x m matrix which are defined as follows

$$\underline{U} = \left\| \begin{matrix} \underline{U}_1 \\ \underline{U}_2 \\ \vdots \\ \underline{U}_R \end{matrix} \right\| \qquad \underline{\underline{A}} = \left\| \begin{matrix} \underline{\underline{A}}_1 \\ \underline{\underline{A}}_2 \\ \vdots \\ \underline{\underline{A}}_R \end{matrix} \right\| \qquad (10)$$

then (8) may be written as the matrix equation

$$\underline{U} = \underline{\underline{A}} \cdot \underline{X} \qquad (11)$$

from where we get the normal equations in a matrix form

$$\underline{\underline{A}}^{*} \underline{U} = \underline{\underline{A}}^{*} \underline{\underline{A}} \cdot \underline{X} \qquad (12)$$

Having in mind (10) we see that

$$\underline{\underline{A}}^{*} \underline{U} = \sum_{r=1}^{R} \underline{\underline{A}}_r^{*} \underline{U}_r \quad \text{and} \quad \underline{\underline{A}}^{*} \underline{\underline{A}} = \sum_{r=1}^{R} \underline{\underline{A}}_r^{*} \underline{\underline{A}}_r \qquad (13)$$

Or the elements of the normal equations (12) for the SA are the sum of the corresponding elements of the individual normal equations (4) composed for the detailed grouping.

III. ANALYSIS OF VARIANCE.

Descriptions of the AV, of its theory and applications, may be found in many books on mathematical statistics, for instance in {6}. It is based on the comparison of the sums of squares of residuals obtained by the method of the least squares obtained (i) when a given hypothesis about the unknowns is made and (ii) without this hypothesis.

The degrees of freedom f of a sum of squares is the number of independent squares by which the sum may be represented. For a sum of squares obtained by the method of the least squares f is equal to the difference between the number of the observations and the number of the unknowns.

If R_1 is the sum of squares for the case (i) with $f = f_1$ and R_o is the sum of squares for the case (ii) with $f = f_2$, the AV is based upon the determination of the Fisher criterion

$$F = \frac{R_1 - R_o}{f_1 - f_o} \Big/ \frac{R_o}{f_o} \qquad (14)$$

which has the distribution of Snedecor or F - distribution with $f_1 - f_o$ and f_o degrees of freedom.

We intend to apply the AV in order to verify whether in our set of R records we have essential differences between the tidal parameters. We shall make the hypothesis that there are not differences, it is that the equation (7) is satisfied.

The equation (7) brings us to the equation (12) from where

$$R_1 = \underline{U}^* \underline{U} - \underline{X}^* \underline{\underline{A}}^* \underline{U} \qquad \text{and} \qquad f_1 = N - m \qquad (15)$$

When this hypothesis is not made we have the general case (2). It brings us to a set of R equations (6) each one relative to one of the records. From each of them we obtain a sum of squares

$$R_{or} = \underline{U}_r^* \underline{U}_r - \underline{Y}_r^* \underline{\underline{B}}_r^* \underline{U}_r \qquad \text{with} \qquad f_{or} = N_r - m_r \qquad (16)$$

degrees of freedom.

The sum R_o will be

$$R_o = \sum_{r=1}^{R} R_{or} \quad \text{with} \quad f_o = \sum_{r=1}^{R} f_{or} = N - \sum_{r=1}^{R} m_r \qquad (17)$$

The elements $\underline{U}_r^* \underline{U}_r$ necessary for the calculation of (15) and R_{or} with f_{or} necessary for the determination of (17) are stored in the storage S_2 when the analysis of the r-th record is over.

With the sums of squares and the degrees of freedom determined we obtain F_o after (14). If the hypothesis is not true and we have greater discrepancies between the parameters of the records we must expect greater values of F_o. On the contrary, if the hypothesis is not true, we must have less important values of F_o.

In the last case F_o must have the mentioned F - distribution. For a given fiducial probability P we may found from a table a value $F_c = F_c$ (P, $f_1 - f_o$, f_o) such that the probability for

$$F_o > F_c \quad \text{is} \quad a = 1 - P \ , \qquad (18)$$

where a is often called level or degree of significance. In such a way a is the probability to make an error if we reject a true hypothesis, in our case if we take a decision that there are significant differences between the parameters of the records when this is not true. It is reasonable to choose a somewhat small value, for instance $a = 0.05 = 5$ % as it is usually done.

So the AV is achieved with the determination of F_o and its comparison with a critical value F_c. If $F_o > F_c$ we may conclude that there are important (significant) differences between the parameters of the records.

IV. EXEMPLES OF SIMULTANEOUS ANALYSIS AND ANALYSIS OF VARIANCE.

We shall give two exemples. The results quoted are to be considered as preliminary. *They are not designed to be used for geophysical purposes* but as illustrations of the methods suggested.

In table 1 are presented the δ factors of four waves obtained from the individual analysis and the SA of four records. They are realized by Prof. Bonatz in four different stations with one same gravimeter. Each record as a length about 100 days.

The critical values F_c determined for a level of significance $a = 0.05 = 5\ \%$ and for the degrees of freedom in the table are (taken from {7})

$$F_c = 1.39 \quad \text{for the diurnal tides}$$

and

$$F_c = 1.46 \quad \text{for the semidiurnal tides.}$$

In the both cases there is $F > F_c$, i.e. we have significant or systematical differences between the four stations.

We have analysed four records obtained in the station Potsdam by one gravimeter by Dr Dittfeld. Some of the results are given in the table 2. Each record has a length of about 1 year. The internal precision of the records may be estimated as a very high one.

The critical values F_c are close to those given above. Here again we have $F > F_c$ or it may be concluded that there are significant differences between the four records.

V. STUDY OF THE VARIATION OF THE TIDAL PARAMETERS WITH TIME AND INDIVIDUAL ESTIMATION OF THE PRECISION OF THE PRINCIPAL TIDES.

In the program SVETLA there is the option to divide the record analysed into short pieces. Each one of them is analysed individualy and then the analysis of the whole record is obtained as a SA of all pieces.

There are two ways to realize the division of the record : (i) giving at the input the dates of interruptions that define the pieces and (ii) by the definition of the length of one piece. In that way we may get the tidal parameters as functions of time. When the record is long enough and when we have many pieces we may estimate the precision of each of the principal wave individually. The determination of a parameter from one piece is accepted as one observation and the estimation of the precision is reanalysed as in the classical case of direct observations.

In the table 3 such an analysis is given for a very large record in the station Dourbes 1. In that case each piece of the record has 360 days observations. It is evident that from such a table the mean square errors can be easily calculated for each wave and it is easy to study the variation of the tidal parameters with the time.

In the treatment of that important serie we have met some difficulties that are still not overgone. That is why we have not succeeded in the SA and the mean square errors are not presented.

The SA and the AV here discussed have been worked out in a collaboration with H. Dittfeld, Zd. Simon, P. Varga and V. Volkov in relation with the simultaneous observations in Pecny.

In conclusion we want to thank Prof. Melchior, Prof. Bonatz and Dr. Dittfeld for providing us the data here used.

TABLE 1 Profile measurements, GS 15/206, M. Bonatz

Station	O1	K1	M2	S2
Bonn 1	1.1669 68	1.1232 46	1.1959 29	1.2279 51
Walferdange	1.1496 37	1.1454 28	1.1905 18	1.1991 29
Bruxelles	1.1753 85	1.1692 58	1.1936 25	1.2442 48
Strasbourg	1.1475 35	1.1355 22	1.1901 25	1.1993 49
SA	1.1617 33	1.1480 23	1.1923 13	1.2177 23
F	3.2		5.1	
degrees freedom	42 / 496		30 / 512	

TABLE 2 Potsdam GS 15/222, H. Dittfeld

Epoch	O1	K1	M2	S2
21.03.74-15.12.74	1.1558 12	1.1367 9	1.1890 6	1.1871 12
21.06.75-29.06.76	1.1522 12	1.1444 8	1.1898 5	1.1946 10
2.07.77-29.06.78	1.1528 13	1.1417 8	1.1889 5	1.1920 10
1.07.76- 1.07.77	1.1517 12	1.1392 8	1.1877 5	1.1921 10
SA	1.1534 6	1.1405 4	1.1889 3	1.1911 5
F	5.5		5.6	
degrees freedom	54 / 1558		36 / 1582	

TABLE 3 Dourbes 1 NS, Pendulum VM 7, P. Melchior, A. Vandewinkel

EPOCH	O1	K1	M2	S2
8.03.63- 3.03.64	0.8854 388	0.4927 245	0.4477 20	0.5303 40
4.03.64-28.02.65	0.8744 282	0.5341 202	0.4431 20	0.5463 37
23.05.66-23.05.67	0.8588 248	0.5192 172	0.4372 15	0.5417 27
23.05.67- 2.06.68	0.8107 241	0.5198 169	0.4333 18	0.5391 32
3.06.68-30.05.69	0.7689 301	0.5143 233	0.4346 21	0.5267 33
30.05.69-26.05.70	0.8622 310	0.4983 213	0.4388 20	0.5329 37
27.05.70- 5.06.71	0.8767 251	0.4845 174	0.4371 19	0.5258 33
6.06.71-27.06.72	0.7903 251	0.4798 174	0.4281 18	0.5299 34
27.06.72- 1.07.73	0.8378 259	0.5692 190	0.4366 19	0.5255 35
2.07.73- 1.07.74	0.8367 267	0.5189 178	0.4376 21	0.5288 41
1.07.74-27.06.75	0.7424 346	0.5243 227	0.4335 45	0.5259 88
28.06.75-31.12.76	0.8408 268	0.5108 172	0.4494 12	0.5384 23

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Time Variant Tidal Estimators - Design and Interpretation As Performed In The HYCON-Method

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Abstract: Time variant tidal parameter functions as derived from the HYCON-Method (Schüller 1976,1977a,b,1978) are reviewed for interpretational purposes. A detailed study on the interactions of model waves and perturbation processes leads to a normalized spectrum of coherent perturbation energies for the tidal wavegroups. By means of this spectrum additional signals, which may exhibit energy in the tidal frequency domains may be uniquely located as well as possible modulations on the tidal constituents.

1. Derivation of time variant tidal parameter functions

A detailed presentation how to derive time variant tidal parameter functions is given in SCHÜLLER 1976,1977a,b, so that the main results will only be summarized here.

Given a record of N hourly sampled tidal observations which is supposed to have no gaps. Let us define a basic interval of length n (n<<N) which allows for a desired resolution of tidal wave groups. If we now shift this basic interval over the total record by an constant displacement ΔT and relate to each shifting the set of estimated auxilary tidal unknowns $x_i^c = \delta_i \cos\kappa_i$ and $x_i^s = \delta_i \sin\kappa_i$ of the tidal admittances δ_i and phase shifts κ_i, we obtain the so called empirical parameter functions

$$x_i^c = x_i^c(T) \; ; \; x_i^s = x_i^s(T) \qquad (1.1)$$

which are now functions of the central time $T = T_o + k\Delta T$ and refer to the center of each shifted interval ($k = 0,1\ldots\frac{N-n}{\Delta T}$).

All values of $x_i^c(T)$, $x_i^s(T)$ are estimated by the ordinary least squares technique where the Hanning window is introduced (SCHÜLLER 1977a) to reduce leakage effects and consequently to allow for a lower sampling rate in T, i.e. for larger displacements ΔT. The relation between the basic interval length n and ΔT was found to be

$$\Delta T \leq \frac{\pi}{\omega_c} \qquad (1.2)$$

where ω_c is the cut off frequency of the spectral window $D(\omega)$. For the Hanning window $\Delta T \leq \frac{n}{16}$ has been derived from (1.2).

As the functional model assumes δ_i and κ_i to be constant with time (what is reasonable for the pure body tide) all time variations may then be interpreted as interactions between the body tide model waves and a perturbation process z(t) 1)++. The properties of z(t) will be discussed in the next section. For the moment it is to state that z(t) causes departures from the expected constants x_{io}^c and x_{io}^s of $x_i^c(T)$ and $x_i^s(T)$ respectively, so that the solution vector becomes

$$\underline{x}(T) = \underline{x}_o(T) + \Delta\underline{x}(T) \qquad (1.3)$$

2. What makes the parameter functions vary with time?

Time variations of the parameter functions, defined in the previous section can be thought to be generated by mainly two interactions of a perturbation process z(t) (z(t) may contain both deterministic and random signals).

a) Additive superimposition

so that the observations can be written as

$$y(t) = y_o(t) + z(t) \qquad (2.1)$$

b) Modulation

$$y(t) = y_o(t) \cdot \bar{z}(t) \qquad (2.2)$$

++ 1) The notation 'perturbation process' is carefully to be taken because here perturbation is meant with respect to the body tide signal. Hence, all signals contained in a tidal record which are no body tides will be considered in this sense as perturbation z(t).

However, as modulation of $y_o(t)$ by $\bar{z}(t)$ means a spreading of the tidal lines, modulation may be subsummed to additive superimposition. Nevertheless, it will later be shown that we can distinguish between events, either related to (2.1) or (2.2).

With respect to $\Delta\underline{x}$ in (1.3), the analytical expression is

$$\Delta\underline{x}(T) = \underline{N}^{-1}(T)\Delta\underline{w}(T) \qquad (2.3)$$

where $\underline{N}(T)$ is the normal equation matrix associated with the solutions for the shifted intervals and $\Delta\underline{w}(T)$ is the corresponding additional absolute vector due to $z(t)$. Hence, we have to investigate the elements of $\underline{N}(T)$ and $\Delta\underline{w}(T)$, what is done in the next section.

3. Evaluation of $\Delta\underline{x}(T)$ in terms of $\underline{N}(T)$ and $\Delta\underline{w}(T)$.

Let

$$\alpha_i(t) = \sum_{j=1}^{u_j} A_{ij}\cos(\omega_{ij}t+\varphi_{ij})$$

and

$$\beta_i(t) = -\sum_{j=1}^{u_j} A_{ij}\sin(\omega_{ij}t+\varphi_{ij}) \qquad (3.1)$$

$$(i = 1,2...u)$$
$$(j = 1,2...u_i)$$

be the theoretical in- and out-of-phase signals for the u tidal wave groups. Then, the elements of the normal equation matrices $\underline{N}(T)$ may be written as energies and cross energies of $\alpha_i(t)$ and $\beta_i(t)$:

$$E_{ij}^{\alpha\alpha}(T) = \sum_{\bar{t}}\alpha_i(\bar{t}+T)\alpha_j(\bar{t}+T)d(\bar{t}) \approx E_{ij}^{\beta\beta}$$

$$\approx \frac{n}{2}\sum_k\sum_l A_{ik}A_{jl}D(\Delta\omega_{ikjl})\cos(\Delta\omega_{ikjl}T+\Delta\varphi_{ikjl}) \qquad (3.2)$$

$$(\bar{t} = \frac{-n+1}{2}, \;.....,\frac{n-1}{2})$$
$$(k,l = 1,..., u_i)$$

where $d(t)$ and $D(\omega)$ are the windows in the time and frequency domains, $\Delta\omega_{ikjl} = \omega_{ik}-\omega_{jl}$, and $\Delta\varphi_{ikjl} = \varphi^o_{ik}-\varphi^o_{jl}$; the phases φ^o refer to the first central time point T_o in absolute time t.

Furthermore,

$$E_{ij}^{\alpha\beta} = \sum_{\bar{t}} \alpha_i(\bar{t}+T)\beta_j(\bar{t}+T)d(\bar{t})$$

$$\approx \frac{n}{2} \sum_k \sum_l A_{ik}A_{jl}D(\Delta\omega_{ikjl})\cos(\Delta\omega_{ikjl}T+\Delta\varphi_{ikjl}+\frac{\pi}{2}) \qquad (3.3)$$

Note, that $E_{ii}^{\alpha\beta} \approx 0$.

For the evaluation of $\Delta\underline{w}$ we assume the perturbation $z(t)$ to be expanded into Fourier series over the total record. Then, the elements of $\Delta\underline{w}$ may be written in an analogue manner to (3.2) and (3.3) as

$$\Delta w_i^c(T) = E_i^{\alpha z}(T) = \sum_{\bar{t}} \alpha(\bar{t}+T)z(\bar{t}+T)d(\bar{t})$$

$$\approx \frac{n}{2} \sum_j \sum_m A_{ij}A_m^z D(\Delta\omega_{ijm})\cos(\Delta\omega_{ijm}T+\Delta\varphi_{ijm}) \qquad (3.4)$$

and

$$\Delta w_i^s(T) = E_i^{\beta z}(T) = \sum_{\bar{t}} \beta(\bar{t}+T)z(\bar{t}+T)d(\bar{t})$$

$$\approx \frac{n}{2} \sum_j \sum_m A_{ij}A_m^z D(\Delta\omega_{ijm})\cos(\Delta\omega_{ijm}T+\Delta\varphi_{ijm}+\frac{\pi}{2}) \qquad (3.5)$$

To illustrate the situation let us evaluate $\Delta\underline{x}$ of (2.3) for two frequency bands:

$$\Delta\underline{x} \approx \begin{bmatrix} E_{11}^{\alpha\alpha}(T), & 0, & E_{12}^{\alpha\alpha}(T), & E_{12}^{\alpha\beta}(T) \\ 0 & E_{11}^{\beta\beta}(T), & E_{21}^{\alpha\beta}(T), & E_{12}^{\beta\beta}(T) \\ E_{12}^{\alpha\alpha}(T), & E_{21}^{\alpha\beta}(T), & E_{22}^{\alpha\alpha}(T), & 0 \\ E_{12}^{\alpha\beta}(T), & E_{12}^{\beta\beta}(T), & 0, & E_{22}^{\beta\beta}(T) \end{bmatrix}^{-1} \begin{bmatrix} E_1^{\alpha z}(T) \\ E_1^{\beta z}(T) \\ E_2^{\alpha z}(T) \\ E_2^{\beta z}(T) \end{bmatrix} \qquad (3.6)$$

For the inversion of $\underline{N}(T)$ we make use of the fact that the diagonal elements are dominant if basic record length n is chosen appropriately with respect to the desired resolution of the tidal wave groups and the spectral Hanning window (SCHÜLLER 1976,1977b). Hence, we can expand $\underline{N}^{-1}(T)$ into a Neumann's series (WOLF 1968):

$$\underline{N}^{-1}(T) = (\underline{N}_o(T)+\Delta\underline{N}(T))^{-1}$$
$$\approx \underline{N}_o^{-1}(T)-N_o^{-1}(T)\Delta\underline{N}(T)N_o^{-1}(T) \qquad (3.7)$$

with $\underline{N}_o(T) = \mathrm{diag}(\underline{N}(T))$.

Finally we end up for the elements of $\Delta\underline{x}$, e.g. $\Delta x_1^c(T)$ and $x_1^s(T)$:

$$\Delta x_1^c(T) \approx \frac{E_1^{\alpha z}(T)}{E_{11}^{\alpha\alpha}(T)} - \frac{E_{12}^{\alpha\alpha}(T)}{E_{11}^{\alpha\alpha}(T)E_{22}^{\alpha\alpha}(T)}E_2^{\alpha z}(T) - \frac{E_{12}^{\alpha\beta}(T)}{E_{11}^{\alpha\alpha}(T)E_{22}^{\beta\beta}(T)}E_2^{\beta z}(T)$$

$$(3.8)$$

$$\Delta x_1^s(T) \approx \frac{E_1^{\beta z}(T)}{E_{11}^{\beta\beta}(T)} - \frac{E_{21}^{\alpha\beta}(T)}{E_{11}^{\beta\beta}(T)E_{22}^{\alpha\alpha}(T)}E_2^{\alpha z}(T) - \frac{E_{12}^{\beta\beta}(T)}{E_{11}^{\beta\beta}(T)E_{22}^{\beta\beta}(T)}E_2^{\beta z}(T)$$

4. Definition of the BMW- and MCMW estimator for the generation of parameter functions

As may be concluded from (3.1), all constituents of the Cartwright-Edden development (Cartwright, Edden 1973) are involved with the estimator for the set of parameter functions (1.3) and hence it is related to tidal frequency bands. Interpreting the shifting of the basic interval as a moving window operation, we shall refer to that estimator as 'Band Moving Window' (BMW) estimator. However, there is one serious difficulty for a unique interpretation of the BMW-parameter functions. As a consequence of (3.8), only the first term in that equation is of importance provided the window is carefully chosen:

$$\Delta x_i^c(T) \approx \frac{E_i^{\alpha z}(T)}{E_{ii}^{\alpha\alpha}(T)} \quad ; \quad \Delta x_i^s(T) \approx \frac{E_i^{\beta z}(T)}{E_{ii}^{\beta\beta}(T)} \qquad (4.1)$$

In order to relate the time variations uniquely to the influence of z(t), the denominators $E_{ii}^{\alpha\alpha}(T) \approx E_{ii}^{\beta\beta}$ in (4.1) must be constant with time. This, however, is not true when grouping tidal bands with several constituents of similar energy contribution. To overcome this difficulty, one can make use of the fact that the body tide admittances and phase shifts are fairly well known ($\delta \simeq 1.160$, $\gamma \simeq 0.687$, $\kappa \simeq 0$). Then, we can evaluate the predicted body tides for all constituents of a tidal wave group. Hence, to get rid of the considerable time variations of $E_{ii}^{\alpha\alpha}$ and $E_{ii}^{\beta\beta}$ in groups like P1K1, S2K2 only the main constituents (MC) of those groups will be included in the body tide model (3.1), where we define MC as the superimposition of all constituents clustering around the biggest one with the maximum frequency distance of the moon's perigee ($0.0046^o/h \hat{=} 8.80$ years) or even less. Consequently, if only the main constituents are modelled the rest of the group has to be substracted from the data by the predicted ones. The estimator dealing with those main constituents for the generation of parameter functions will be referred to as '<u>Main Constituent Moving Window (MCMW)</u>' <u>estimator</u>. Since the associated $E_{ii}^{\alpha\alpha}(T)$ and $E_{ii}^{\beta\beta}(T)$ are rather constant with respect to the total record length N, time variations are now uniquely due to the influence of z(t). Even if the elimination of the remainder of the group is not perfectly done by its prediction we are able to identify this fact as it will be shown later on.

5. The normalized spectrum of the residual parameter functions - a tool for signaldetection and interpretation.

To illustrate the further processing of parameter functions the following general situation is discussed (Fig.1):

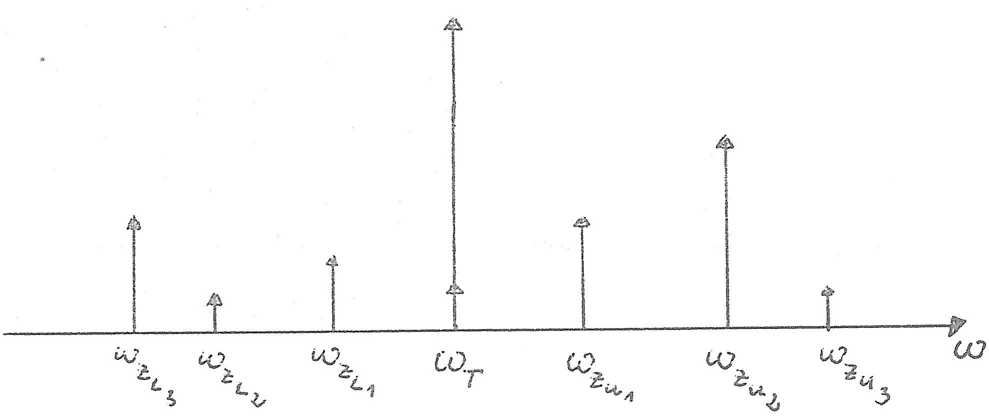

Fig.1: MC and perturbation lines

The tidal band i contains the main constituent with mean A_T, φ_T, ω_T and additional perturbation constituents located around ω_T. The problem is to estimate ω_{z_i}, A_{z_i}, φ_{z_i} from the parameter functions. In order to reduce mathematical work, let us consider only one pair $z_{U1}(t) = z_U(t)$ and $z_{L1}(t) = z_L(t)$ so that

$$z(t) = z_U(t) + z_L(t). \tag{5.1}$$

To deal with the general case let us additionally assume, that $|\Delta\omega_{T,L}| = |\omega_T - \omega_{z_L}| = |\omega_T - \omega_{z_U}| = |\Delta\omega_{T,U}| = |\Delta\omega|$ what means a symmetrical perturbation pattern with respect to the tidal frequency ω_T.

In the first step we generate the residual parameter functions

$$r_c(T) = x^c(T) - x_M^c \; ; \quad r_s(t) = x^c(T) - x_M^s \tag{5.2}$$

where x_M^c and x_M^s are the averages of $x^c(T)$ and $x^s(T)$ respectively. It should be noted that if there is a perturbation with the tidal frequency itself, all its energy is consumed by x_M^c and x_m^s in biasing the true values x_o^c and x_o^s and therefore cannot be detected.

These residual parameter functions can now be represented according to (3.2) - (3.6) and (3.8) as

$$\begin{aligned} r_c(T) \approx\ & \Delta_U \cos(-\Delta\omega T + \Delta\varphi_U) \\ & + \Delta_L \cos(\ \Delta\omega T + \Delta\varphi_L) \end{aligned} \tag{5.3}$$

where

$$\begin{aligned} &\Delta_U \approx \frac{A_{z_U}}{A_T} D(\Delta\omega), \; \Delta_L \approx \frac{A_{z_L}}{A_T} D(\Delta\omega), \; \Delta\varphi_U \approx \varphi_T^o - \varphi_{z_U}^o \\ &\Delta\varphi_L \approx \varphi_T^o - \varphi_{z_L}^o \end{aligned} \tag{5.4}$$

or, with a similar equation of kind (5.3) for $r_s(t)$:

$$\begin{aligned} r_c(T) &\approx \Delta_U \cos(\Delta\omega T - \Delta\varphi_U) + \Delta_L \cos(\Delta\omega T + \Delta\varphi_L) \\ r_s(T) &\approx \Delta_U \sin(\Delta\omega T - \Delta\varphi_U) - \Delta_L \sin(\Delta\omega T + \Delta\varphi_L) \end{aligned} \tag{5.5}$$

From a Fourier analysis of $r_c(T)$ and $r_s(T)$, we estimate the Fourier coefficients $a_c(\Delta\omega)$, $b_c(\Delta\omega)$, $a_s(\Delta\omega)$, $b_s(\Delta\omega)$ (SCHÜLLER 1977b) so that (5.5) can alternatively described by

$$\begin{aligned} r_c(T) &= a_c(\Delta\omega)\cos\Delta\omega T - b_c(\Delta\omega)\sin\Delta\omega T \\ r_s(T) &= a_s(\Delta\omega)\cos\Delta\omega T - b_s(\Delta\omega)\sin\Delta\omega T \end{aligned} \tag{5.6}$$

Equating (5.5) and (5.6), it follows

$$\begin{bmatrix} \Delta_U\cos\Delta\varphi_U \\ \Delta_U\sin\Delta\varphi_U \\ \Delta_L\cos\Delta\varphi_L \\ \Delta_L\sin\Delta\varphi_L \end{bmatrix} = \begin{bmatrix} c_U \\ s_U \\ c_L \\ s_L \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & -1 & -1 & 0 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & -1 & 0 \end{bmatrix} \begin{bmatrix} a_c(\Delta\omega) \\ b_c(\Delta\omega) \\ a_s(\Delta\omega) \\ b_s(\Delta\omega) \end{bmatrix} \tag{5.7}$$

Finally, we obtain:

$$\begin{aligned} \Delta_U &= \sqrt{c_U^2 + s_U^2} \simeq \frac{A_{z_U}}{A_T} D(\Delta\omega) \\ \Delta\varphi_U &= \arctan\left(\frac{s_U}{c_U}\right) \simeq \varphi_T^o - \varphi_{z_U}^o \\ \Delta_L &= \sqrt{c_L^2 + s_L^2} \simeq \frac{A_{z_L}}{A_T} D(\Delta\omega) \\ \Delta\varphi_L &= \arctan\left(\frac{s_L}{c_L}\right) \simeq \varphi_T^o - \varphi_{z_L}^o \end{aligned} \tag{5.8}$$

Since A_T, φ_T^o, ω_T, $D(\Delta\omega)$ are given, the parameter of the perturbation constituents, i.e. A_{z_U}, A_{z_L}, $\varphi_{z_U}^o$, $\varphi_{z_L}^o$, ω_{z_U}, ω_{z_L} can be approximately determined. Compared to the results in SCHÜLLER 1977b this presentation is an extension of what information can be derived from time variant analysis. The procedure described can be applied in a similar way for any pairs of perturbation constituents around the tidal frequencies. Generalizing these results, a normalized amplitude spectrum $\Delta(\Delta\omega)$ and phase spectrum $\Delta\varphi(\Delta\omega)$ for $\frac{-\pi}{\Delta T} \leq \Delta\omega \leq \frac{\pi}{\Delta T}$ may be generated for every tidal band. For the interpretation of these spectra the following conclusions are valid with respect to the influence of the perturbation $z(t)$:

a) z(t) is additive and random

If we assume a rather constant energy distribution over the tidal bands, the normalized spectrum will follow the shape of the spectral window $D(\omega)$ due to (5.8). The phase spectrum is arbitrary.

b) z(t) is additive and deterministic

If z(t) contains constituents with energy concentrations in the tidal bands, the normalized spectrum will exhibit peaks.

c) z(t) is acting as a modulation

If most of the energy of the modulation z(t) is concentrated at frequencies less than the bandwidth of $D(\omega)$ (what is usually the case) the normalized amplitude spectrum $\Delta(\Delta\omega)$ is symmetric around $\Delta\omega = 0$ (i.e. $A_z(\omega)$ is symmetric around the tidal frequency ω_T) and the phase spectrum $\Delta\varphi(\Delta\omega)$ is antisymmetric around $\Delta\omega = 0$. This feature becomes extremely important when looking for time variations of the elastic properties of the Earth, dilatancy effects (BERGER, BEAUMONT 1974) , non linear responses (BEAUMONT 1978) etc.

6. Numerical results

In this section the proposed procedure is demonstrated by numerical examples. Fig.2a,b show the residual parameter functions (5.2) for the 2N2 band of a theoretical tide record, superimposed by an additive perturbation z(t), which has energy concentration in the 2N2 band. Fig.2a presents the BMW-residual parameter functions while Fig.2b refers to MCMW-ones. Comparison of both figures emphazises that those raw time variations have to be interpreted with care because the rather exciting variations of BMW-origin are due to the presence of the relatively big constituent μ_2 which causes that particularly interesting scatter. In Fig.2b μ_2 has been removed from the data and only 2N2-MC was modelled in (3.1). Now the dominant time variations occur with rather long periods indicating a perturbation energy concentration near 2N2-MC, which is consistent with the nature of the generated z(t).

The superior properties of MCMW-parameter functions over BMW-ones in bands where two or more big constituents are present are demonstrated in Fig.3, but now by means of the normalized Fourier amplitude spectrum $\Delta(\Delta\omega)$ for the K1-group. There at P1 an energy concentration of z(t) was generated. As Fig.3 illustrates the BMW-spectrum (solid line) smears the perturbation energy over the complete band, while the MCMW-spectrum points correctly at P1 frequency.

Another experiment was done in order to derive the parameter of perturbation constituents quantitatively. For this purpose energy concentrations at MP1 and OP2 were generated in a one year theoretical record. From the parameter functions based on a 1356 hours basic interval and the normalized Fourier spectrum (Fig.4, Fig.5) respectively, the following results have been derived (Table 1):

ω	Δ(theory)	Δ(est.)	$\Delta\varphi$(theory)	$\Delta\varphi$(est.)
[°/h]	[$1\cdot10^{-4}$]	[$1\cdot10^{-4}$]	[°]	[°]
14.02	12.9	15.2	89.0	82.3
28.90	15.1	18.4	-89.0	-81.6

Table 1

Since the theoretical amplitudes of O1 and M2 are A_{O1}= 30.4µGal and A_{M2}= 28.05µGal the amplitudes of z(t) are in the order of 0.04µGal. Though no noise was present on the data, the experiment demonstrates that even small signals can be detected provided they are beyond the intrinsic noise level.

The final example aims at meeting the real situation by using a model series which is composed of theoretical tides (δ = 1.16, κ = 0) and observed air pressure induced gravity changes (assumed regression coefficient 0.3µGal/mBar. Fig.6 and 7 show the normalized Fourier line spectra at the fundamental frequencies for K1 and S2. There we observed more or less uniform spectra except at S1 ($\omega = 15^o/h$) and T2 ($\omega = 29.96^o/h$), which are significantly beyond the noise level. Note that at K1 and S2 frequency the air pressure induced energy is completely consumed by the mean values of the parameter functions so that there is no energy left. Anyway, this example shows that the normalized Fourier spectrum may become a powerful tool with respect to multichannel regression analysis in the frequency domain.

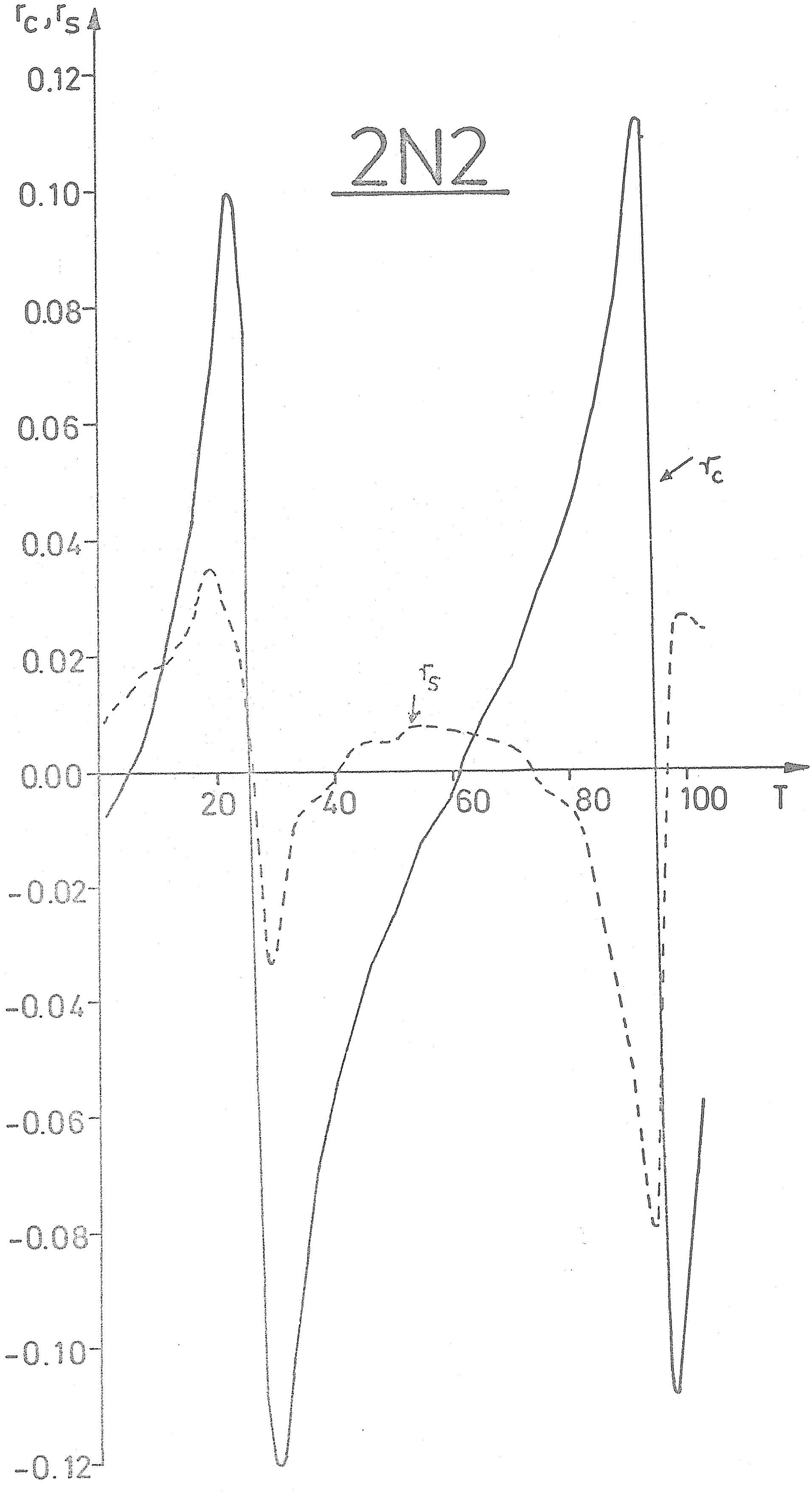

Fig.2a: Residuals of $\delta\cos x$ and $\delta\sin x$ for BMW-estimator

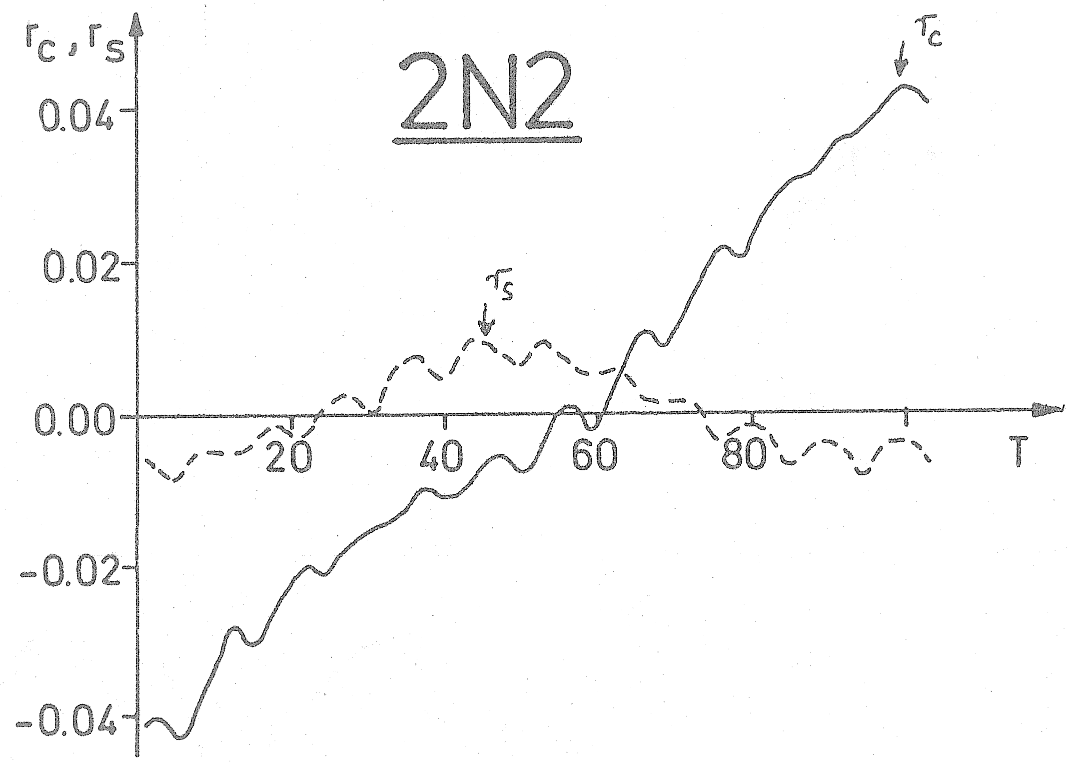

Fig.2b: Residuals of δcosx and δsinx for MCMW-estimator

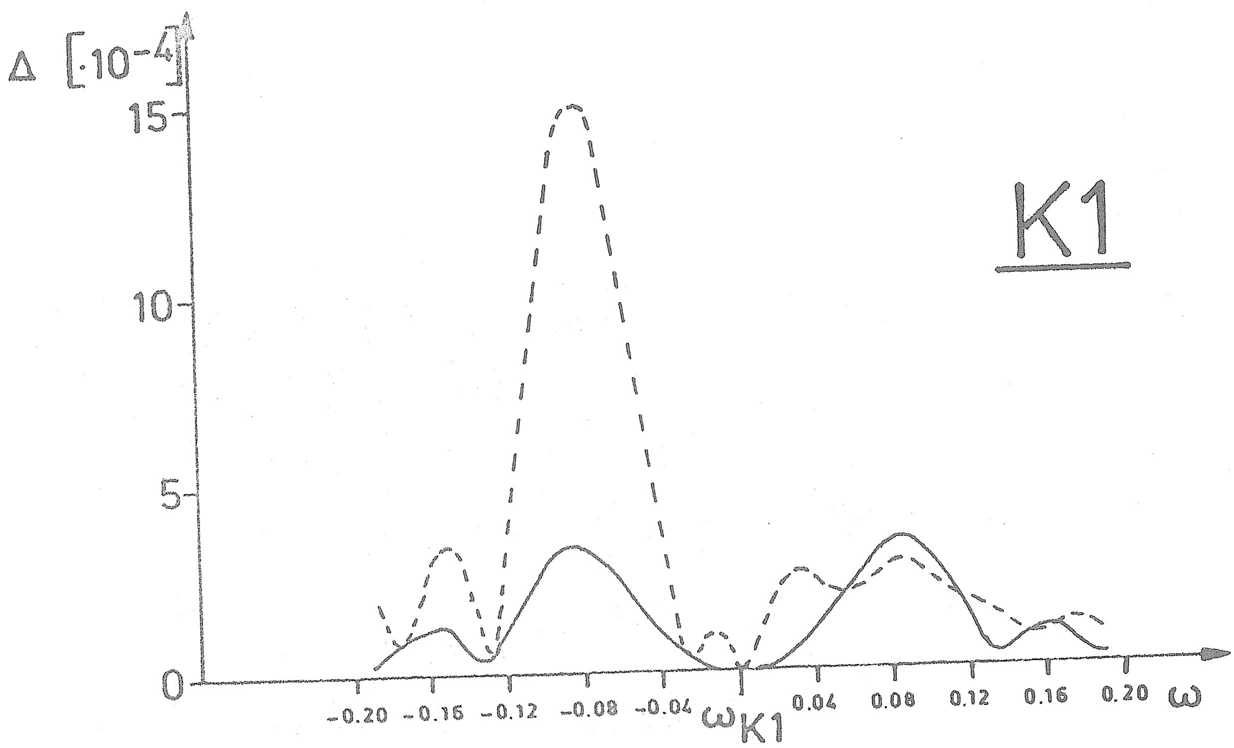

Fig. 3: —— Spectrum based on BMW-estimator
- - - Spectrum based on MCMW-estimator

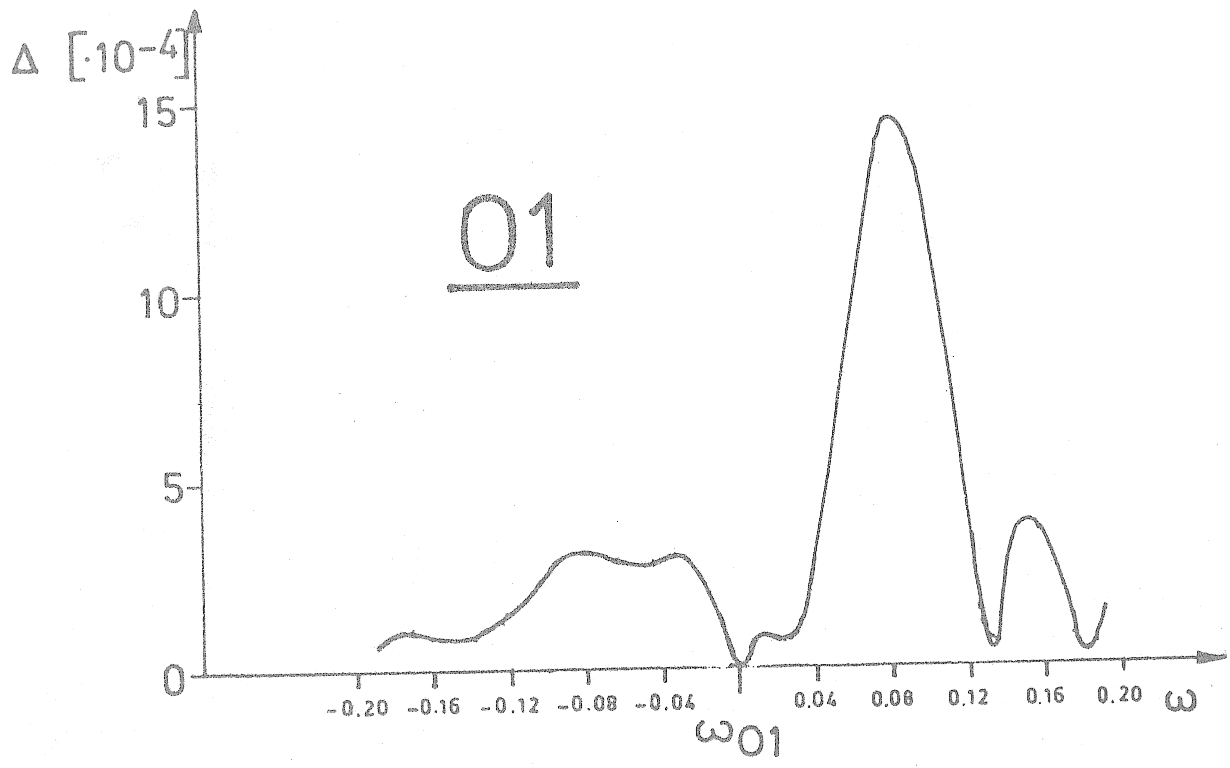

Fig. 4: Tidal Band Perturbation Spectrum for O1

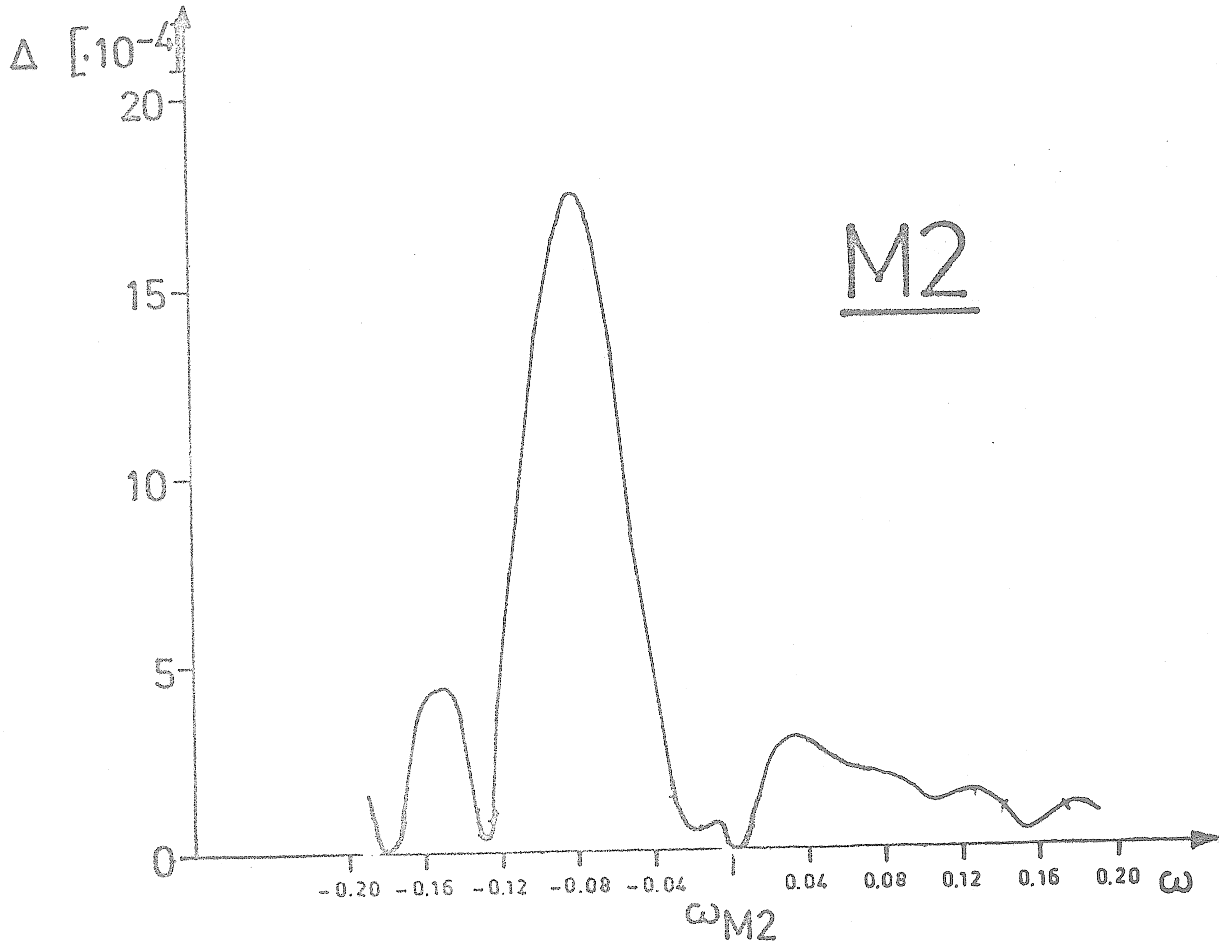

Fig.5: Tidal Band Perturbation Spectrum for M2

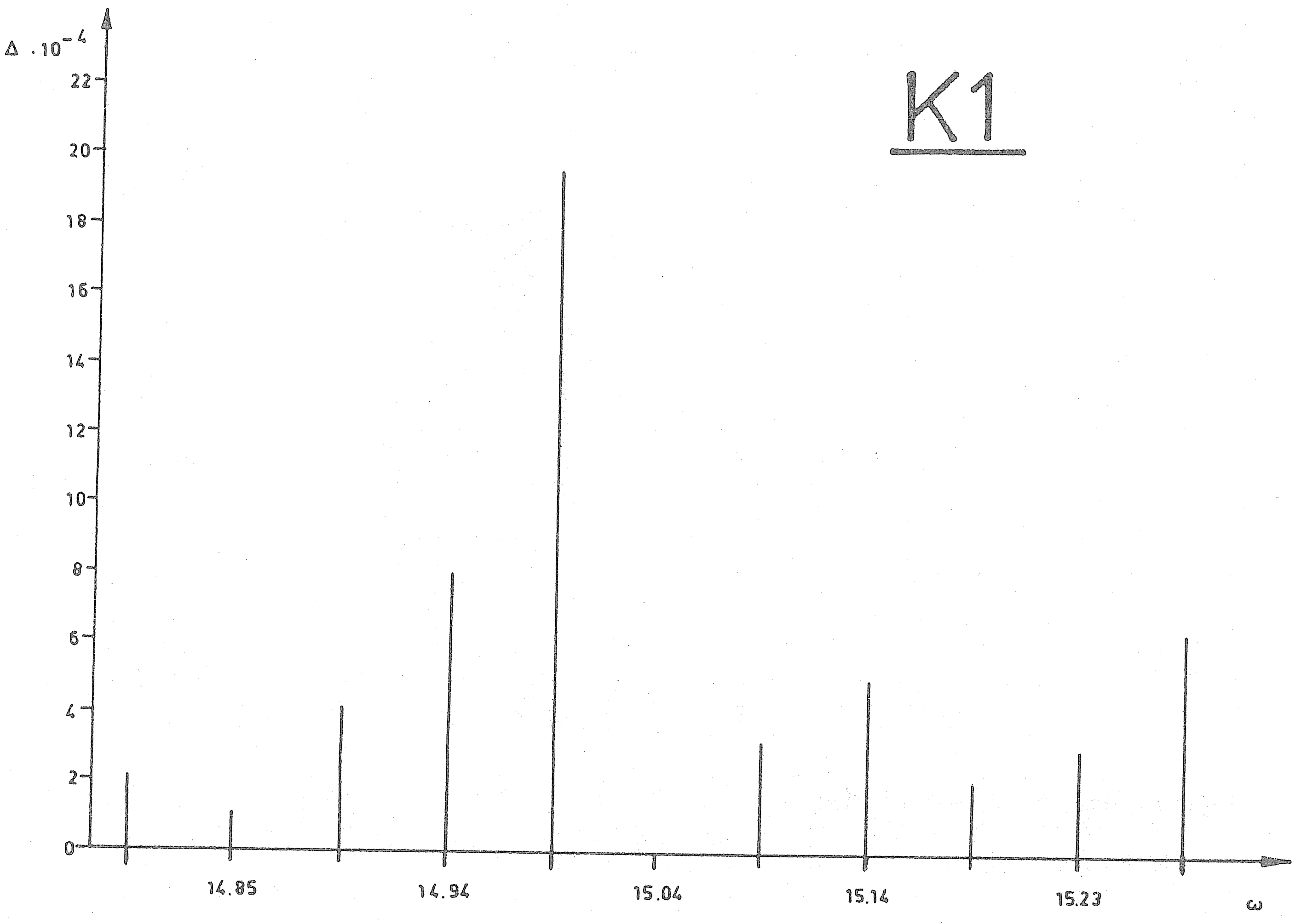

Fig.6: Model: Airpressure + Tides

(MCMW-estimator)

$$y_M(t) = 1.16 \cdot y(t) + 0.3\,p(t)$$

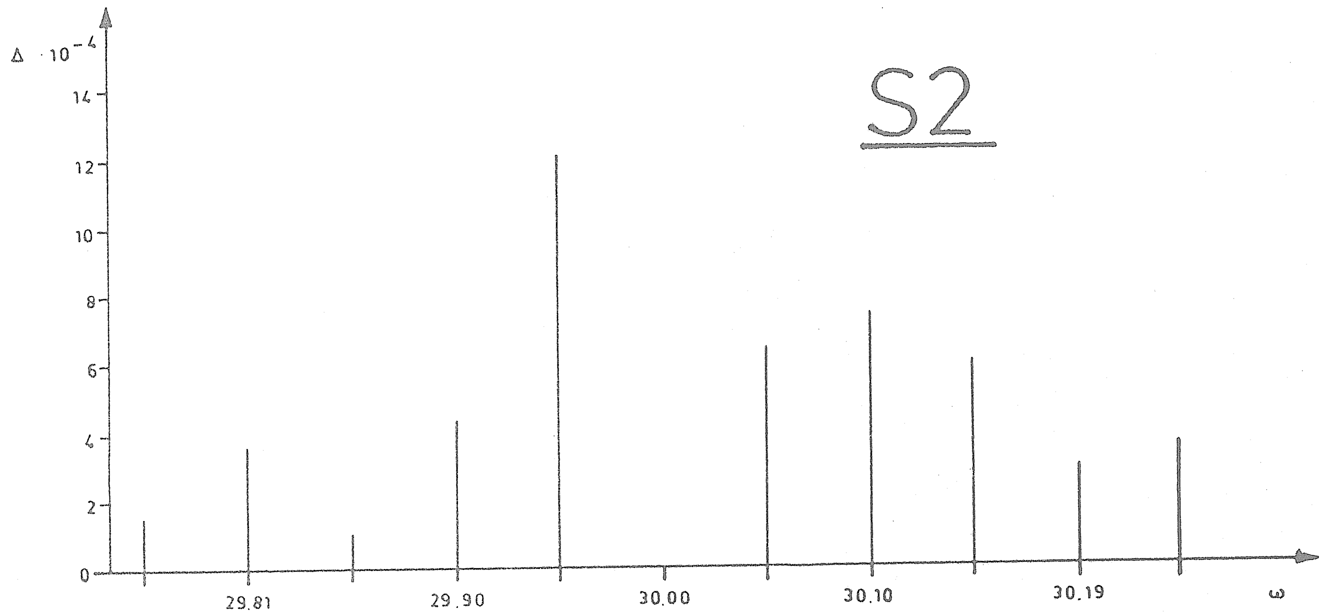

Fig. 7: Model : Airpressure + Tides

(MCMW-estimator)

$y_M(t) = 1.16 \cdot y(t) + 0.3\, p(t)$

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DETERMINATION OF THE LONG PERIOD TIDAL WAVES

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I. INTRODUCTION

The first observation of the Earth tides with useful quantative results was the determination of the long period tides (LP) by G. Darwin (1(p.163)).

In the present time when more direct methods of instrumental observations are used the problem was somewhat delayed. The reason was in the important difficulties, namely the lack of a high enough precision and the lack of long enough records without or with a very stable drift. For the same reasons the development of methods for the analysis and the determination of the LP seems to have been also somewhat delayed.

It may be said that Chojnicki (2) has activated the problem. He developed and applied a method based upon the zero-point procedure. In (3, 4), however, some important failures in that procedure have been discussed. Barsenkov has also used the zero-points but in a way that seems to avoid partly its disadvantages.

An important approach has been realized by Wenzel (3).

In the present paper we intend to propose a method for the determination of the LP and some results from its application.

The method is based upon the general computing scheme accepted in (6,1(p.179)) and in (7). We apply a pair of filters amplifying the LP and eliminating the drift (as well as possible). The filters are applied on intervals without overlaping and the filtered values are then treated by the method of the least squares.

The reason for the substitution of the hourly ordinates by the filtered values as directly observed quantities is similar to that implied in the determination of the short period (SP) tides. Here, however, the substitution is still more important. The separation of the LP from the drift is extremely difficult and it important residual influences of the drift may be expected. Indeed the hourly ordinates become strongly correlated and their treatment as independant observations is a nonsense.

In other words, the noise is not a white one. As far as it may be perceived as a stationary noise and we may talk about its spectrum, it must have important finite portions of its energy distributed over the low frequencies of the LP. The analysis must take into account these properties of the noise especially at the estimation of the precision. The substitution namely ensures an estimation that takes into account at least a part of the noise at the frequencies of the waves that are determined.

The application of that general scheme needed the resolution of a series of problems : (i) choice of the length of the filtered intervals, (ii) construction of the filters (iii) choice between the elimination and non-elimination of the other SP tides, (iv) grouping the LP or constitution of the equations of observations, (v) constitution of a computer program and, (vi) application of the method.

In the following parts we shall consider the solutions of these problems, some of them very briefly.

II. LENGTH OF THE FILTERED INTERVALS.

In the resolution of some of the problems stated above we have been facilitated in a sense by the great difficulties of the task. It is a priori clear, and this was proved by our experiments, that we cannot reach a great precision. The task has its natural limits and they cannot be evergone using the restricted power of the numerical processing. Thus the experimentation of a very great number of variants appeared to be useless and to be a waste of efforts and machine time. That is why among them it is enough to choose anyone conform to the practical circumstances and exigencies.

The length of the intervals will be denoted by N (N hours or N coefficients of the filters to be applied). There are too many possible N but the advantages of one or another value are not very evident. Or it is not certain that an advantage will compensate the faults related to it.

A greater value of N has the advantage that some longer waves may be determined. It implies also a possibility for a more sophisticated representation of the drift. At the same time the drift itself becomes more sophisticated with greater risks for interruptions and of changes of its character. Thus we may easily get a worse elimination of the drift.

In that vague situation we had restricted our attention to an important practical situation.

For the determination of a LP tide with a period T hours it is absolutely necessary to process portions of a record with lengths $N \geq T$ without interruptions. An useful information for the analysis may be obtained from intervals with $N < T$ only if there is no drift which is not our case.

The records are usually realized with the main objective to determine the SP for which the interruptions are not very important. Thus if N is a great number there is a risk to remain with a very little amount of data.

This is why we decided to abandon the determination of very long waves, and restrict ourselves to the direct determination of Mf, and to choose the lowest reasonable N corresponding to Mf :

$$N = 360 \quad (= 15 \text{ days}) \tag{1}$$

which is a slightly higher than the period of Mf which is favorable for the separation from the drift.

Of course there is room for other variants of N in the program we apply.

III. CONSTRUCTION OF THE FILTERS.

Let L_t be the ordinate at the time t in a given interval and t the time, measured in hours from the centre of the interval. Thus for the sequence of the N ordinates t takes the values

$$t = -n, \quad -n+1, \quad \ldots \quad n, \quad n = (N-1)/2 \tag{2}$$

where t and n are integers + 1/2 when N is an even number. For N = 360, n = 179.5.

We shall write the equations of L_t in an interval in the following general form

$$L_t = \sum_{k=1}^{2} \sum_{i=1}^{m} A_{ik}(t) \cdot X_{ik} + e_t \ , \tag{3}$$

where e_t is the error, X_{ik} are unknowns functions of the central epoch of the interval, in general, different for each interval, and $A_{ik}(t)$ are known functions of t only. For k = 1 these are even functions - like cos wt or $t^{2\ell}$ and for k = 2 these are odd functions, like sin wt or $t^{2\ell-1}$. If k is omited it should be understood whichever of the two types of functions.

The construction of the filters is made according to the technics given in (7), namely through the consecutive orthogonalysation of the functions $A_i(t)$.

Let $\underline{A}_i$ be a N dimensional vector column whose elements are the values of $A_i(t)$ for (2). The sequence of vectors $\underline{A}_i$ (i = 1, ... m) is replaced by the vectors $\underline{B}_i$ defined as follows. B_i is a linear combination of $\underline{A}_1$,... and $\underline{A}_i$ and is orthogonal to $\underline{A}_1$, ... and $\underline{A}_{i-1}$ but not to $\underline{A}_i$. The filters are then obtained through the normalization $\underline{B}_i$, i.e.

$$\underline{F}_i = \underline{B}_i / \left| \underline{B}_i \right| \qquad (4)$$

This filter eliminates the components with index $j < i$, amplifies by a factor 1 the component with index i if it is of the same type - even or odd - and, in general, does not eliminate the components with $j > i$. Thus for a given sequence of components A_i we obtain a sequence of filters. If the components are arranged as

$$A_1, A_2, \ldots . A_i, \ldots A_m \qquad (5)$$

the filter corresponding to A_i will eliminate the components situated to the left of A_i.

The filtered value obtained by a filter $\underline{F}_{ik}$, where k is added to indicate whether it is an even or an odd filter, is

$$U_{ik} = \underline{F}_{ik}^{*} \underline{L} = \sum_{t=-n}^{n} F_{ik}(t) L_t \quad . \qquad (6)$$

If e_t are independant errors with a variance s^2, then the variance of U_{ik} will be :

$$S_{ik}^2 = \underline{F}_{ik}^{*} \underline{F}_{ik} \cdot s^2 \qquad (7)$$

and s^2 may be estimated as

$$s^2 = \sum_{t=-n}^{n} L_t^2 - \sum_{k=1}^{2} \sum_{i=1}^{m} U_{ik}^2 / (\underline{F}_{ik}^{*} \underline{F}_{ik}) \qquad (8)$$

If the filtered values are to be weighed as suggested in (7) the weights are choosen as inverse to (7), determined with s^2 from (8). When we do not want to weigh U_{ik} we proceed in the same way but we put $s^2 = 1$.

In the following we shall consider the choice of the components A_i in relation with our goal.

IV. REPRESENTATION AND ELIMINATION OF THE DRIFT.

The value already choosen $N = 360$ practically solves the problem without variants. As N is very close to the period of Mf, the only representation of the drift D_t within an interval is the linear function

$$D_t = Z_o + Z_1 \cdot t \quad , \qquad (9)$$

where Z_o and Z_1 are unknowns related to a given interval.

We shall denote

$$P_1(t) = t^o = 1 \quad \text{and} \quad P_2(t) = t \qquad (10)$$

and by P one whichever of these two functions. We want in any case to eliminate the representation (9) of the drift. For that purpose, we shall have to put the function P as a first component in the sequence (5).

V. REPRESENTATION OF THE TIDE.

We shall use the Darwin symbols of the tides, for instance Mf, to designate the functions cos wt or sin wt which are in fact the functions $A_{ik}(t)$ in (3), related to the tides. In that way the composition of the sequence (5) by the symbols of some tides (plus the symbol P for the drift presentation) will mean that the cosine and the sine terms of these waves are included in the equation (3). For each included tide we shall obtain a pair of filters (even and odd) which will amplify it and will eliminate the other components situated to its left.

It is clear that one of the tides must be Mf and that it must be situated to the right of P. The filter corresponding and amplifying Mf shall be designated by F_{Mf} and in general the filter corresponding to a tide V - by F_V.

It is still necessary to include other tides because (i) we may want F_{Mf} to eliminate some tides and (ii) in order to have an accurate expression (3), with which is related the calculation of the weights through (7) and (8).

We have established that it is necessary to represente the LP tides by MM and MTM. As N is very small it is not possible to search a separation of Mf from MM and MTM. That is why they must be in any case to the right of Mf.

It appeared that the SP tides must be represented in details. We have choosen the following set of tides which we shall designate by {D,SD} -

{D,SD} = SIG1, Q1, O1, M1, K1, J1, OO1, EPS2, MU2, M2, L2, S2, ETA2 . (11)

For the relation between Mf and this sequence {D,SD} there are two options : (i) F_{Mf} eliminates {D,SD} and (ii) F_{Mf} does not eliminate {D,SD}. In the case (ii) it will be necessary to include some groups for the diurnal and the semidiurnal tides in the equations for the values filtered by F_{Mf}. The tide M3 is of very small amplitude and very high frequency and may be neglegted in the sequence (11) and in the equations for the filtered values.

Corresponding to these two cases we have the following two options of filters bult up through the orthogonal transformations of the following components

Filters 9 : P, {D,SD}, Mf, MM, MTM
Filters 10 : P, Mf, {D,SD}, MM, MTM

The numbers 9 and 10 mean that there are still 8 other options used before them. Some other variants are presumed but it does not seem that they ensure a serious improvement of the results.

VI. THE COMPOSITION OF THE EQUATIONS FOR THE FILTERED VALUES (GROUPING OF THE LONG PERIOD TIDES) AND THEIR SOLUTION.

The observation equations for the filtered values are composed as in (6,1(p.179)) with the unknowns ζ and η and the grouping of the tides.

We have the following 3 variants of grouping

TABLE 1

Variant 5		Variant 6		Variant 7	
O55 - O68	MM	O55 - O68	MM		
O71 - O77	Mf	O71 - OX3	Mf	O55 - OX3	Mf
O80 - OX3	MTM				

The beginning and the end of each group is defined by the first three digits of the argument number of Doodson. The number of the variants are 5, 6 and 7 because in the program we use there is another sequence of variants 1 to 4 in which we have groups like SSa whose determination is a simple nonsense.

Here the groups MM and MTM are included because they are not eliminated. One could expect some results about at least MTM but the small amplitudes in that group restrict considerably the precision. It seems that the last variant has more or less good perspectives.

The filters 9 eliminate quite well the SP tides and they can be ignored in the equations. For the filters 10 it is necessary to take them into account. Having in mind the low precision as well as that an imperfection in the representation of the SP is a high frequency noise relatively to the LP, all diurnal tides as well as all semidiurnal tides are associated in one group.

The description of the constitution of the equations and their solution is not necessary as it is analogous to that in (6, 1(p.179)) to (7) when the filtered values are weighed. The same program as for the determination of the SI tides (or a given part from it) may be used.

VII. RESULTS.

It is natural that for such a delicate problem we need very high quality data. It is important to have in mind that data which are good for the determination of the diurnal and semidiurnal tides may be not suitable for the LP waves if there are many interruptions.

In relation to the interruptions the use of filters with a fixed length has an evident disadvantage. If after an interval without interruption follows a part of the record of $N' < N$ hours but N' is not very small, in a sense, than we shall have to loose it. For such a case we presume in our program from a filtered interval of N hours to keep a given number of N_r ordinates in reserve. If in the next record we have $N' < N$ hours without interruptions and $N - N' \leq N_r$, then a new interval is formed using both the N_r and N hours. Evidently N_r must be a reasonably small number in order to avoid many and great overlapings.

In the material joint to the present paper we give some results from the analysis of data. They are :

1. The analysis of a set of theoretical tides of Dr. Wenzel.
2. The analysis of a long record from Frankfurt; the correction of the sensibility by 1.00139 / year is taken into account.
3. The analysis of a long record from Dourbes 1; in the practical handling of these data we have met important difficulties that are not overgone and the results must be considered as preliminary.
4. The analysis of 4 years observations in Potsdam. Despite the high quality of these data, the precision obtained is not very high. It is possible to be worsen .... from the great number of interruptions. The results are obtained without the application of the option to have some N_r ordinates in reserve. These results are also to be considered as preliminary.

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A Data-Base System for Storage and Retrieval of Time-Series Data.
- Earth-Tide Registration and CDC QUERY UPDATE -

by Horst KREMERS, Technical University of Berlin

Summary:

The modern use of digital recording equipment for data acquisition with geophysical and meteorological time-series data and the increasing availability of data-base systems even on small computers make the use of this tool for data storage and retrieval a serious point of consideration. The experience gained here with earth-tide recordings are easily applied to other series of continuously recorded data. The CDC (Control Data Corp.) QUERY UPDATE data-base software system can be regarded as an example for the general use of similar software available on other computers. The main structures of organization are shown, main emphasis was laid upon ease of use and flexibility for potential users. A long write-up of all software used is encluded since, although CDC-dependent, users may have access to the QUERY UPDATE system considering the increasing number of interconnected computer systems.

0.1 Introduction

The software described in the following conceptually differs very distinctly from other work on data-base systems in geodesy published sofar. TSCHERNING (1978) and FRANKE (1979) extensively make use of the data-base concept with special regard to point-related information (coordinates, physical properties, statistical parameters, etc.). In such a general case the items defined are very different from each other with various (logical) relations between them and a considerable need for updating previously stored information. A general introduction to the data-base concept can be found in MARTIN (1975) (with applications using IBM Data Language) experience with CDC software is reported by LAVALLEE and OHAYON (1974).

Here, the implementation of a data-base system for time-series was chosen because of other points of view. Data acquisition and retrieval with long and multiple time-series is routine work at its most. This states the necessity to handle all data very quickly and effectively an at the same time increase flexibility of usage an control on input and output. Some of the features of a data-base software system appeared to be very useful in this sense and the results are quite promising.

0.2 Data Storage (hardware)

Storage media in use sofar are

- lists(handwritten)
- punched cards
- paper tape
- magnetic tape / disk

The choice of medium for primary acquisition is very much depending on the facilities of recording the time-series and the equipment at hand on the site. Since even in the case of direct recording on paper tape or magnetic tape it shows to be useful to have an intermediate storage on punched cards (because of the general necessity of data manipulation) these cards also are used for data storage and retrieval at the end. There is not much difference with regard to the overall organization in having these cards copied on a magnetic tape. There, the equivalent file structure is maintained, the only advantages are the avoidance of a card reader during input and a better protection against vandalism. This organization can only be considered as a kind of hardware- or physical data-base. For instance, it will be very difficult to make changes or extensions on specific data blocks, especially when trying to find standard procedures for this.

0.3 Data Storage (software)

The conventional way of storing data on punched cards does not imply any need for sustaining software after the data leave the "manipulation" stage. First considerations of system-related software occurs with storage by the help of socalled UPDATE-Systems. These are of common use on every computer. The main features are:

- each data card is seen as one logical record (not dividable into smaller units nor exeeding the 80 columns card image)
- user-supplied identifiers
- system-generated sequencing information.

In most cases, identifiers as well as sequencing information do not have any logical relation to the data stored, a fact that makes it very difficult to generate standard procedures for input or output.

A little more complicated but much more versatile and less error-prone is the use of special data-base software since much of the care to be taken during update and retrieval of data will be controlled by that system and users get a better overview and flexibility in data handling.

1.0 Description of a Data-Base System

Figure 1 shows a diagram of structure for the overall organization of a data-base system. The upper part of it as well as its lower end will strongly depend on the individual facilities of data acquisition and use of data for analysis. The most interesting "kernel" of the system is established by the components user, system, and organization software, input, and output needs.

Two regions of activities can be distinguished in establishing a data-base system:

- construction and administration of the base from the organizational point of view
- the special requirements of potential users and their own communication with the system.

1.1 Construction and Administration

The fundamental task of preparation is a complete and detailed analysis of the information tc be stored and the way this information will be used.

In detail, this means:

- establishing a complete catalogue of all kind of data to be entered into the base and their computer-specific description (format)

- finding data elements that can serve as key or identifier for certain groups of data
- considering relations between data elements of the base or other data files (possibly residing on a different tape or disk in the system)
- implementation of security controls (access permittions to certain users for reading or modifying parts of the data-base)
- cooperation with the creation of standard procedures for input/output routines
- implementation of an inventory system.

1.2 Users / Application Programs

Communication with the base is possible with the help of a so-called command language. The data-base receives instructions for the performance of specific tasks:

- insert new data
- change existing data
- extract data upon local files, cards, or lists.

These are standard tasks when considering time-series data and since these tasks are of common structure, the preparation of standard procedures is answering the purpose.

2.0 The CDC QUERY UPDATE Data-Base Software System

The software listed in the figures was generated on the basis of the reference manuals listed in the bibliography.

According to the overview in 1.1, structure and characteristics of data must be specified, first. This is accomplished within a SUBSCHEMA that is compiled and stored separately. Fig. 2 gives a simple example of data structure used in such a schema: two files, no sectional structuring within files, one record type for each file, element groups are formed by structuring records by three levels of index, every (single) element can be considered to have group element characteristics with regard to upper or lower levels of index.

At this point already, the first advantages over normal UPDATE or the mere use of punched cards appear:

- every type of record is named and can be addressed by that name, thus, different types of record can be handled and easily be related to each other, if necessary
- data as element of a record can be named individually or grouped by level indexing (access to variuos sets of data, or forming subsets)
- repeated elements (array) can be addressed individually or all at once
- up to 819 elements may be defined within one record (this property might allow the simultaneous storage of recordings from up to 130 gravity meters using the international format).

2.1 Subschema

The term SCHEMA defines the set of all possible SUBSCHEMAs derivable from a certain kind of data organization. The actual use during any access routine is controlled by a subschema that defines the set of data a user has access to. The programming language is the "Data Description Language" (DDL) already mentioned. Since the idea of the data-base concept generated from commercial needs it is obvious that it is orientated towards standard COBOL, but there are some attempts already to construct even ALGOL or FORTRAN interfaces to such software systems.

2.2 Input/Output and Updates

Depending on the structure of data defined in a subschema which has to match the structure of data representation on the file used, data can be inserted, updated, or extracted from the file. Central term and element for each record is the "key" element by which each record can be identified. In handling time-series data it is obvious to choose the date (and time) for primary keys. This establishes an automatic well-defined sorting facility which is effected by the system itself. During input, for example, records (i.e. punched cards) do not have to be sorted, the system will place each one in the right position on the file with warning at the encounter of duplicate keys. Again it is stressed that the key is one of the data elements itself, a fact that will facilitate every kind of access.

Communication with the base is not restricted to jobs operated in batch mode but also possible in connecting the data-base on a local file to a video-terminal and directly accessing the base "on-line". Considering the amount of data to be handled in time-series work and the standard nature of it, batch jobs will be focused upon and appropriate standard procedures developed (Fig. 3).

2.3 Report Writer

A listing of data extracted from the base can be generated by the help of a "Report" utility. The general features are

- tabular listing
- headings, footings, summaries
- facility of mathematical operations on the data (statistics etc.).

Fig. 3 shows an example for a standard report procedure and a sample output page is shown in Fig. 7.

3.0 Actual Organization of the base.

According to the SUBSCHEMA in Fig. 2 the following data elements are administered in the base:

Gregorian date, Julian date, Theoretical Tides (array) analog recordings (digitized manually) (array), digital recordings (array), air pressure (array) + site information.

Arrays are dimensioned 6, the format for intra-base storage is identical with the international format for earth-tide recordings. (This is not obligatory since during input as well as during output values for elements can be treated arithmetically, new elements computed from other input elements or non-standard formats converted and vice-versa.) Key element for each record is the Gregorian Date which serves for unique identification of records. (Note: the standard format requests 0 or 2 to be added to the cyphers of the date to identify half-days; each record contains information over 12 hours).

Since the theoretical values of the tidal effect easily can be computed in advance, these can be inserted annually by an INSERT run (procedure IN1, Fig.3), record elements Gregorian Date, Julian date and theoretical tides are created, other elements of different time-series defined can be updated (proc. UP1, UP2, UP3 Fig.3) by the time they are prepared for storage in the base. (Note: there is no need of keeping a certain order of update since the complete records are created by an insert run and elements get default values (blank or zero) if not accessed during that run.)

In case it shows out necessary to have certain elements changed in value this is accomplished by that same standard update-run that can follow the insert. With the standard procedures, at least one complete data card has to be supplied for input. As mentioned above, each single element can be addressed (and updated) by interactive dialogue with the base.

Beside the tabular listing, a standard procedure for preparing a local file in the international format was added. This permits generating a data file of all information from the base that refers to a specific time-series and at the same time structuring the data to international format for analysis program input or punch-file output. Each single time-series can be addressed individually and the range (in time) of information requested can be given by a start and stop date (see Fig. 3).

3.1 Standard Procedures

Since the international standard data structure was chosen for each time-series in the base, job directives can make use of this. To reduce the number of actually needed instructions for any run, standard procedures have been designed and catalogued on a special system-resident file. In order to identify different time-series in the use of one basic procedure, extensive use was made of the facility to substitute character strings during input and execution depending on parameters given on the procedure-calling statement (see f.e. first statement of proc. LIST, Fig.3), a very useful tool provided by Cyber Control Language (CCL).

Predominant feature of the use of standard procedures is the fact that there is less danger in mixing up job control statement cards, using wrong parameters, etc. All the instructions for a job (as listed in the job-dayfiles of Fig. 6) are compiles by the successive call of several standard procedures and initiated in principle by only one card during actual job input (first BEGIN call). Procedures listed in Fig. 3 are catalogued (one section each) on a permantent file that is easily made available to the job by an ATTACH-statement. Procedures are automatically compiled for job processing on the encounter of a BEGIN-statement. A user manual showing the very simple organization for actual work with the base is compiled in Fig. 5.

4. Summary and Outlook

The use of a data-base system has some sincere advantages over conventional ways of data handling:

- records are not limited to the content of a 80 columns punched card
- identification of records is controlled by a key element that is data-inheritant
- great amounts of data from different series can easily be handled
- standard procedures, problem- and user-oriented, are easily provided for
- records are automatically sorted and updated by the "time" element of the series.

Practical demonstration of the method uses registration of earth-tide data but the concept can be applied to other types of time-series that must be handled for a considerable time-span, compiled from different sources, and provided for a variety of users with different access interest.

The subschema-example given must be considered as a "lowest-order" data-base description. A more advanced system should be capable of handling data for more instruments and different observation sites, including calibration tables etc. Intermediately, each instrument can have its own data-base stored on a separate magnetic tape but using essentially the same software during access. A unified treatment under an extended schema will have to take into account the need of several more "key" elements (alternate key organization) with regard to site identification and others.

For information on what is going on with the base it will show up to be quite useful to establish an inventory for the base - a separate section of the data-base file that is updated each time an insert or update-run occurs and also comprehensively generates overviews on what kind of data had been inserted/updated, by what user, and what is the overall range of data accessible for each time-series stored.

Since a data-base system is implemented not only for a single user, the complexity of organization and the value of the system imply the need of considering data security. Some aspects of control have been pointed out, already, but for instance, there is no thorough means for restricting access to certail parts of the base by the QUERY UPDATE software system. Future systems will have to take account of that need.

Nevertheless, the use of a data-base software system for storage and retrieval of time-series data showed up to be highly beneficila once users get an impression of its possibilities and the much more simple actual organization in job processing (preparing data-blocks for stepwise monthly analyses etc.).

Especially when considering the connection of various computer systems by communication links (Rechnernetze und Datenfernverarbeitung, 1976) (Datenbanken in Rechnernetzen, 1978) as a means of distributed data acquisition and processing it becomes obvious that such a complex structure is operable only with the help of an appropriate data-base software system.

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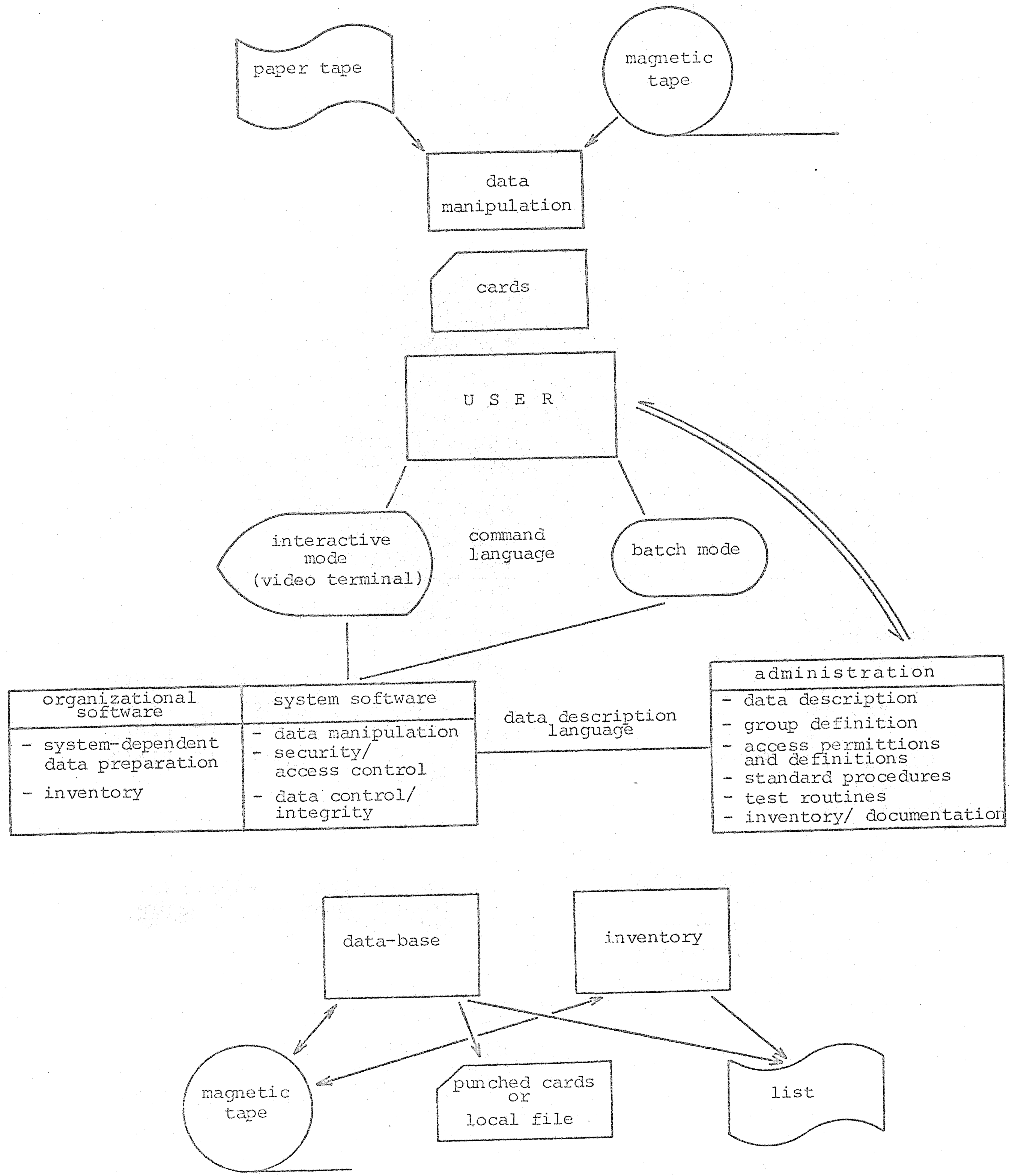

Fig. 1: Data-base System

```
 IDENTIFICATION DIVISION.
 SUB-SCHEMA NAME IS GEOSCHEMA
 DATA DIVISION.
*************
*************                    AREA DEFINITION
*************
 AREA-NAME IS GEODATA TEMPORARY
*            *******
 ORGANIZATION IS INDEXED
 KEY IS DATE
 INDEX-LEVEL IS 4
 RECORD-NAME IS MEASURE
    02 INSTRUMENT-TYPE           PIC X(10)
    02 INSTRUMENT-NO             PIC Z(3)9
    02 STATION-NO                PIC ZZZZ
    02 STATION-NAME              PIC X(20)
    02 COORDINATES
      03 LONG-LAT
        04 LONGITUDE             PIC Z(7).999
        04 LATITUDE              PIC Z(7).99
      03 X-Y-H
        04 X                     PIC Z(10).99
        04 Y                     PIC Z(10).99
        04 H                     PIC Z(5).99
        04 SYSTEM                PIC X(15)
    02 DATE                      PIC Z(6)9
    02 JULDATE                   PIC Z(5)
    02 MAINTENANCE               PIC ZZ
    02 THEORY                    PIC S99999   OCCURS 12 TIMES
    02 ANALOG                    PIC S99999   OCCURS 12 TIMES
    02 DIGITAL                   PIC S99999   OCCURS 12 TIMES
    02 AIR-PRESSURE              PIC Z(4)9    OCCURS 12 TIMES
    02 FILLER                    PIC X(60)
*************
*************                    AREA DEFINITION
*************
 AREA-NAME IS KARTEN TEMPORARY
*            ******                   File KARTEN is needed for
 ORGANIZATION IS SEQUENTIAL           system-dependent data-pre-
 RECORD-TYPE IS ZERO-BYTE             paration (see proc. QUPRE)
 RECORD-NAME IS KARTIN
 02 S1                           PIC 9999
 02 S2                           PIC 9999
 02 JUL                          PIC 99999
 02 D1                           PIC ZZZZZZZ
 02 A1                           PIC S99999   OCCURS 12 TIMES
```

Fig. 2: SUBSCHEMA

Procedure QUPRE:

Preparing routine to be run with all accesses to the base by procedures IN1, UP1, UP2, UP3.

```
.PROC,QUPRE.
LABEL,NT,R,L=GEODATA,D=PE,RING.
COPYBF,NT,GEODATA.
REWIND,GEODATA.
.*
ATTACH,ASLIB,PERMFILE1723ASTROLIB,ID=1723,MR=1.
LIBRARY,ASLIB.
COPYBR,INPUT,TAPE22.
REWIND,TAPE22.
QUP.
COPYBF,TAPE30,CARDS.
RETURN,TAPE22,TAPE30.
REWIND,CARDS.
FILE,CARDS,RT=Z.
.*
REQUEST,QUJ,*Q.
COPYBR,QUCO,QUJ.
.*
COPYBR,QUCO,QUJ.
.*
QU,I=QUINO,T=QUF.
.*
SKIPB,QUF.
COPYBR,QUF,QUJ.
REWIND,CARDS.
COPYBF,CARDS,QUJ.
RETURN,CARDS,QUINO,QUF,QUCO.
ROUTE,QUJ.DC=IN,TID=C.
ROUTE,OUTPUT,DC=SC.
.*
.DATA QUCO
A1723,PW=PW,CM30000,T3,FC=YES,STTUB.
COPYSBF,,.
.*
```

LABEL: Control of tape label and copy of data-base to local file (disc).

ATTACH: Attach the program library of the institute (or file that contains all programs and subroutines in compiled form) for later use.

QUP: Program QUP requests data from TAPE22 and writes to TAPE30.

Intermediate handling of data via file KARTEN (see SUB-SCHEMA).

QU: QUERY UPDATE SYSTEM call; input of statements is expected from file QUINO whose content is differently defined by procedures IN1, UP1 etc.

File QUF gives a control output, listing directives encountered.

Procedure IN1:

```
.PROC,IN1.
BEGIN,QUPRE,QUPCC.
BEGIN,SAVE,QUPCC.
.*
.DATA QUINO
USE CARDS OF GEOSCHEMA(ID=1723,PW=LET)
REWIND CARDS
SEP ITEM-SIZE
EXTRACT UPON ART S2 D1 JUL A1(ALL)
REWIND ART
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
INSERT FROM ART USING STATION-NO DATE +
JULDAT  THEORY(ALL)
END
```

INSERT: At the insert of new records, values for station-no and julian date are assigned in addition to theoretical values of tides.

Procedure UP1:

```
.PROC,UP1.
BEGIN,QUPRE,QUPCC.
BEGIN,SAVE,QUPCC.
.*
.DATA QUINO
USE CARDS OF GEOSCHEMA(ID=1723,PW=LET)
REWIND CARDS
SEP ITEM-SIZE
EXTRACT UPON ART S1 D1 A1(ALL)
REWIND ART
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
UPDATE FROM ART USING INSTRUMENT-NO DATE +
ANALOG(ALL)
END
```

Fig. 3: Procedures Listing

Procedure UP2:

```
.PROC,UP2.
BEGIN,QUPRE,QUPCC.
BEGIN,SAVE,QUPCC.
.*
.DATA QUINO
USE CARDS OF GEOSCHEMA(ID=1723,PW=LET)
REWIND CARDS
SEP ITEM-SIZE
EXTRACT UPON ART D1 A1(ALL)
REWIND ART
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
UPDATE FROM ART USING DATE DIGITAL(ALL)
END
```

Procedures UP2 and UP3 assign values for elements DIGITAL and AIR-PRESSURE depending on key "DATE".

Procedure UP3:

```
.PROC,UP3.
BEGIN,QUPRE,QUPCC.
BEGIN,SAVE,QUPCC.
.*
.DATA QUINO
USE CARDS OF GEOSCHEMA(ID=1723,PW=LET)
REWIND CARDS
SEP ITEM-SIZE
EXTRACT UPON ART D1 A1(ALL)
REWIND ART
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
UPDATE FROM ART USING DATE AIR-PRESSURE(ALL)
END
```

Procedure SAVE:

```
.PROC,SAVE.
REWIND,NT,GEODATA.
COPYBF,GEODATA,NT.
UNLOAD,NT.
COMMENT. ************************
COMMENT. *
COMMENT. *  CONTROL OF DATA
COMMENT. *  BY  REPORT
COMMENT. *  PROCED.    L I S T
COMMENT. *
COMMENT. ************************
.*
```

Copy modified data-base to tape.

Message to be inserted in job-dayfile.

Procedure COPTAP:

```
.PROC,COPTAP.
LABEL,NT,R,L=GEODATA,D=PE,NORING.
COPYBF,NT,GEODATA.
UNLOAD,NT.
REWIND,GEODATA.
.*
```

In procedures LIST and CARDS this procedure causes copy of tape NT to local file, disk, GEODATA.

Fig. 3: Procedures Listing (continued)

Procedure CARDS:

```
.PROC,CARDS,DATA,FROM,TO.
BEGIN,COPTAP,QUPCC.
REQUEST,FILE1,*Q.
FILE,FILE1,RT=Z,BT=C.
.*
QU,I=CARDC,RO,O=SCR.
.*
RETURN,QUPCC,CARDC.
REWIND,FILE1.
COPYSBF,FILE1.
REWIND,FILE1.
COPYBF,FILE1,PUNCH.
ROUTE,PUNCH,TID=C.
REWIND,FILE1.
COMMENT. *************************************
COMMENT. *
COMMENT. *  DATA ON FILE  P U N C H
COMMENT. *  REQUEST CARDS FROM CENTRAL SITE
COMMENT. *
COMMENT. *************************************
COMMENT. *
COMMENT. *  CONTINUE ANALYSIS OF DATA
COMMENT. *  FROM    F I L E 1
COMMENT. *
COMMENT. *************************************
.*
.#DATA,CARDC
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
REWIND,FILE1
SEP ITEM-SIZE
IF DATE GE FROM AND DATE LE TO +
DISPLAY UPON FILE1 INSTRUMENT-NO STATION-NO +
JULDAT DATE DATA_(ALL)
```

Input of QUERY UPDATE directives is expected from the file CARDC defined by the .DATA-statement.

FILE1 is copied to output and punch.

These comments are inserted to the job dayfile.

QUERY UPDATE directives for the choice of data-groups in limits FROM and TO. Character-string DATA is replaced by its parameter value at the time of call by a BEGIN-statement.

Procedure LIST:

```
.PROC,LIST,DATA,FROM,TO.
BEGIN,COPTAP,QUPCC.
RETURN,QUPCC.
QU,I=ANREP,RO.
RETURN,OUTPUT.
COPYBF,INVENTORY.
.*
.#DATA,ANREP
USE GEODATA OF GEOSCHEMA(ID=1723,PW=LET)
REWIND,FILE1
.*
IF DATE GE FROM AND DATE LE TO +
EXTRACT UPON FILE1 INSTRUMENT-NO JULDAT DATE +
STATION-NO DATA_(ALL)
.*
FORMAT INVENTORY
DETAIL IS INSTRUMENT-NO IN COLUMN 2 IS  +
STATION-NO IN COLUMN 9 IS +
JULDAT IN COLUMN 20 IS +
DATE IN COLUMN 30 IS +
DATA_(1) IN COLUMN 40 IS +
DATA_(2) IN COLUMN 47 IS +
DATA_(3) IN COLUMN 54 IS +
DATA_(4) IN COLUMN 61 IS +
DATA_(5) IN COLUMN 68 IS +
DATA_(6) IN COLUMN 75 IS +
DATA_(7) IN COLUMN 83 IS +
DATA_(8) IN COLUMN 90 IS +
DATA_(9) IN COLUMN 97 IS +
DATA_(10) IN COLUMN 104 IS +
DATA_(11) IN COLUMN 111 IS +
DATA_(12) IN COLUMN 118
TITLE AT LINE 2 IS  +
$INVENTORY OF DATA RANGE DATE FROM  -  DATE TO  $  +
IN COLUMN 20 +
AT LINE 3 IS $  $ +
AT LINE 4 IS $INSTRUMENT$ IN COLUMN 1 +
IS $STATION$ IN COLUMN 8 +
IS $JULDAT$ IN COLUMN 20 +
IS $DATE$ IN COLUMN 31 +
IS $TIDES-_DATA  12 WERTE$ IN COLUMN 40 +
AT LINE 5 IS $  $
PAGE-SIZE IS 40 LINES 130 COLUMNS
PAGE-NUMBER AT TITLE-LINE COLUMN 113
DATE AT LINE 2 COLUMN 94
TIME AT LINE 3 COLUMN 94
.*
PREPARE INVENTORY #FROM FILE1
```

Description of COPTAP see Fig. 3.

QUERY UPDATE directive; input expected from file ANREP, output (control listing of directives and system responses) will be written to the file SCR, normally not of further use.

Content of file ANREP is defined by a .DATA - directive.

Character-String DATA will be substituted everywhere it is not protected by a -sign.

Depending on key "DATE" elements available in the base are extracted upon FILE1.

Definition of a Report named INVENTORY. By the same name a local file is established on which the Report-output is listed after calling the PREPARE directive.

Directives DETAIL, TITLE, PAGE-SIZE etc. define the overall structure of the report.

Report INVENTORY is prepared from the content of file FILE1.

Control of job is returned to the calling procedure; the COPYBF,INVENTORY.-statement serves for listing output on a line printer. During interactive work at a video-terminal, output can be listed on the screen.

Fig. 3: Procedures Listing (continued)

```
      PROGRAM QUP(INPUT,OUTPUT,TAPE22,TAPE30)
      DIMENSION I(16)
      CALL REMARK(15HQUP FROM TAPE22)
C
C
C       DATA  ELEMENTS ARE FILLED WITH LEADING ZEROS
C       TO CIRCUMVENT BLANKS DURING INPUT FOR THE
C       QUERY UPDATE SYSTEM
C
C
      REWIND 22
      REWIND 30
    1 READ(22,20)(I(K),K=1,16)
      IF(EOF(22))100,2
   20 FORMAT(2I4,I5,I7,12I5)
    2 CONTINUE
      DO 23 L=1,16
      IF(I(L).EQ.0)I(L)=+0
   23 CONTINUE
      WRITE(30,21)(I(K),K=1,16)
   21 FORMAT(2I4.4,I5.5,I7.7,12I5.5)
      GOTO 1
  100 REWIND 30
      CALL REMARK(15HQUP UPON TAPE30)
      STOP
      END
```

Fig. 4: Auxiliary Program QUP (used in proc. QUPRE, see Fig. 3)

User Manual for Data-Base System GEODATA under QUERY UPDATE

Use of magnetic tapes (9-track) is supported, only.

Control of INSERT and UPDATE is established by procedures IN1, UP1, UP2, and UP3.

Functions of procedures in detail:

a) IN1: Input of theoretical tides (vertical comp.) is requested. Values for elements STATION-NO, DATE, and JULDAT are assigned. For each UPDATE requested lateron, at least DATE must be defined.

b) UP1: Input of ANALOG-recorded values is requested. Additionally, INSTRUMENT-NO is assigned.

c) UP2: Input of DIGITAL-recorded values is requested.

d) UP3: Input of AIR-PRESSURE is requested.

Job-Structure:

```
Job...,CM100000,T300,IO500,NT1.
VSN,NT=1075.      RING
ATTACH,QUPCC,ID=1723,PW=LET.
BEGIN, proc,QUPCC.
E - O - S
 data
E - O - F
```

use appropriate name for parameter proc. IN1, UP1, UP2, or UP3.

Listing of input-data will not occur! Control by separately running procedure LIST (report INVENTORY) .

Fig. 5: User-Manual

User Manual (continued)

Extracts of Data-Groups on Punched Cards or Local Files

Procedure CARDS generates selective extracts from GEODATA on Punched-Cards or preparing a local file for further use in an analysis program.

Job-Structure:

```
Job...,CM100000,T300,IO300,NT1.
VSN,NT=1075.        NORING
ATTACH,QUPCC,ID=1723,PW=LET.
BEGIN,CARDS,QUPCC,data,from,to.
     .
     .
     .
E - O - F
```

After the BEGIN,CARDS,...-statement, statements for further job processing can be inserted. The data requested reside on file FILE1 in international format.

Listing Information from Data-Base GEODATA

Procedure LIST generates selective extracts of data-groups from GEODATA.

Job-Structure:

```
Job...,CM100000,T300,IO300,NT1,FC=YES.
VSN,NT=1075.        NORING
ATTACH,QUPCC,ID=1723,PW=LET.
BEGIN,LIST,QUPCC,data,from,to.
E - O - F
```

Description of Parameters:

data — naming data-group.
admissible names: THEORY, ANALOG, DIGITAL, AIR-PRESSURE

from
to — start and stop date of time-interval requested. All data of group are listed. The format of this parameter is identical with the format of Gregorian date as aggreed upon with tide-recordings:

jjmmddx : jj= year
mm= month
dd= day
x = O or 2 (identifying half-days)

Fig. 5: User-Manual (continued)

```
TUB  NOS/BE 1.2            L447 F      20/03/79
09.55.42.A17235A  FROM
09.55.42.IP  00000192 WORDS - FILE INPUT  , DC 04
09.55.45.A1723,PW=**,CM110000,T300,IO300,NT1,FC=)
09.55.45.ES.
09.55.46.
09.55.46.VSN,NT=1075.  *** OHNE RING****
09.55.46.
09.55.46.
09.55.46.
09.55.46.ATTACH,QUPCC,ID=1723,PW=*---*.
09.55.46.PFN IS
09.55.46.QUPCC
09.55.46.PF CYCLE NO. = 001
09.55.47.BEGIN,UP3,QUPCC.
09.55.49.BEGIN,QUPRE,QUPCC.
09.55.50.LABEL,NT,R,L=GEODATA,D=PE,RING.
09.56.41.( NT 052 ASSIGNED)
09.56.41.NT52 VOLUME SERIAL NUMBER IS  001075
09.56.43. LABEL READ WAS      GEODATA
09.56.43.   EDITION NUMBER    00
09.56.43.   RETENTION CYCLE   999
09.56.43.   CREATION DATE     78139
09.56.43.   REEL NUMBER       0001
09.56.43.COPYBF,NT,GEODATA.
10.00.52.REWIND,GEODATA.
10.00.53.ATTACH,ASLIB,PERMFILE1723ASTROLIB,ID=17
10.00.53.3,MR=1.
10.00.54.PF CYCLE NO. = 001
10.00.55.LIBRARY,ASLIB.
10.01.03.COPYBR,INPUT,TAPE22.
10.01.12.REWIND,TAPE22.
10.01.13.QUP.
10.01.35.  CM LWA+1 = 23260B, LOADER USED  37300
10.01.35.QUP FROM TAPE22
10.01.36.QUP AUF TAPE30
10.01.36.     STOP
10.01.36.COPYBF,TAPE30,KARTEN.
10.01.38.RETURN,TAPE22,TAPE30.
10.01.46.REWIND,KARTEN.
10.01.49.FILE,KARTEN,RT=Z.
10.01.52.REQUEST,QUJ,*Q.
10.02.00.COPYBR,QUCO,QUJ.
10.02.02.EOI ENCOUNTERED IMMEDIATELY BY COPYBR
10.02.02.QU,I=QUINO,T=QUF.
10.03.14.SKIPB,QUF.
10.03.16.COPYBR,QUF,QUJ.
10.03.17.REWIND,KARTEN.
10.03.18.COPYBF,KARTEN,QUJ.
10.03.19.ROUTE,QUJ,DC=IN,TID=C,ST=TUB.
10.03.20.
10.03.20.
10.03.20.RETURN,KARTEN,QUINO,QUF,QUCO.
10.03.21.ROUTE,OUTPUT,DC=SC.
10.03.21.  ROUTED  A17235A
10.03.22.REVERT.CCL
10.03.23.BEGIN,SAVE,QUPCC.
10.03.30.REWIND,NT,GEODATA.
10.03.33.COPYBF,GEODATA,NT.
10.03.37.TAPE I/O ERROR
10.03.37. UNIT 52 TYPE 669
10.03.37. FILE NAME  NT
10.03.37. FET ADDRESS  000615
10.03.37.SHOULD WRITING BE ALLOWED ON UNEXPIRED TAPE
10.04.07.YES.
10.09.37.UNLOAD,NT.
10.09.39.NT52  BLOCKS WRITTEN -000706
10.09.40. ************************
10.09.40. *
10.09.40. *  CONTROL OF DATA
10.09.40. *  BY REPORT
10.09.40. *  PROCED. L I S T
10.09.40. *
10.09.40. ************************
10.09.40.REVERT.CCL
10.09.53.REVERT.CCL
10.09.56.ROUTE,OUTPUT,DC=LS,TID=C.
```

← Name the magnetic tape, on which the data-base resides. (line 09.55.46.VSN)

← This permanent file contains all procedures that are callable by a BEGIN,... statement. (line 09.55.46.ATTACH)

Procedures are described in Fig. 3.

Fig. 6: Example Job Dayfile for Update-Run

```
TUB  NOS/BE 1.2          L447 F      20/03/7
08.58.05.A172315  FROM
08.58.05.IP  00000128 WORDS - FILE INPUT  , DC 04
08.58.06.A1723,PW=**,CM100000,T300,IO500,NT1,FC=Y
08.58.06.ES.
08.58.06.
08.58.06.VSN,NT=1075.  *** OHNE RING****
08.58.06.ATTACH,QUPCC,ID=1723,PW=*---*.
08.58.06.PFN IS
08.58.06.QUPCC
08.58.06.PF CYCLE NO. = 001
08.58.07.BEGIN,CARDS,QUPCC,THEORIE,7803010,780402
08.58.07.2.
08.58.07.BEGIN,COPTAP,QUPCC.
08.58.08.LABEL,NT,R,L=GEODATA,D=PE,NORING.
08.58.08.( NT 052 ASSIGNED)
08.58.08.NT52 VOLUME SERIAL NUMBER IS  001075
08.58.09. LABEL READ WAS      GEODATA
08.58.09.   EDITION NUMBER    00
08.58.09.   RETENTION CYCLE   999
08.58.09.   CREATION DATE     78139
08.58.09.   REEL NUMBER       0001
08.58.09.COPYBF,NT,GEODATA.
08.58.40.UNLOAD,NT.
08.58.40.NT52  BLOCKS READ 000706
08.58.40.REWIND,GEODATA.
08.58.40.REVERT.CCL
08.58.41.REQUEST,FILE1,*Q.
08.58.41.FILE,FILE1,RT=Z,BT=C.
08.58.41.QU,I=CARDC,RO,O=SCR.
08.58.50.RETURN,QUPCC,CARDC.
08.58.50.REWIND,FILE1.
08.58.50.COPYSBF,FILE1.
08.58.50.REWIND,FILE1.
08.58.50.COPYBF,FILE1,PUNCH.
08.58.50.EOI ENCOUNTERED AFTER COPY OF FILE
08.58.50.          0, RECORD  1
08.58.50.ROUTE,PUNCH,TID=C.
08.58.50.OP  00000704 WORDS - FILE PUNCH  , DC 10
08.58.50.  ROUTED  A172315
08.58.51.REWIND,FILE1.
08.58.51. ****************************************
08.58.51. *
08.58.51. *  DATA ON FILE  P U N C H
08.58.51. *  REQUEST CARDS FROM CENTRAL SITE
08.58.51. *
08.58.51. ****************************************
08.58.51. *
08.58.51. *  CONTINUE ANALYSIS OF DATA
08.58.51. *  FROM  F I L E 1
08.58.51. *
08.58.51. ****************************************
08.58.51.REVERT.CCL
08.58.51.OP  00001728 WORDS - FILE OUTPUT , DC 40
08.58.52.MS    7168  WORDS  (  129024 MAX USED)
08.58.52.CPA      5.632 SEC.        2.816 ADJ.
08.58.52.CPB       .959 SEC.         .479 ADJ.
08.58.52.IO      12.239 SEC.        4.895 ADJ.
08.58.52.CM     216.379 KWS.        3.461 ADJ.
08.58.52.SS                        11.654
08.58.52.PP      38.391 SEC.    DATE 04/04/79
08.58.52.EJ  END OF JOB, **
```

Fig. 6: (continued) Dayfile of CARDS- Job

BESTAND THEORIE VON DATUM 7805050 BIS DATUM 7807010 -03/04/79 13.24.33 PAGE 00003

GERAET	STATION	JULDAT	DATUM	GEZEITEN-THEORIE 12 WERTE											
318	750	43668	7806090	-0584	-0557	-0575	-0625	-0677	-0696	-0651	-0521	-0309	-0035	00257	00518
318	750	43669	7806092	00700	00764	00697	00510	00238	-0069	-0360	-0590	-0733	-0784	-0760	-0691
318	750	43669	7806100	-0614	-0556	-0536	-0551	-0587	-0614	-0605	-0535	-0393	-0188	00054	00295
318	750	43670	7806102	00492	00605	00609	00501	00297	00034	-0242	-0487	-0666	-0762	-0778	-0732
318	750	43670	7806110	-0654	-0573	-0514	-0487	-0489	-0505	-0512	-0487	-0412	-0284	-0111	00081
318	750	43671	7806112	00262	00396	00452	00415	00286	00085	-0153	-0391	-0591	-0725	-0782	-0767
318	750	43671	7806120	-0700	-0607	-0513	-0439	-0395	-0379	-0380	-0380	-0360	-0307	-0216	-0095
318	750	43672	7806122	00039	00160	00242	00260	00203	00073	-0110	-0319	-0519	-0678	-0773	-0795
318	750	43672	7806130	-0750	-0655	-0535	-0414	-0315	-0250	-0221	-0220	-0235	-0246	-0240	-0206
318	750	43673	7806132	-0145	-0069	00003	00050	00050	-0008	-0124	-0285	-0464	-0630	-0754	-0813
318	750	43673	7806140	-0799	-0716	-0582	-0422	-0264	-0135	-0052	-0023	-0043	-0098	-0165	-0225
318	750	43674	7806142	-0258	-0259	-0230	-0189	-0156	-0156	-0203	-0300	-0438	-0591	-0729	-0822
318	750	43674	7806150	-0844	-0787	-0654	-0467	-0256	-0056	00098	00186	00194	00129	00011	-0131
318	750	43675	7806152	-0266	-0367	-0418	-0422	-0392	-0357	-0343	-0372	-0451	-0570	-0705	-0820
318	750	43675	7806160	-0880	-0860	-0749	-0555	-0304	-0036	00202	00373	00446	00411	00278	00078
318	750	43676	7806162	-0147	-0358	-0515	-0601	-0616	-0582	-0531	-0499	-0512	-0578	-0687	-0808
318	750	43676	7806170	-0901	-0926	-0855	-0680	-0415	-0096	00224	00492	00660	00698	00601	00387
318	750	43677	7806172	00100	-0207	-0480	-0676	-0777	-0788	-0738	-0667	-0619	-0622	-0685	-0790
318	750	43677	7806180	-0901	-0971	-0956	-0827	-0582	-0245	00135	00498	00778	00926	00912	00741
318	750	43678	7806182	00444	00077	-0294	-0609	-0824	-0921	-0916	-0844	-0757	-0700	-0703	-0771
318	750	43678	7806190	-0878	-0980	-1025	-0965	-0778	-0466	-0067	00360	00745	01018	01128	01054
318	750	43679	7806192	00811	00443	00016	-0395	-0726	-0936	-1016	-0988	-0898	-0801	-0745	-0758
318	750	43679	7806200	-0835	-0945	-1037	-1055	-0953	-0713	-0349	00092	00542	00924	01169	01231
318	750	43680	7806202	01098	00796	00379	-0076	-0497	-0818	-1005	-1058	-1007	-0903	-0805	-0759
318	750	43680	7806210	-0784	-0871	-0981	-1060	-1051	-0913	-0637	-0245	00209	00651	01004	01204
318	750	43681	7806212	01213	01031	00691	00256	-0197	-0595	-0883	-1033	-1054	-0982	-0871	-0777
318	750	43681	7806220	-0741	-0776	-0867	-0971	-1033	-1001	-0842	-0552	-0162	00270	00673	00973
318	750	43682	7806222	01116	01075	00858	00506	00084	-0336	-0688	-0925	-1029	-1016	-0925	-0809
318	750	43682	7806230	-0719	-0688	-0726	-0811	-0902	-0946	-0900	-0737	-0461	-0105	00273	00609
318	750	43683	7806232	00840	00922	00840	00608	00269	-0114	-0479	-0768	-0945	-1001	-0955	-0846
318	750	43683	7806240	-0723	-0631	-0597	-0625	-0695	-0768	-0800	-0752	-0607	-0372	-0078	00222
318	750	43684	7806242	00476	00631	00658	00548	00320	00015	-0312	-0608	-0828	-0944	-0953	-0875
318	750	43684	7806250	-0748	-0614	-0511	-0464	-0474	-0524	-0582	-0610	-0578	-0473	-0300	-0088
318	750	43685	7806252	00123	00292	00380	00365	00245	00039	-0217	-0482	-0708	-0862	-0922	-0889
318	750	43685	7806260	-0782	-0633	-0481	-0359	-0291	-0280	-0314	-0365	-0405	-0407	-0359	-0264

Fig. 7: Sample page from Report INVENTORY