THE NANOGAL SOFTWARE: EARTH TIDE DATA PROCESSING PACKAGE

ETERNA 3.30

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Abstract

This is to announce that the new version 3.30 of the earth tide data processing package ETERNA will be available after July 1st, 1996. The earth tide data processing package ETERNA version 3.30 allows the recording, preprocessing and analysis of earth tide observations under operating system MS-DOS on an IBM-AT compatible personal computer 80386/387 upwards. The computing kernels DETIDE, DESPIKE, ANALYZE, OCELOAD and PREDICT may also be compiled on a work station under UNIX operating system. The new standard format for the storage and exchange of high rate or high resolution earth tide data (Wenzel 1995) is used in all parts of the ETERNA 3.30 package.

Compared to previous versions, we have included into the earth tide analysis package ETERNA (e.g. Wenzel 1994b,c) the most accurate tidal potential catalogue by Hartmann and Wenzel (1995a,b). In all programs, the DUT1 correction due to the Earth's variable rotation has been implemented using DUT1 values provided by the International Earth Rotation Service IERS. Together with the Hartmann and Wenzel (1995) tidal potential catalogue, this upgrade enables the preprocessing and analysis of earth tide observations and the prediction of earth tide signals with a model accuracy better than 1 ngal (1 ngal = 0.01 nm/s^2).

Several parts of the ETERNA earth tide analysis package have been rewritten and several other pieces have been added. For the computation of the tidal signals we have implemented recursion formulas which reduce the total computation time for some data sets down to 35% compared to previous versions without loss of accuracy. The ETERNA package has been given a new and better structure, and several programs have been renamed (e.g. the former program ETERNA has been renamed to ANALYZE, the former program ETGTAB has been renamed to PREDICT, the former program PRETERNA has been splitted into programs DETIDE and DESPIKE). The program OCELOAD has been included which enables the computation of ocean tide loading effects using the Schwidersky (1980) ocean tide model. We believe that a substantial improvement with respect to accuracy, flexibility and operational comfort has been achieved compared to previous versions of the package. ETERNA 3.30 is currently the only earth tide data processing package beeing able to process earth tide observations with a model accuracy better than 1 ngal.

1 Structure of ETERNA 3.30

The ETERNA 3.30 package is installed by an automatic installation procedure within several directories (Fig. 1). It consists of the programs

Directory	Program	Purpose
RECTID	RECTID	earth tide recording program
	ETSTEP	instrumental phase lag determination by step response
	STEPPLOT	plot of recorded step response
PREPRO	DETIDE	calibration and detiding of earth tide observations
	PREGRED	graphical editor for earth tide data preprocessing
	DESPIKE	despiking and decimation of earth tide observations
	PREPLOT	plot of earth tide data
ANALYZE	ANALYZE	analysis of earth tide observations
	PLOTDATA	plot of data and residuals
	PLOTHIST	plot of a histogram of residuals
	PLOTSPEC	plot of a spectrum of residuals
	PLOTRESA	interactive plot of residuals
	RESFFT	FFT spectrum of the residuals
OCELOAD	OCELOAD	computation of ocean tide loading
PREDICT	PREDICT	prediction of earth tides

Earth tide data acquisition can be carried out with program RECTIDE (in MS-QuickBasic), which allows the sampling of data from different sensors at 1 s or 5 s interval. After on-line subtraction of computed model tides from the sampled data, the residuals are displayed on the colour graphic screen of the pc. The sampled data are numerically filtered using a symmetrical FIR lowpass filter with zero phase shift; the filtered data are decimated to 1 min interval and the decimated data are stored on diskette and hard disk.

The preprocessing of 1 min earth tide and meteorological data can be carried out with programs DETIDE, DESPIKE (in Fortran 77/90) amd PREGRED (in MS-Visual C++). The data preprocessing is carried out using a remove-restore technique: At first all well-known signals (computed model tides and computed air pressure influence) are removed with program DETIDE. The graphical editor PREGRED (Vetter and Wenzel 1995) is a very comfortable tool to delete corrupted parts of the data, to correct steps and to interpolate gaps under graphical control of the operator. With program DESPIKE, the residual signal (the earth tide sensor's drift) is automatically cleaned (destepped, despiked, and degapped) and the known signals are added back to the cleaned residual signal. The corrected samples at 1 min interval are finally numerically filtered and decimated to 5 min samples and subsequently to hourly samples. For the data preprocessing may be used

- up to 500 data sets within one batch run,
- up to 300 data blocks for each data set,
- as observations: tidal potential, gravity tides, tilt tides, vertical displacements, horizontal displacements, vertical strain, horizontal strain, areal strain, shear strain, volume strain and ocean tides,
- seven different tidal potential developments (Doodson 1921, Cartwright et al. 1971, 1973, Büllesfeld 1985, Tamura 1987, Xi 1989, Roosbeek 1996, Hartmann and Wenzel 1995),
- up to 85 wavegroups,
- up to 8 additional meteorological parameters.

The analysis of earth tide observations can be carried out with program ANALYZE (in Fortran 77/90), using the least squares adjustment procedure with multi channel input to derive tidal parameters, pole tide parameters and meteorological parameters. The spectrum of the residuals is used to derive standard deviations of the adjusted parameters. The mathematical model of the ANALYZE earth tide analysis program has been developed by Chojnicki (1973) and modified and completed by Schüller (1976, 1977a, 1977b, 1978, 1986), and Wenzel (1976a, 1976b, 1977, 1994a, b). With ANALYZE version 3.30 may be used

- up to 500 different data sets within one batch run,
- up to 300 data blocks for each data set,
- up to 85 wavegroups,
- up to 175 unknown parameters,
- unlimited number of observations within each data block,
- seven different tidal potential developments (Doodson 1921, Cartwright et al. 1971, 1973, Büllesfeld 1985, Tamura 1987, Xi 1989, Roosbeek 1996, Hartmann and Wenzel 1995),
- single- or multi-channel input,
- up to eight meteorological parameters,
- correction of pole tides with a priori pole tide parameters,
- correction of gravity variations due to length of day variation,
- adjustment of pole tide regression parameters,
- either highpass filtering of the data or drift modelling,
- in case of highpass filtering: eight symmetric numerical FIR filters of different length and quality are available,
- in case of drift modelling: Tschebyscheff-polynomials of individual degree per observation block may be adjusted,
- unity window or Hann-window may be applied for the weights of the least squares adjustment,
- error estimation by least squares adjustment or by Fourier-spectrum of residuals.

The prediction of earth tide signals can be carried out with program PREDICT, using the same parameter model as in program ANALYZE. With PREDICT version 3.30 may be used

- up to 85 wavegroups,
- seven different tidal potential developments (Doodson 1921, Cartwright et al. 1971, 1973, Büllesfeld 1985, Tamura 1987, Xi 1989, Roosbeek 1996, Hartmann and Wenzel 1995),
- gravity pole tides with a priori pole tide parameters,
- gravity variations due to length of day variation.

The computation of ocean tide loading effects can be carried out with program OCELOAD, using the Schwidersky (1980) global ocean tide model and applying loading Green's functions. More recent global ocean tide models from satellite altimetry will probably be included in future versions of the program.

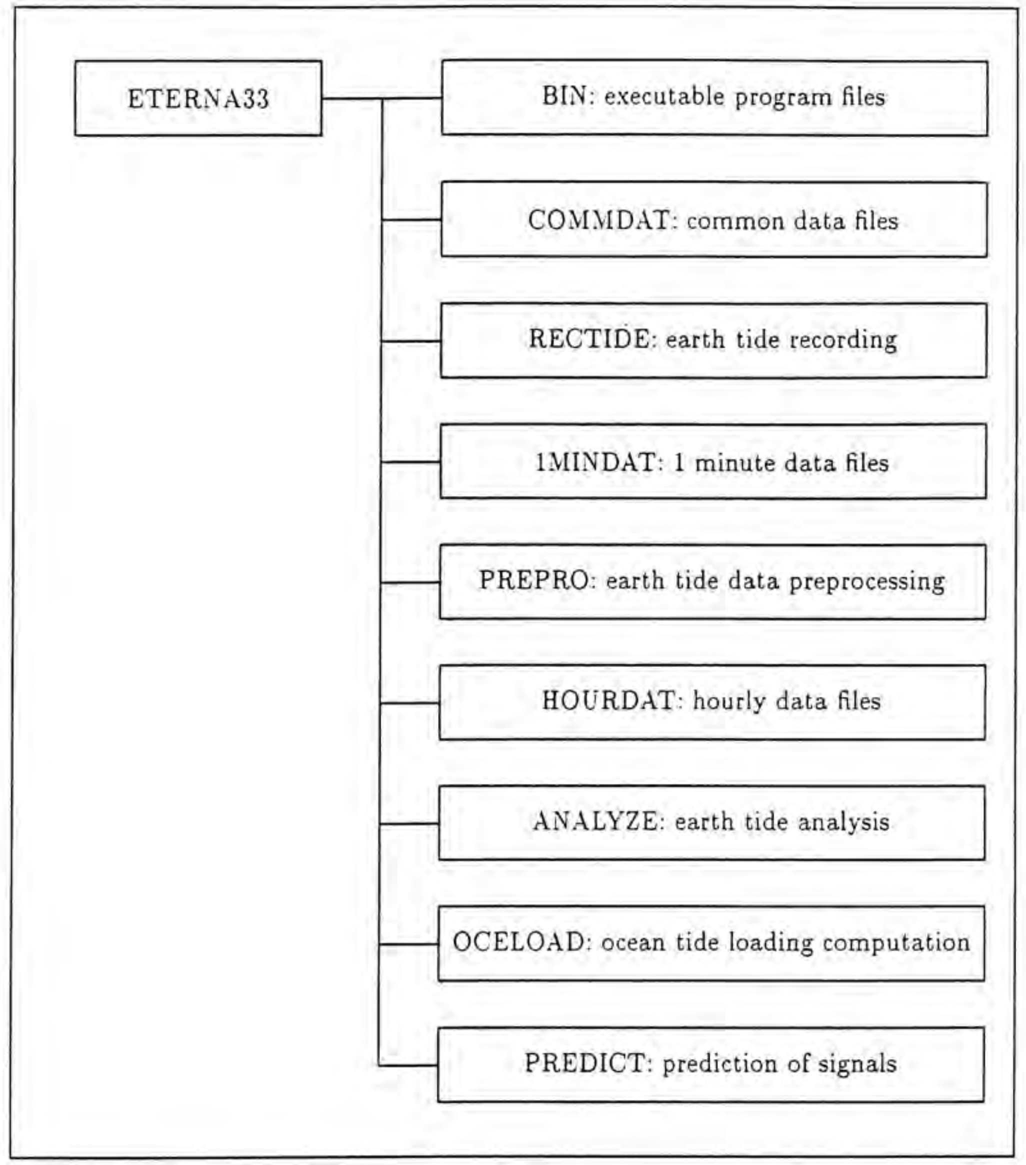

Fig. 1: Directories of the earth tide data processing package ETERNA version 3.30

2 Accuracy of ETERNA 3.30

Within the last year, a new tidal potential catalogue (Hartmann and Wenzel 1995) became available which allows the computation of earth tide signals with an accuracy better than 1 ngal, as has been verified by comparison with different benchmark gravity tide series (Wenzel 1996). Therefore, the Hartmann and Wenzel (1995) tidal potential catalogue using in total 12 935 tidal waves has been implemented into the ETERNA package version 3.30. This tidal potential catalogue includes the potential due to the Moon up to degree 6, to the Sun up to degree 3, to the planets Mercury, Venus, Mars, Jupiter and Saturn to degree 2, and the potential due to the Earth's flattening by the Moon and the Sun. The errors of gravity tides computed from the Hartmann and Wenzel (1995) tidal potential catalogue are 1.4 pm/s^2 rms and 10.4 pm/s^2 (1 pm/s^2 = 0.1 ngal) at maximum, as has been verified by comparison with several different benchmark gravity tide series (Wenzel 1996).

Because the computation of tides using the full 12 935 tidal waves of the Hartmann and Wenzel (1995) tidal potential catalogue is rather time consuming and may often be unnessesary compared to the accuracy of the data, a truncation parameter may be used to truncate the tidal potential catalogue, which degrades the accuracy of the computed tides but saves computation time. Due to the truncation option, there is in principle no need to use other tidal potential catalogues, even if very rough tidal computations shall be carried out. Nevertheless, we have made available with ETERNA 3.30 seven different tidal potential catalogues for comparison purpose. Because the Hartmann and Wenzel (1995) potential uses a straighforward and simple normalization beeing different from the complicated Doodson (1921) normalization, the tidal potential catalogues of Doodson (1921), Cartwright et al. (1971, 1973), Büllesfeld (1985), Tamura (1987), Xi (1989) and Roosbeek (1996) have been transformed into the Hartmann and Wenzel (1995) normalization. Resulting from intensive accuracy tests, the astronomical arguments from Tamura (1987) are used for the tidal potential catalogues of Doodson (1921), Cartwright et al. (1971, 1973), Büllesfeld (1985), Tamura (1987), and Xi (1989). For Roosbeek (1996) and Hartmann and Wenzel (1995), the astronomical arguments given in Hartmann and Wenzel (1995) are used.

Because the astronomical arguments are computed by polynomials of up to degree 4, it is necessary to recompute the phases of the tidal waves from the astronomical arguments at monthly interval in order to achieve the desired accuracy for the computation of tidal signals. For the computation of the tidal signals we have implemented recursion formulas which reduce the total computation time of programs ANALYZE, DETIDE and PREDICT for some data sets down to 35% compared to previous versions without loss of accuracy.

Within ETERNA 3.30, the time scale of the observations (or predicted signals) is assumed to be UTC (Universal Time Coordinated), which is distributed by radio transmitters and by GPS (Global Positioning System). For the accurate computation of tides, the time scales UT1 (Universal Time No. 1, describes the rotation of the Earth) and TDB (Dynamical Barycentric Time, used to describe the positions of the Moon and of the planets) have to be made available. Within ETERNA 3.30 we have implemented for the first time for tidal computations the correction DUT1 = UT1 - UTC, which is interpolated from daily tabulated values of DUT1 provided by the International Earth Rotation Service IERS. The difference DDT = TDT - UTC, which is constant for several months or years, is also taken from a table. The difference TDB - TDT (a few ms only) is computed from a closed formula. The effect of DUT1 can reach 0.1 nm/s^2 at maximum (e.g. Fig. 8, 9).

The accuracy of the tidal potential catalogue by Hartmann and Wenzel (1995) has been estimated by comparison with several gravity tide benchmark series (Wenzel 1996). We have used here a gravity tide benchmark series called BFDE403E computed from the most recent and most accurate DE403/LE403 ephemerides (Standish et al. 1995) to verify the accuracy of the model tide computation within ETERNA 3.30. The series BFDE403E consists of hourly gravity tides for a rigid model Earth computed directly from the ephemerides of the Moon, Sun, Mercury, Venus, Mars, Jupiter and Saturn at station BFO ($\phi = 48.3306^0, \lambda = 8.3300^0$, h = 589 m) between January 1st 1987 and December 31st 1994. This benchmark series has been computed for the UTC time scale and has included corrections DUT1 and DDT. The accuracy of the BFDE403E benchmark gravity tide series is estimated to better than 1 pm/s^2. In Fig. 2 and 4 are given residuals of the earth tide analyis from program ANALYZE for the benchmark gravity tide series when using the tidal potential catalogues of Tamura (1987) and Hartmann and Wenzel (1995); in Fig. 3 and 5 are given the corresponding Fourier amplitude spectra. One has to have in mind that the residuals of the least squares adjustment always underestimate the errors, because the parameters determined by least squares adjustment absorb to a certain extend the errors. We can see maximum errors of 0.5 nm/s^2 and 0.012 nm/s^2 resp. in time domain and 0.015 nm/s^2 and 0.0005 nm/s^2 resp. in frequency domain for the tidal potential catalogues of Tamura (1987) and Hartmann and Wenzel (1995) resp. In Tab. 1 is given the last page from program ANALYZE for the benchmark gravity

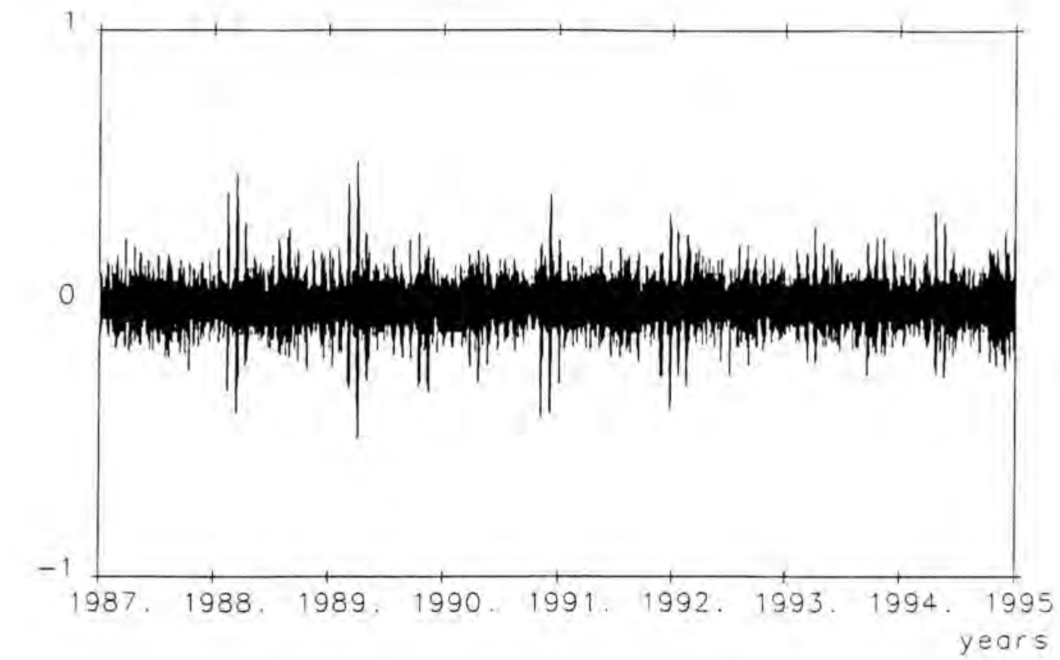

Fig.2: Residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Tamura (1987) tidal potential catalogue; DUT1 corrected.

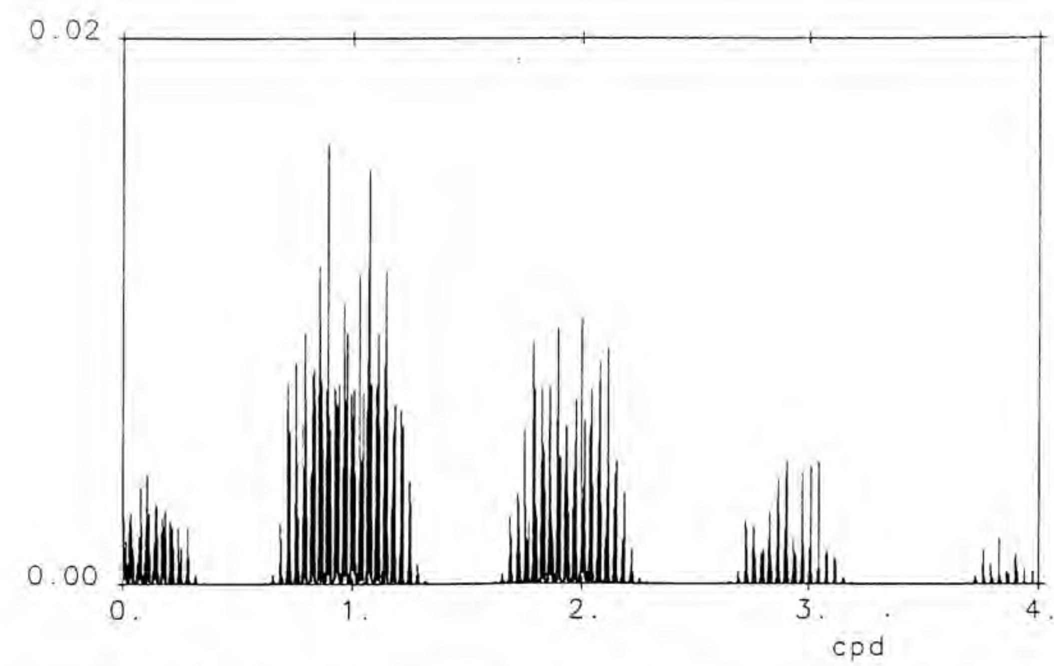

Fig.3: Amplitude spectrum of residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Tamura (1987) tidal potential catalogue; DUT1 corrected.

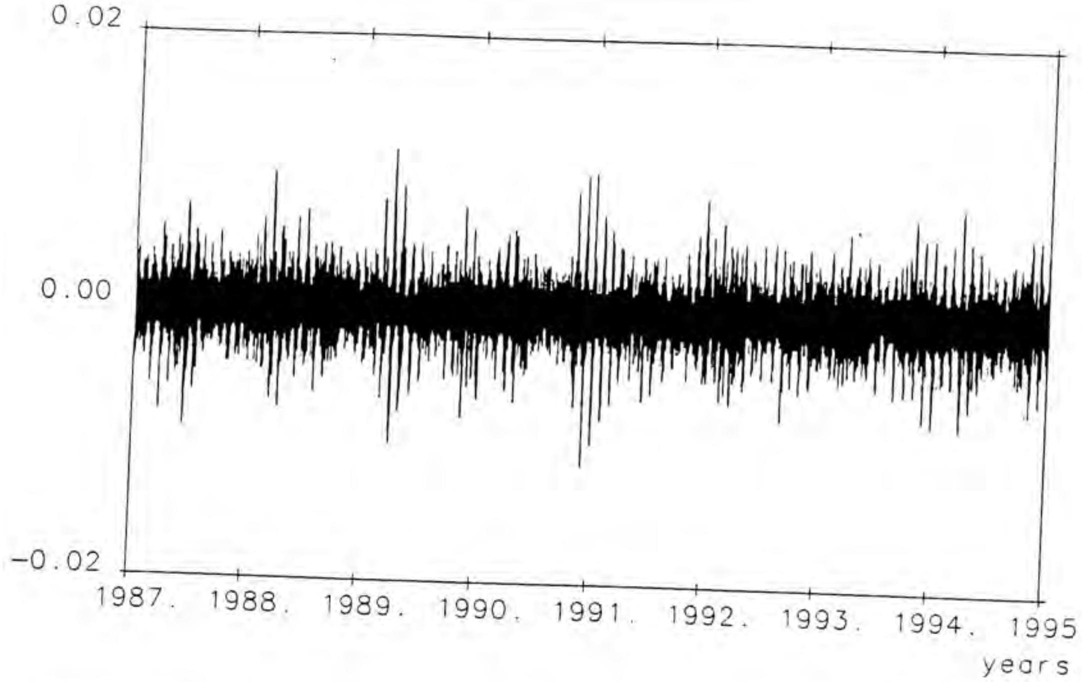

Fig.4: Residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 corrected.

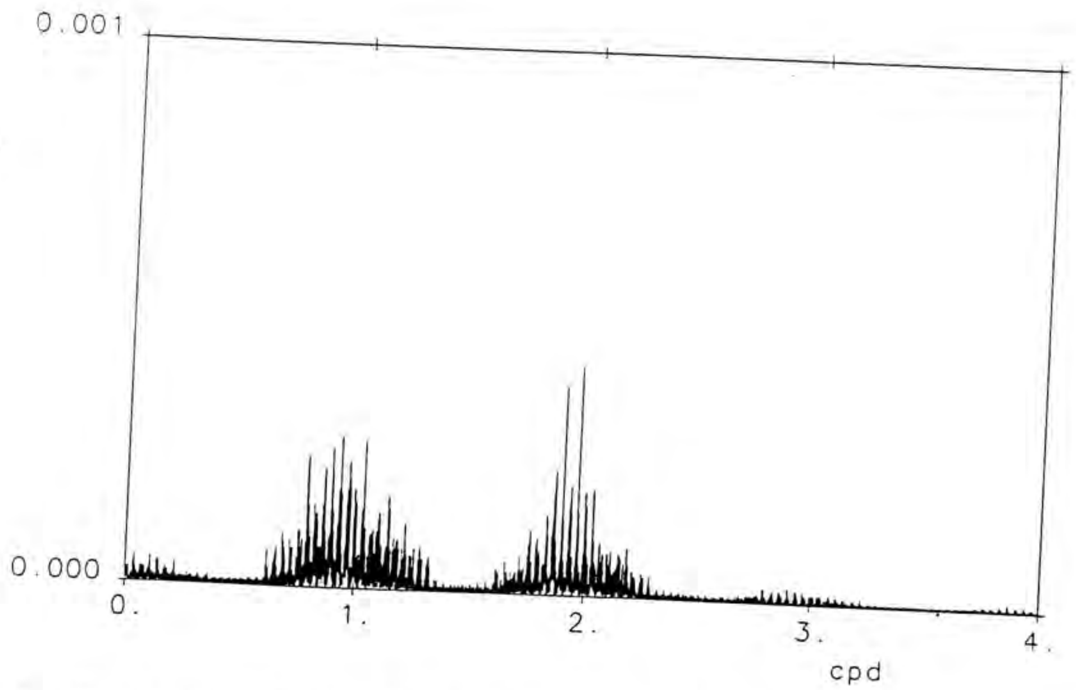

Fig.5: Amplitude spectrum of residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 corrected.

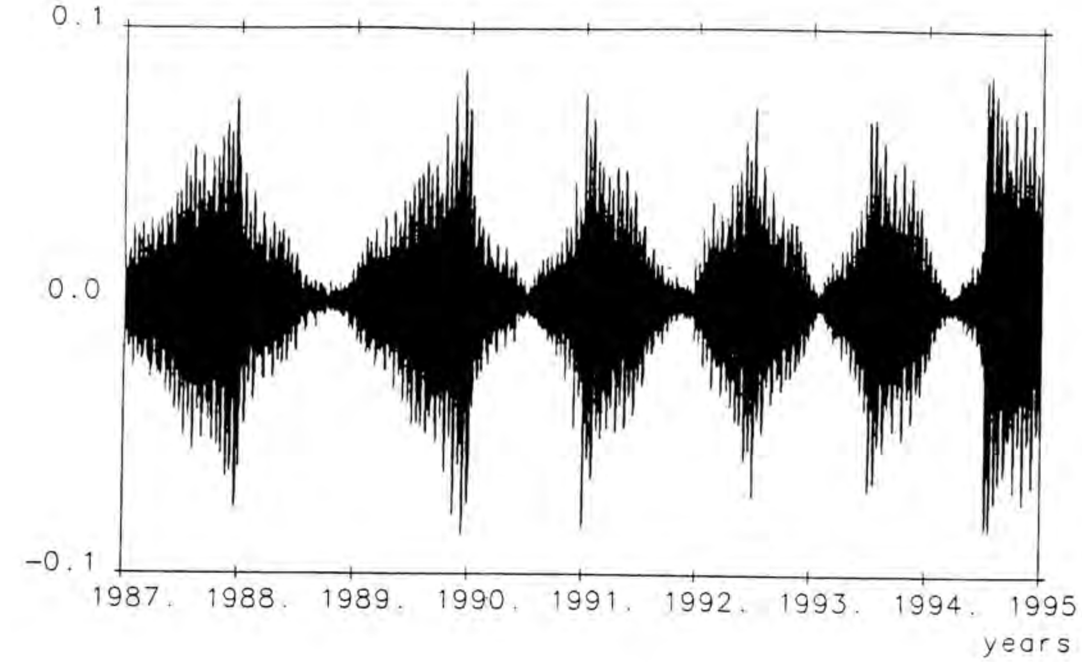

Fig.6: Residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 not corrected.

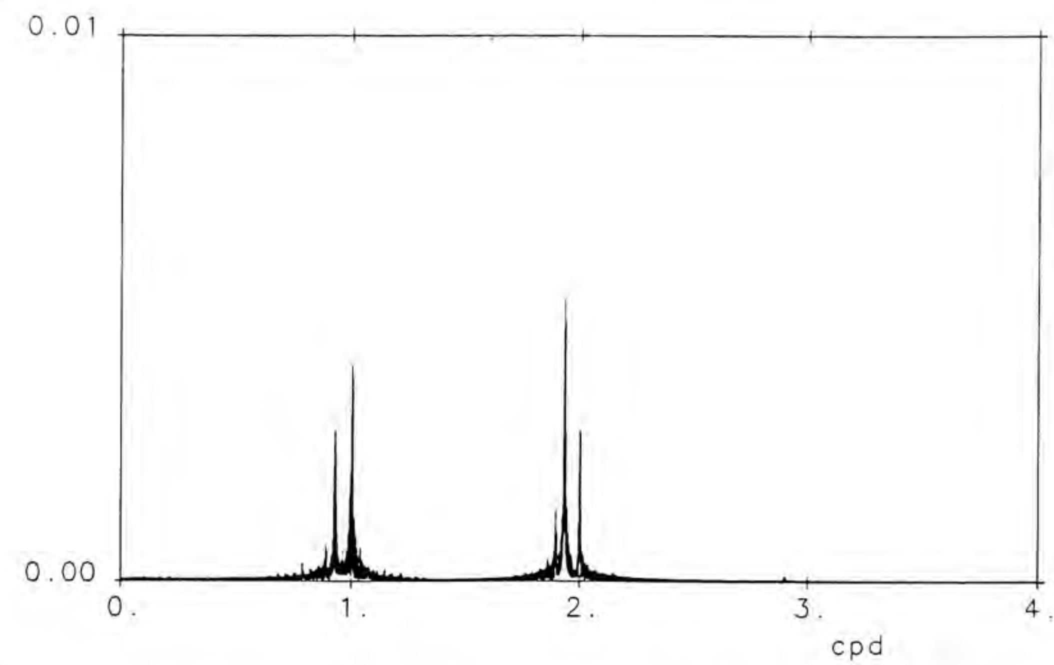

Fig.7: Amplitude spectrum of residuals of earth tide analysis with program ANALYZE for benchmark gravity tide series BFDE403E when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 not corrected.

Tab. 1: Result of analysis of benchmark gravity tide series BFDE403E

Program ANALYZE, version 3.30 960318 File: BFDE403E

Latitude: 48.3306 deg, longitude: 8.3300 deg, azimuth: 0.000 deg.
Summary of observation data : 19870101 0...19941231230000
Number of recorded days in total : 2922.00
HARTMANN+WENZEL 1995 tidal potential used.
Rigid Earth model used.
Inertial correction not applied.
UNITY window used for least squares adjustment.
Numerical filter is NO FILTER with 1 coefficients.
Spectral condition number of normal equations: 100.767

Estimation of noise by FOURIER-spectrum of residuals

0.1 cpd band	0.0000 nm/s**2	1.0 cpd band	0.0000 nm/s**2
2.0 cpd band	0.0000 nm/s**2	3.0 cpd band	0.0000 nm/s**2
4.0 cpd band	0.0000 nm/s**2	white noise	0.0000 nm/s**2

adjusted tidal parameters :

from [cpd]	to [cpd]	wave	ampl. [nm/s**2]	ampl.fac.	stdv.	ph. lead [deg]	stdv. [deg]
0.000100	0.004000	SA	18.0710	1.00001	0.00126	0.0003	0.0556
0.004001	0.020000	SSA	20.0225	1.00000	0.00001	0.0000	0.0004
0.020001	0.050000	MM	22.7686	1.00000	0.00000	-0.0001	0.0001
0.050001	0.080000	MF	43.1098	1.00000	0.00000	0.0000	0.0000
0.080001	0.600000	MTM	8.2541	1.00000	0.00000	-0.0001	0.0000
0.600001	0.910000	Q1	59.1065	1.00000	0.00000	0.0000	0.0000
0.910001	0.949000	O1	308.7083	1.00000	0.00000	-0.0001	0.0000
0.949001	0.980000	M1	24.2656	0.99999	0.00000	-0.0001	0.0001
0.980001	0.999000	P1	143.3722	1.00000	0.00000	-0.0001	0.0000
0.999001	1.001000	S1	3.4426	1.00003	0.00001	-0.0045	0.0007
1.001001	1.004000	K1	296.6587	1.00000	0.00000	-0.0001	0.0000
1.004001	1.006000	PSI1	3.4439	1.00000	0.00001	-0.0013	0.0005
1.006001	1.012000	PHI1	6.1680	0.99998	0.00000	-0.0003	0.0003
1.012001	1.050000	J1	24.2746	1.00000	0.00000	-0.0004	0.0001
1.050001	1.500000	OO1	13.2795	1.00000	0.00000	-0.0006	0.0001
1.500001	1.875000	2N2	10.1612	1.00000	0.00000	0.0004	0.0001
1.875001	1.910000	N2	63.6222	1.00000	0.00000	-0.0002	0.0000
1.910001	1.950000	M2	332.2901	1.00000	0.00000	-0.0002	0.0000
1.950001	1.985000	L2	9.3932	1.00000	0.00000	-0.0002	0.0001
1.985001	2.003000	S2	154.3181	1.00000	0.00000	-0.0003	0.0000
2.003001	2.500000	K2	28.7077	1.00000	0.00000	-0.0003	0.0000
2.500001	7.000000	M3M6	4.3445	1.00000	0.00000	-0.0004	0.0000

Adjusted TSCHEBYSCHEFF polynomial bias parameters :

block	degree	bias	stdv.
1	0	203.610182 nm/s**2	0.000018 nm/s**2
1	1	0.002442 nm/s**2	0.000052 nm/s**2

Standard deviation of weight unit:	0.002
Degree of freedom:	70082
Max. correlation:	-0.935 bias 1 2 X-wave-SA
Standard deviation:	0.002 nm/s**2

tide series BFDE403E when using the full Hartmann and Wenzel (1995) tidal potential catalogue. The maximum error of the adjusted tidal parameters is $3 \cdot 10^{-5}$ and 0.0045^0 for wave S1. In Fig. 6 and 7 are given the residuals and their Fourier amplitude spectrum for the benchmark gravity tide series BFDE403E when using the Hartmann and Wenzel (1995) tidal potential catalogue but neglecting the DUT1-correction within program ANALYZE. We can see that the DUT1-correction can amount up to 0.1 nm/s^2 in time domain and up to 0.005 nm/s^2 in frequency domain.

3 How to obtain ETERNA 3.30

The earth tide data processing package ETERNA 3.30 is available to anybody; the package should however not be copied and given to third parties by any user. In order to cover the expenses for copying and distributing the ETERNA package, a fee of US $ 300.- has to be charged to university and research institutes. The program files (source code and executable files), data files and result files are distributed either on 3.5" floppy disks or on a CD-Rom, together with a manual. All programs can be executed on an IBM-AT compatible personal computer 80386/387 upwards under MS-DOS operating system, and the computing kernels DETIDE, DESPIKE, ANALYZE, OCELOAD and PREDICT (written in Fortran 77 / Fortran 90) can also be compiled on a work station under UNIX operating system. Requests for the ETERNA 3.30 package should be submitted to (please use the order form on the last page for your convenience): Prof. Dr.-Ing. H.-G. Wenzel, Black Forest Observatory, Universität Karlsruhe, Englerstr. 7, D-76128 KARLSRUHE, Germany. Tel.: ++49-721-6082307, FAX: ++49-721-694552. e-mail: wenzel@gik.bau-verm.uni-karlsruhe.de

4 Conclusions

The implementation of the Hartmann and Wenzel (1995) tidal potential catalogue into the ETERNA 3.30 package was the final stroke under a four years project to improve the accuracy of the available tidal potential catalogues. We have now in our hands several tools to process earth tide data with very low model errors below 1 ngal.

One reason to improve the accuracy of the tidal potential catalogues was certainly that it was believed that the tidal potential catalogues available in 1989 could significantly contribute to the total error budget when processing high precision earth tide data. Thus, one could expect that improved tidal potential catalogues would reduce the residuals when analyzing high precision earth tide data. From the first application of the earth tide analysis program ANALYZE to different data sets (Tab. 2), we can see an improvement from the Doodson (1921) over the Cartwright et al. (1971,1973) to the Büllesfeld (1985) and the Tamura (1987) tidal potential catalogues. We can however hardly see any significant difference when using the tidal potential catalogues of Tamura (1987), Xi (1989), Roosbeek (1996) or Hartmann and Wenzel (1995) for the analysis of observed data. Even the most precise data sets currently available (which have partly been preprocessed with previous versions of ETERNA) are too much corrupted by other error sources (like e.g. atmospheric pressure induced gravity signals) to show the effect of using improved tidal potential catalogues (Fig. 8 ... 11); they are also unable to show the effect of the DUT1-correction.

Nevertheless, we believe that a substantial improvement with respect to accuracy, flexibility and operational comfort has been achieved compared to previous versions of the ETERNA package. ETERNA 3.30 is currently the only earth tide data processing package beeing able to process earth tide observations with a model accuracy better than 1 ngal.

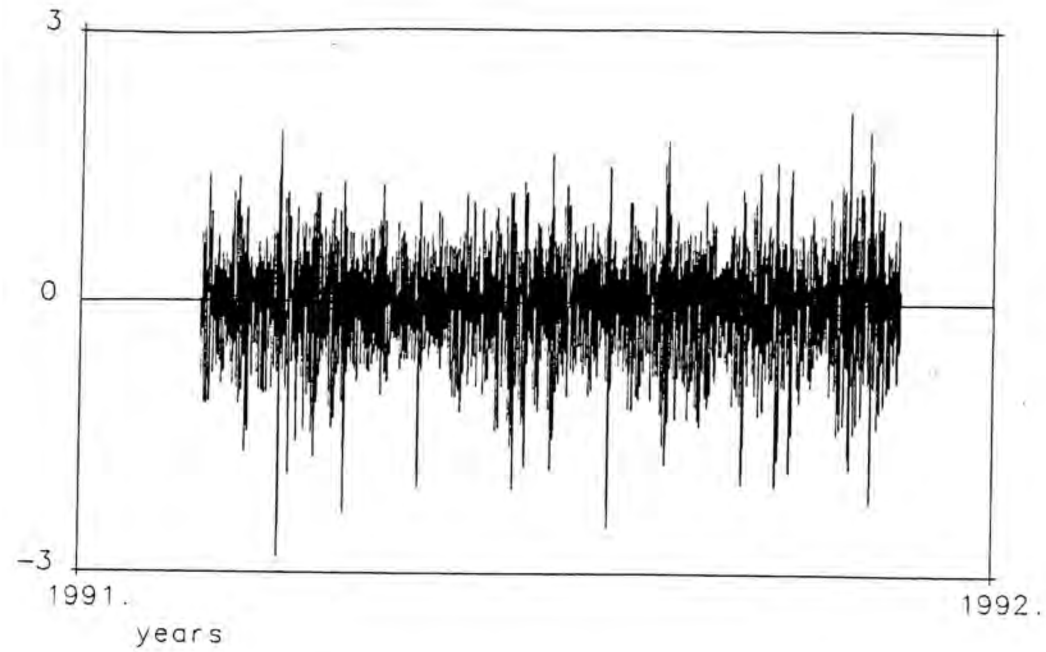

Fig.8: Residuals of earth tide analysis with program ANALYZE for observed gravity tide series BFET1907 when using the Tamura (1987) tidal potential catalogue; DUT1 corrected.

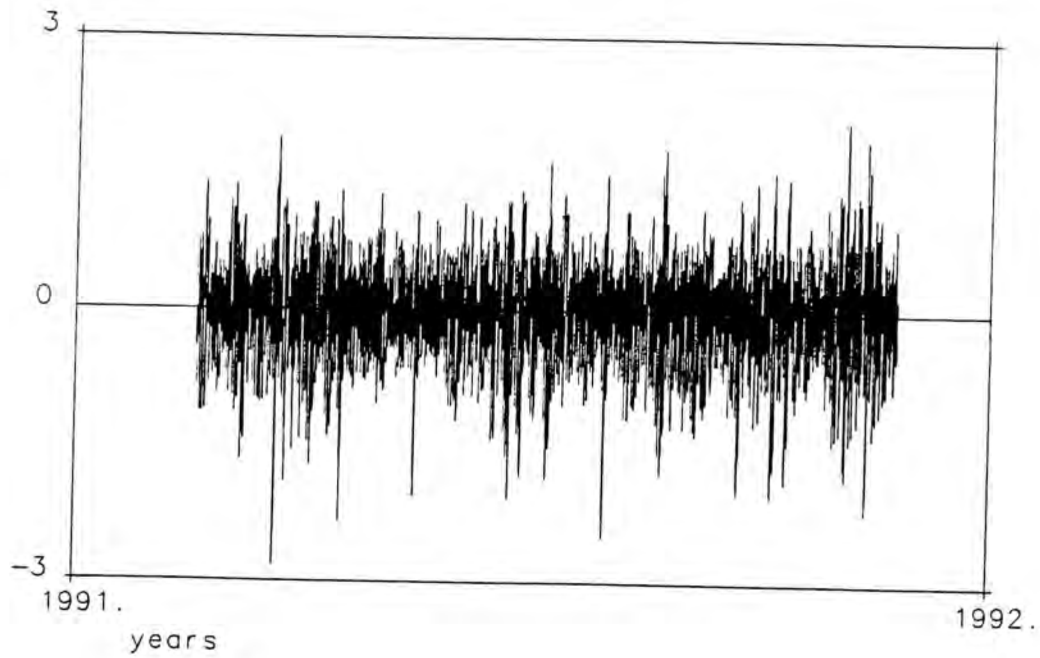

Fig.9: Residuals of earth tide analysis with program ANALYZE for observed gravity tide series BFET1907 when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 corrected.

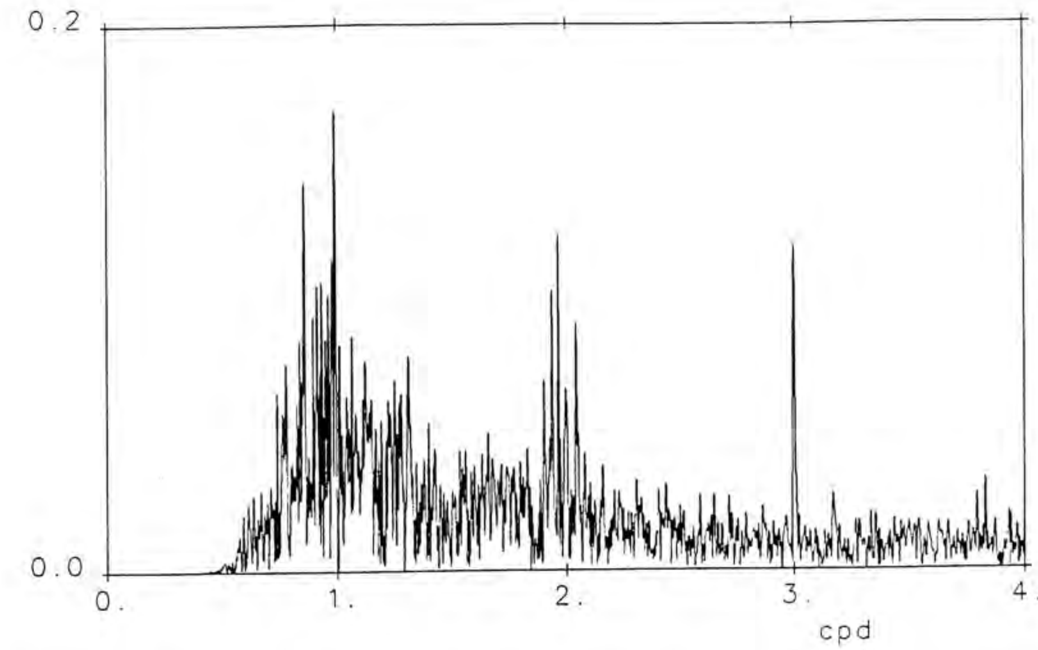

Fig.10: Amplitude spectrum of residuals of earth tide analysis with program ANALYZE for observed gravity tide series BFET1907 when using the Tamura (1987) tidal potential catalogue; DUT1 corrected.

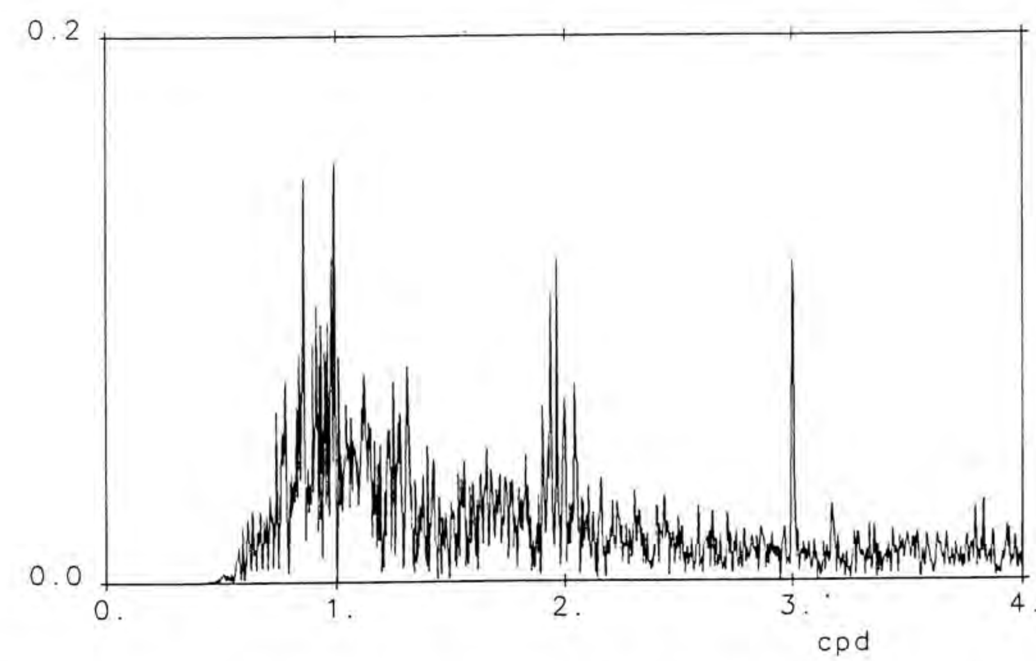

Fig.11: Amplitude spectrum of residuals of earth tide analysis with program ANALYZE for observed gravity tide series BFET1907 when using the Hartmann and Wenzel (1995) tidal potential catalogue; DUT1 corrected.

Tab. 2: Standard deviations from analysis when using different tidal potential catalogues.

DO 1921	=	Doodson (1921)	CT 1973	=	Cartwright et al. (1971, 1973)
BU 1985	=	Buellesfeld (1985)	TA 1987	=	Tamura (1987)
XI 1989	=	Xi (1989)	RO 1996	=	Roosbeek (1996)
HW 1995	=	Hartmann and Wenzel (1995)			

series	unit	DO 1921	CT 1973	BU 1985	TA 1987	XI 1989	RO 1996	HW 1995
BFDE403E	[nm/s^2]	0.910	0.350	0.225	0.068	0.053	0.012	0.002
BFAL8793	[nm/s^2]	0.916	0.351	0.225	0.068	0.051	0.011	0.002
BFD00801	[nstr]	1.577	1.578	1.578	1.578	1.578	1.578	1.578
BFL24903	[nm/s^2]	0.854	0.794	0.676	0.635	0.635	0.634	0.632
BFET1906	[nm/s^2]	0.573	0.528	0.506	0.458	0.462	0.459	0.458
BFET1907	[nm/s^2]	0.752	0.676	0.622	0.561	0.555	0.556	0.556
BHTT4003	[nm/s^2]	6.927	6.890	6.888	6.883	6.885	6.884	6.884
HAL29901	[nm/s^2]	7.044	6.954	6.930	6.948	6.956	6.952	6.952

Series	instrument	epoch	length [days]	filter	remarks
BFDE403E	benchmark	1987-1994	2922.0	no filter	DE403/LE403 ephemerides
BFAL8793	benchmark	1987-1993	2557.0	no filter	DE200 ephemerides
BFL24903	LCR-G249F	1989	121.0	bandpass	BFO Schiltach, digital recording
BFET1906	LCR-ET19	1990	114.5	bandpass	BFO Schiltach, digital recording
BFET1907	LCR-ET19	1991	286.0	bandpass	BFO Schiltach, digital recording
BHTT4003	GWR-TT40	1981-1984	1004.5	no filter	Bad Homburg, digital recording
HAL29901	LCR-G299	1973	63.5	bandpass	Hannover, analog recording

Acknowledgements

Data and programs used in the ETERNA 3.30 package have been supplied by O. Francis and F. Roosbeek (Observatoire Royal de Belgique, Bruxelles), T. Hartmann (Institut für Theoretische Astrophysik, Universität Tübingen/Germany), B. Richter (Institut für Angewandte Geodäsie, Frankfurt a.M/Germany), E.M. Standish (Jet Propulsion Laboratory, Pasadena/USA), Q. Xi (Center for Analysis and Prediction, State Seismological Bureau, Beijing/China), Y. Tamura (National Astronomical Observatory, Mizusawa/Japan). This is gratefully acknowledged.

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