

# 1. Analysis of Earth and Ocean Tides

## 1.1 Enhancements of the functional model

### 1.1.1 Theoretical tides

#### 1.1.1.1 Tide Generating Potential Development (TGP) and related tidal components

- Providing a high-resolution structure for Tide Generating Potential (TGP) constituents
  - by identifying the main constituents of a wave group by their well-known Darwin symbols
  - by identifying constituents derived from the Moon's ascending node and perigee as well from annual modulations and supplying them with new symbol names up to 10 character in lengths.
  - minor constituents with Darwin symbols are associated with a wave group and remain unchanged.
- Tidal components supported, denoted by a 3-character Tidal Component Identifier (TCI):
  - = -1 -> TPO for tidal potential in  $m^2/s^2$ .
  - = 0 -> GRA for tidal gravity in  $nm/s^2$ .
  - = 1 -> TIX = tidal tilt north
  - TIY = tidal tilt east
  - TIA = tidal tilt any direction
  - = 2 -> VDZ = tidal vertical displacement in mm.
  - = 3 -> HDX = tidal horizontal displacement in mm in azimuth north
  - HDY = in azimuth east,
  - HAD = in any direction
  - = 4 -> VSZ = tidal vertical strain in  $10^{-9} = nstr$ .
  - = 5 -> HSX = tidal horizontal strain in  $10^{-9} = nstr$ , north
  - HSY = in azimuth STATAZIMUT east,
  - HAS = in any direction
  - = 6 -> ASN = tidal areal strain in  $10^{-9} = nstr$ .
  - = 7 -> SSN = tidal shear strain in  $10^{-9} = nstr$ .
  - = 8 -> VSN = tidal volume strain in  $10^{-9} = nstr$ .
  - = 9 -> OTZ = static ocean or equilibrium tides in mm.
- Implementation of this new structure for the TGPs of Hartmann, Wenzel 1995, Kudryavtsev 2003 and Tamura 1987.

#### 1.1.1.2 Earth models

- In addition to the WDC Earth model, the DDW-H and DDW-NHi Earth models are selectable for analysis.
- Approximations of gravimetric and diminishing factors of potential degree 6 for all supported Earth models based on the Gutenberg-Bullen-A Earth model.
- Approximations of Love and Shida numbers of potential degrees 4-6 for all supported Earth models based on the Gutenberg-Bullen-A Earth model.
- Free core nutation modelling based on the supported Earth models for all tidal components including displacements and strains.

- Alternatively using Earth model tidal parameters instead of adjusted parameters from a Least Squares analysis for calculating the observation residuals.

### 1.1.2 Optimal wave grouping

- Generalizing the functional model by integrating constituents of degree 1 of the TGP.
- Definition of reference potential functions  $V_{ij}$ , i.e.
  - **V20, V21, V22, V33, V44, V55, V66**
  - the  $V_{ij}$  are totally covering the tidal frequency domains and each  $V_{ij}$  only containing constituents  $j$  of a certain potential degree  $i$ .
- Definition of non-reference or satellite potential functions  $V_{kj}$  of different potential degrees  $l$  than the reference potential functions ( $k \neq i$ ) but possessing the same orders  $j$  so that they share the same frequency domains (e.g. V31 in V21, V32 in V22 etc.) :
  - **V10, V11**
  - **V30, V31, V32**
  - **V40, V41, V42, V43**
  - **V50, V51, V52, V53, V54**
  - **V60, V61, V62, V63, V64, V65**
- Hypothesis free grouping of tidal constituents by means of reference and satellite wave groups defined by degree-dependent option codes.
- Provision of templates for optimal wave grouping suited for different observation lengths like > 18 years, 4 years, 1 year.
- Provision of the quality criterion "Correlation RMSE Amplifier (CRA)" for assessing the optimal wave group model.

### 1.1.3 Astronomical channels like pole and LOD tides

- Pole and LOD tide information from
  - **"IERS EOP PC Observatoire de Paris"**, (<http://hpiers.obspm.fr/eop-pc/index.php?index=C04&lang=en>), or from
  - **"The United States Naval Observatory (USNO) Washington"**, <ftp://maia.usno.navy.mil/ser7/finals2000A.all>.
  - No extra programs are needed due to TAI-UT1 being tabulated or evaluated.
- Interpolation of daily pole and LOD tide data to hourly and minute samples by cubic splines with continuous conditions or Lagrange interpolation.
- Reduction of the astronomical channels from the tidal observations by predefined reduction coefficients prior to a Least Squares analysis .

#### 1.1.4 Meteorological regression channels

- Modelling meteorological regression channels (e.g. station air pressure, ATMACS gravity ,etc.) by **causal and/or non - causal impulse response functions of arbitrary lengths**.
- Estimating the associated frequency transfer functions yielding frequency-dependent regression coefficients and phase shifts.
- Reduction of the meteorological channels (e.g. station air pressure, ATMACS gravity ,etc.) from the tidal observations by predefined reduction coefficients prior to a Least Squares analysis.

#### 1.1.5 Polynomial model

- Uniform polynomial model over the complete tidal record with identical coefficients for all blocks.

#### 1.1.6 Non - linear and additional harmonics

- Modelling of non-linear harmonics of tidal origin with known non-linear frequencies by an iterative feed-back analysis procedure.
- Modelling of additional harmonics of tidal and/or non-tidal origin by an iterative feed-back analysis procedure.

#### 1.1.7 Windows

- Deployment of window functions in combination with the Least Squares technology for improving analysis design and interpretation.

### 1.2 Observation data

- Processing of equally spaced observations with sampling intervals between 1 second and 1day with an arbitrary number of gaps.
- Search for gross error in the observations including a sequence check.
- Providing high, low and band pass filters.
- Automated resampling from minute to hourly data prior to analysis.
- Automatic replacement of Earth/ocean tides data by those of the meteorological or astronomical regression channels to analyze the spectral distribution of their signals.

### 1.3 Least squares parameter estimation based on the Gauss-Markov-model

#### 1.3.1 Parameter estimation

- Maximum resolution LS estimators for all parameters of the functional model.

- Minimum leakage LS estimators for all parameters of the functional model.
- Estimation of tidal parameters of different potential degrees and orders.
- Correlation analysis of selected parameters by the “**SPECTRAL CORRELATION VIEWER (SCV)**” with graphic support.
- Calculation of the “**Correlation RMSE Amplifier (CRA)**” of each tidal and non-tidal wave group.
- Assessment of optimal wave grouping by means of the CRAs.
- Iterative analysis procedure to "whiten" the residuals.

### 1.3.2 Reduction mode processing by means of PASSGROUPS and STOPGROUPS

- Reduction of the observations by channels with predefined reduction factors prior to analysis.
- Pre-processing analysis of tidal observations to yield reduced observations containing unmodelled signals, noise and a groups of signals defined as Pass Groups ( example: only the long periodic signals for subsequent analysis). The resulting data file is of type \*.pas in the ETERNA data format.
- Pre-processing analysis of tidal observations to subtract a defined group of signals, the Stop Groups (example: signals beyond a certain frequency to avoid aliasing when increasing the sampling interval). The resulting data file is of type \*.stp in the ETERNA data format.

### 1.3.3 "High Resolution Spectral Analyser (HRSA)"

- Domain-wise analysing the residuals.
- Estimating and presenting residual spectra together with their signal to noise ratios to detect hidden signals.
- Deriving spectral information for frequency-dependent RMSEs and confidence intervals.

### 1.3.4 Residual vector information

- Calculation of residual vectors **B** (B, beta) for all modelled main Earth tide constituents as difference of the (observed=analysed) tidal parameters and those derived from the chosen Earth model.
- Calculation of mean load vectors **L** (L, lambda) based on different ocean models and processing Greenwich and local tidal phase lags/leads.
- Calculation of ocean load corrected amplitude factors and phase shifts for the main tidal constituents.
- Calculation of residual vectors **x** (x, chi) based on the ocean load corrected observed tidal parameters and those of the provided Earth models for the main tidal wave groups.
- Consistency check by comparing the load vectors **L** from ocean models with the residual vectors **B** of the analysis.
- Comparing the ocean corrected amplitude factors with those of the Earth models implemented.

### 1.3.5 Miscellaneous Information enhancements

- Thorough parameterization (\*.ini) for gaining utmost flexibility for Earth/ocean tides analysis and prediction.
- Comprehensive consistency checks on syntax, domains, and inter parameter rules for the parameters in \*.ini.
- Analysing regression channels with the functional tidal model prior to analysis.
- Enhanced block/gap management (minimum block lengths, automated elimination of blocks).
- Providing online graphic presentation support for a better interpretation of the analysis results by the open source **SIMDEM/SIMFIT** package in system variant \*winsil.
- Flexible output parameters to control the flow of information.
- Support of nano radiant dimension for tilt.

## 1.4 Enhancements of the stochastic model

- Redesign of the stochastic model now fully based on Least Squares and statistical theory.
- Statistical hypothesis tests on normal distribution of the observations (Kolmogorov - Smirnow,  $\chi^2$ ).
- Overall correlation analysis of the estimated parameters by the “**Spectral Correlation Viewer (SCV)**”.
- The “**Correlation RMSE Amplifier CRA**” for verifying disadvantageous impacts of algebraic correlations of the LS parameters.
- Generation of consistent residual spectra derived from the autocovariance function of the residuals to derive **frequency dependent RMSE  $m_{0,i}$**  of arbitrary spectral domains  $d_i$  over the whole Nyquist interval.
- Derivation of **95% confidence intervals** for the frequency dependent RMSE  $m_{0,i}$  and all estimated parameters.
- **Relative RMSEs (rRMSE)** of the amplitude quotients and/or amplitudes for real and best circumstances as measures of achievable precisions for a specific station and observation record.
- **Quality criteria** based on rRMSE, CRA, record lengths and signal strengths.

## 2. Earth and ocean tide prediction

- Integration of the tidal analysis and prediction into one program
- Prediction based on the supported Earth models (DDW-H, DDW-NHi, WDZ) and/or prior analysis results.
- Optionally including pole and LOD tides.
- Optionally including ocean load information.
- Optionally including additional harmonics.
- For simulation purposes:
  - Optionally superimposing the predicted signal by selected harmonics.

- Optionally superimposing the predicted signal by a white noise process of a chosen RMSE  $m_0$ .

### 3. Documentation

- Theoretical basis
- Installation Guides (system specific),
- UsersGuide
- Release Notes

## 4. Computer platforms and software

### 4.1 MS WINDOWS 10

#### 4.1.1 System variant **et34-x-vmn-winsil**

- Providing the executable **et34-ana-vmn-winsil.exe** on 32- and 64-bit MS-Windows computers for current updates of WINDOWS 10.
- FORTRAN - Compiler **FTN95**, 32-bit, from Silverfrost LTD, Manchester, UK, (Commercial software).
- **Graphic package** SIMDEM/SIMFIT, 32 bit version, of Dr. W.G. Bardsley, University of Manchester, UK (Open Source).

#### 4.1.2 System variant **et34-x-vmn-wingnu**

- Providing an executable **et34-ana-vmn-wingnu** on 32- and 64-bit MS-Windows computers for current updates of WINDOWS 10
- FORTRAN - Compiler **gfortran** of the GNU Fortran project for **Windows**, developing a free [Fortran 95/2003/2008](#) compiler for GCC, the GNU Compiler Collection.

### 4.2 LINUX

#### 4.2.1 System variant **et34-x-vmn-lnxgnu**

- Providing an executable **et34-ana-vmn-lnxgnu** compiled on **Fedora LINUX release 29 on x86\_64 architecture**
- FORTRAN - Compiler **gfortran** of the GNU Fortran project for **Linux**, developing a free [Fortran 95/2003/2008](#) compiler for GCC, the GNU Compiler Collection.