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 **T**idal **C**omponent **I**dentifier (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 WDZ 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 Vij, i.e.

  - **V20, V21, V22, V33, V44, V55, V66**
  - the Vij are totally covering the tidal frequency domains and each Vij only containing constituents j of a certain potential degree i.

- Definition of non-reference or satellite potential functions Vkj of different potential degrees l than the reference potential functions (k .ne. 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.
- Repository as data description tool for modelling non-linear tidal constituents similar to the TGP
- Project dependent repositories as data description tools for modelling additional harmonics of unknown origin as well as their modulations.

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.
- Organizing the observation data in a central data archive.
- Dynamic memory allocation to check for sufficient ressources.

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, χ^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 m0,i** of arbitrary spectral domains di over the whole Nyquist interval.
- Derivation of **95% confidence intervals** for the frequency dependent RMSE m0,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 m0.

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 et**34-x-vmn-gnusim**

- Providing an executable et**34-ana-vmn-wingnu** on 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.
- **Graphic package** SIMDEM/SIMFIT, 32 bit version, of Dr. W.G. Bardsley, University of Manchester, UK (Open Source).

4.2 LINUX

4.2.1 System variant et**34-x-vmn-lnxgnu**

- Providing an executable et**34-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.