The VLBI data analysis software νSolve: development progress and plans for future

Sergei Bolotin, Karen Baver, John M. Gipson, David Gordon and Daniel S. MacMillan

NVI, Inc. at Goddard Space Flight Center
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VLBI data analysis software

- Necessity of new generation VLBI data analysis software
  - Increase in number of sessions, stations, observations.
  - VLBI Global Observing System (VGOS) introduces new observables.
- History of **νSolve** development
  - The IVS Working Group on VLBI data structures (IVS WG4) was established in 2007.
  - In August of 2009 the VLBI group at the NASA GSFC started the development of new VLBI data analysis software.
  - A design of system architecture was presented at the IVS GM in Hobart, 2010.
  - We demonstrated a prototype version of **νSolve** at the 20^{th} EVGA Meeting in Bonn, 2011.
  - A first version of **νSolve** was presented at the IVS GM in Madrid, 2012.
  - Since July 2012 GSFC uses **νSolve** for data analysis of INT and R4 sessions.
  - A public release of **νSolve** was made on 20^{th} of February, 2014.
- **νSolve** and geodetic VLBI data flow
  - **νSolve** is designed to replace most sensitive and user time consuming part of CALC/SOLVE system, interactive SOLVE.
  - It produces **Version 4** databases: edited, with resolved group ambiguities and ionospheric corrections, ready for analysis in a batch mode.
- In this presentation we will cover the current status of the software.

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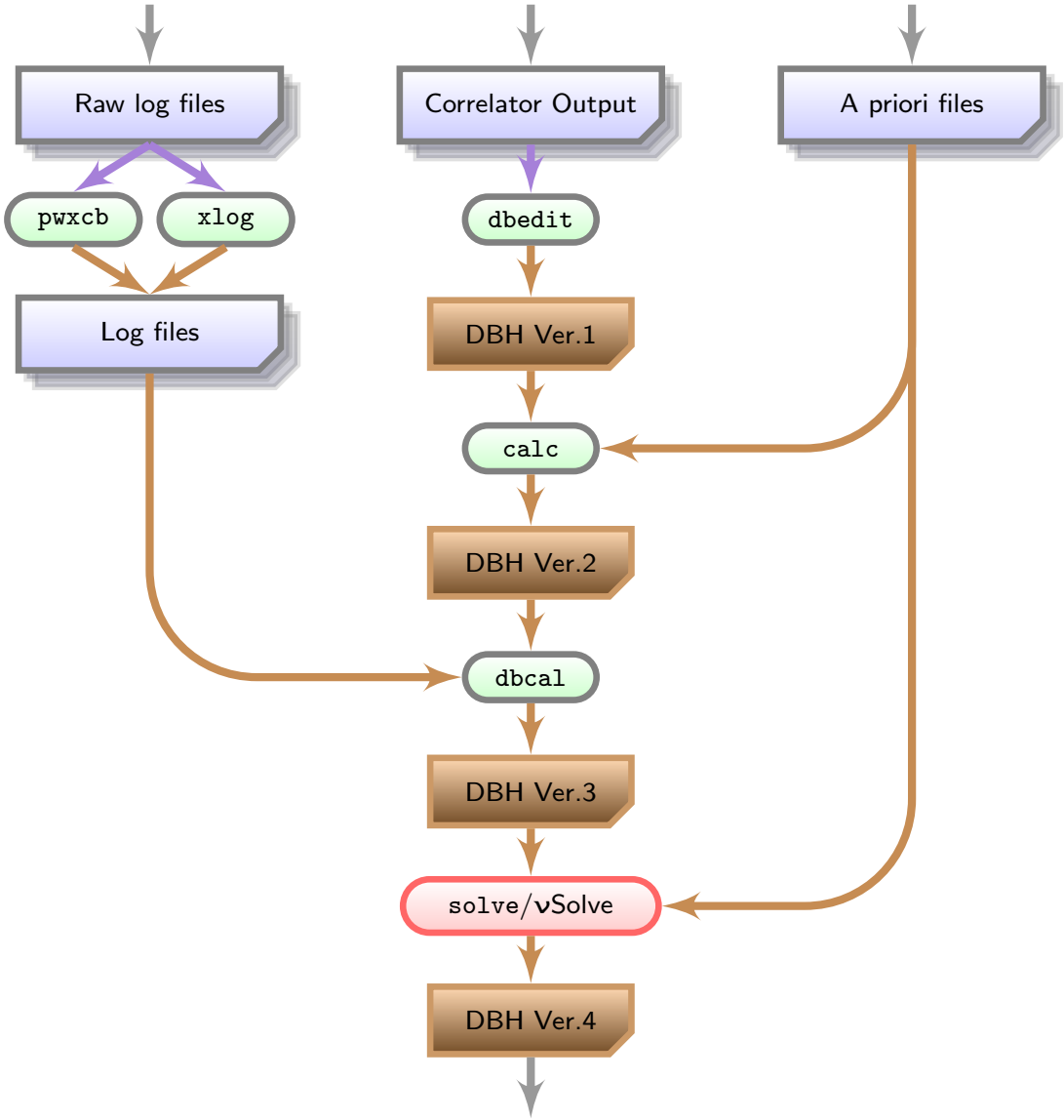
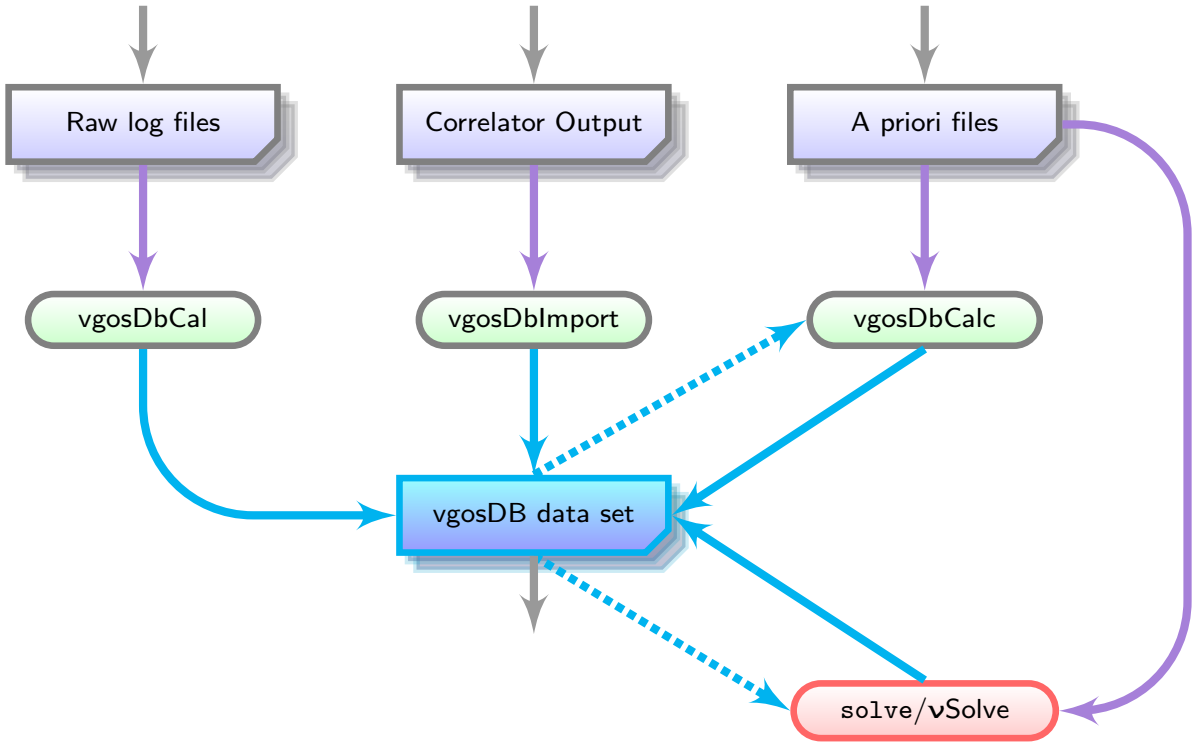
Geodetic VLBI data flow: current state



Geodetic VLBI data flow: changes in 2014



Software development environment

The software is designed to (but not limited) work under Linux/GNU operation system.

It is written in **C++ programing language**.

We distribute the software code and use **GNU Build System** to make it portable.

It uses the **Qt** library for high level data abstraction and system's **libc** and **libm** for low level system functions. For vgosDB IO interface **netCDF** library is used.

Currently, it consists of two parts:

- **Space Geodesy Library**, where all algorithms are implemented (90% of source code);
- an executable **νSolve** – a driver that calls the library and organizes work with an end-user (10% of source code).

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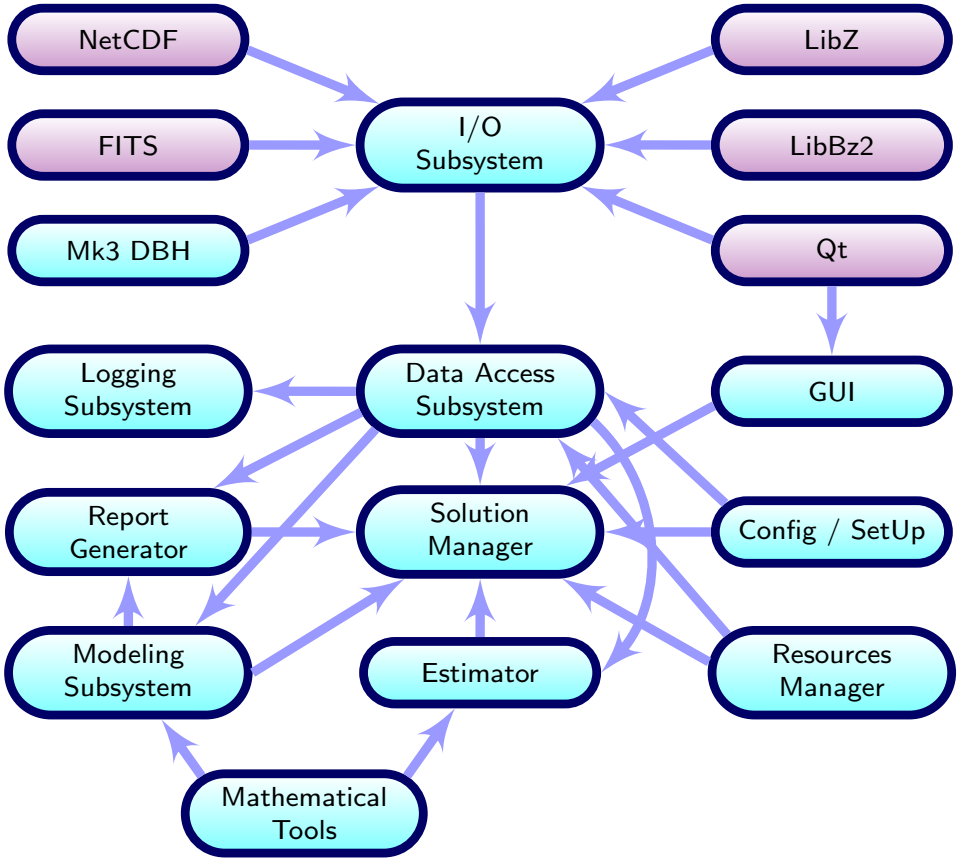
Modular structure of the software



System Decomposition

To keep our system stable and flexible we designed it modular.

Module is a logical block of code that is loosely tied with other parts of the software.

Each arrow on the diagram represents a **dependency** or, in other words, provides information (types, function calls, constants).

Only main **dependencies** are shown on the diagram.

General features

Data processing

- Single session mode:
  - **νSolve** is designed to analyze a single session, performs necessary calibrations and data editing.
  - Later it will evolve in powerful session editor that allows us to fix all known anomalies of the VLBI observation.
- Multiple session mode:
  - **νSolve** does not make global solutions. A separate executable (driver) will be developed later to perform data analysis of multiple sessions of VLBI observations.

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General features

Current functionality

Features of the software:

- The software is able to read and write data in Mk3 DBH format
- It can also use new vgosDB format
- There is no limitations on number of stations, sources or observations
- It can work either through CALC/SOLVE catalog subsystem or in a standalone mode
- Process of VLBI data analysis can be automated

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General features

Operation

The software is able to:

- Read/write files in Mk3 DBH and vgosDB formats
- Display on plots various information that were stored in the files
- Process a single VLBI session and save results
- Estimate various parameters
- Detect and process clock breaks
- Resolve group delay ambiguities
- Perform ionospheric correction
- Calibrate weights of observations to make a normalized χ^2 equal to unity
- Eliminate outliers
- Use different models in data analysis
- Apply external *a priori* information

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Estimator

Types of parameters

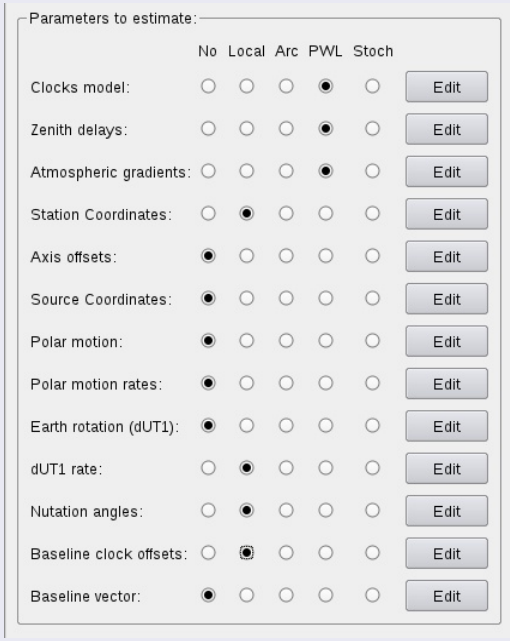
- The estimated parameters can be modeled as:
  - Local parameter – an unbiased parameter determined for whole session
  - Arc parameter – an unbiased parameter estimated for specified by user interval (e.g., 1 hour)
  - Piecewise linear function (PWL), coefficients of continuous linear function are estimated from data, an interval between nodes is specified by user. The PWL parameters are realized by:
    - Incremental rates
    - Basic splines
  - Stochastic parameters
- There is no limitations on length of arcs or step between nodes of piecewise linear functions.

Estimator

Estimated parameters

We can estimate:

- Clock parameters
- Zenith delays and theirs gradients
- Stations positions
- Antenna axis offsets
- Sources coordinates
- Polar motion offsets and rates
- Earth rotation and its rate
- Angles of nutation
- Baseline clock offsets
- Baseline vectors



GUI: Estimated parameters

VLBI data analysis

Typical processing of a regular 24-hr VLBI session

- Read observations
- Obtain single band delay solution
- Check for clock breaks
- Switch to group delay residuals and resolve ambiguities for both bands
- Check for clock breaks
- Evaluate ionosphere corrections
- Add to the list of estimated parameters zenith delays and station positions
- Manually remove big outliers
- Switch estimated parameters (clocks and zenith delays) to PWL functions
- Manually remove large outliers
- Add to the list of estimated parameters UT1 rate and angles of nutation
- Calibrate weights of observations
- Eliminate outliers
- Iterate reweighting/outlier processing
- Write edit information and corrections, generate reports

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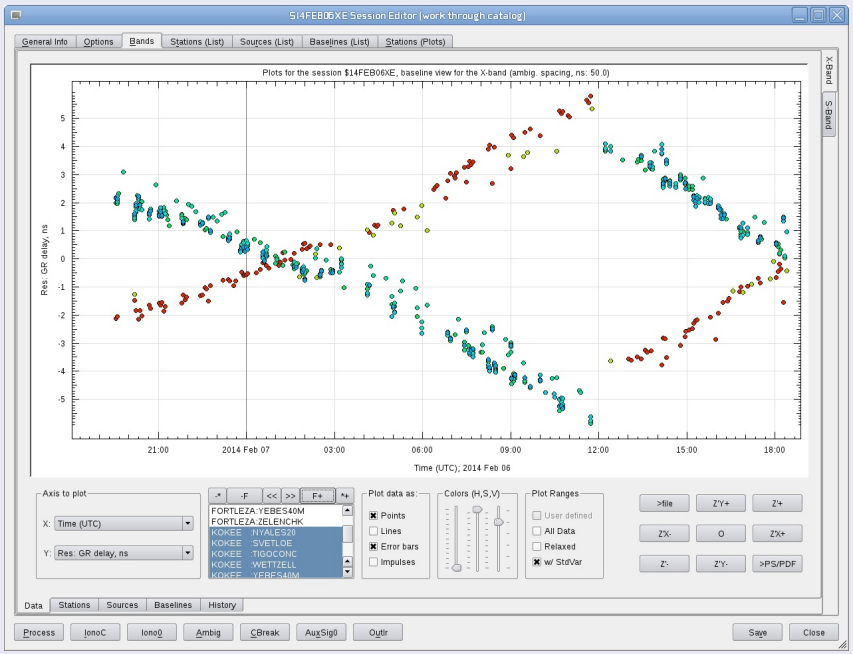
Operations

Clock break processing

- To compensate a clock break, **νSolve** adds a step-wise linear function to the station clocks.
- There are session wide and band dependent clock break models.
- Clock breaks can be detected and corrected in automatic, semi-automatic and manual mode.

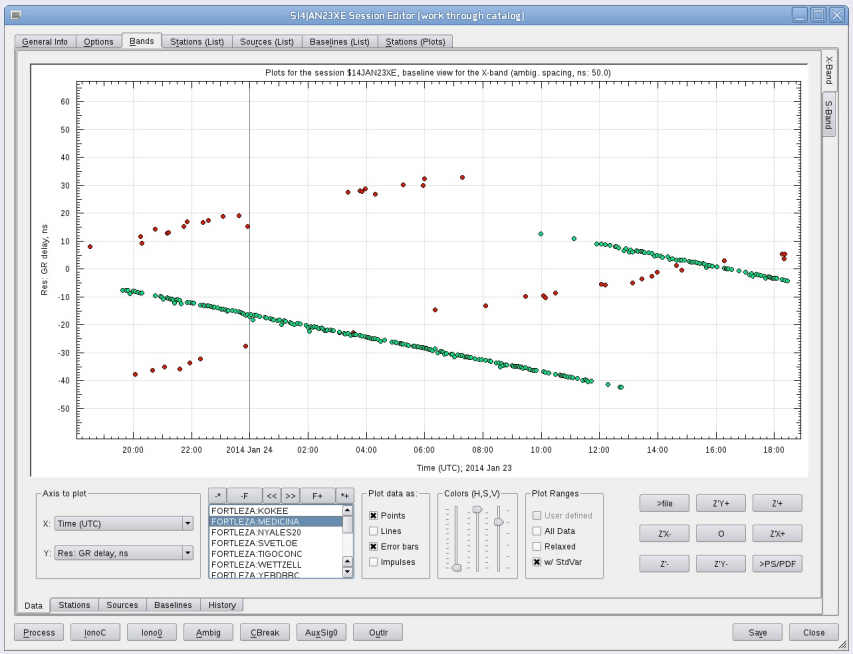


Example of an unresolved clock break on station KOKEE during $14FEB06XE session

Operations

Ambiguity resolution

- Ambiguity resolution is done using ideas implemented in CALC/SOLVE.
- There is no assumption about ambiguity spacing. **νSolve** can process sessions with mixed ambiguity spacing.
- In addition, there is ability to adjust multipliers of ambiguity manually.

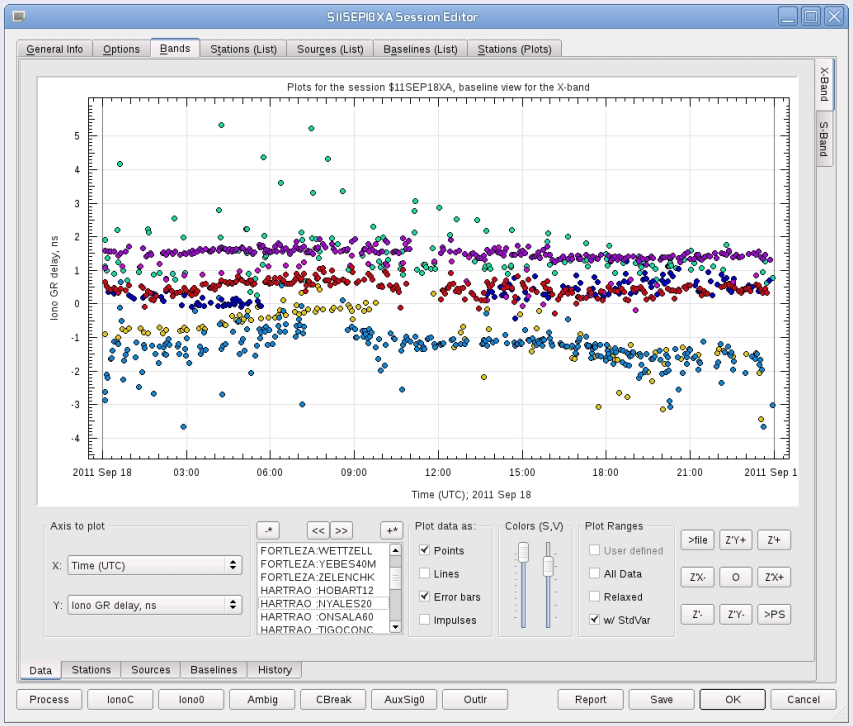


Group delay residuals with unresolved ambiguities at FORTLEZA:MEDICINA and MEDICINA:WETTZELL baselines of $14JAN23XE session

Operations

Ionospheric correction

- From dual band observations the group delay, phase rate and phase delay ionospheric corrections are evaluated.
- Ionospheric corrections are performed after clock breaks and ambiguity resolutions were processed.

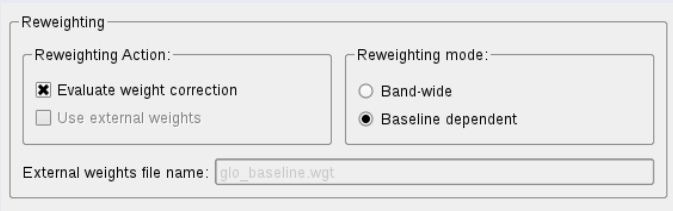


Impact of ionospheric effect on group delay residuals

Operations

Corrections of weights of observations

- Weight correction is performed to keep normalized χ^2 equal to unit.
- Two modes of reweighting:
  - Session wide
  - Baseline dependent
- Also, weight corrections can be imported from an external file.
- Reweighting is performed in conjunction with outlier elimination.

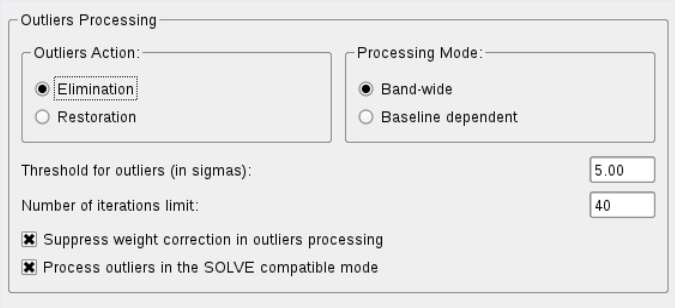


GUI: controls of weight correction

Operations

Outliers processing

- Outlier is an observation which absolute value of normalized residual is greater than user specified threshold.
- Two modes of outliers processing:
  - Session wide;
  - Baseline dependent.
- Excluded observations can be included back in restoration action.
- Outlier elimination is performed in conjunction with weight correction.



GUI: controls of outliers processing

Operations

Applying models

- CALC/SOLVE system takes into account a model of some geophysical effect using *contributions* – corrections to the theoretical values caused by the effect.
- Some models are already included in the theoretical values, some are not.
- To change a model: substract the corresponding contribution and add new precomputed one.

GUI: controls of applying contributions

Operations

Using external a priori files

- Update a priori information is done through external a priori files.
- The following a priori information can be changed:
  - Station positions and velocities
  - Sources coordinates
  - Axis offsets of antennae
  - Mean site tropospheric gradients
  - Earth rotation parameters
  - Diurnal and semidiurnal ERP
- Correction to the theoretical values for new a priori info:

$$\delta\tau = \frac{\partial\tau}{\partial\vec{x}}(\vec{x}^{new} - \vec{x}^{dbh})$$

GUI: controls of using external a priori files

Next releases, plans for future

νSolve has been used in house for 18 months for analysis of INT and R4 sessions. Also, first broad band experiments were analysied with **νSolve** software.

A first public release of **νSolve** was made in 20th of February release of CALC/SOLVE system.

We welcome users to provide comments and suggestions, that will improve the software.

In the next release we will focus on the following issues:

- The plotting system will be reworked
- Optimization of execution time
- Extending functionality
- Introducing of elements of automatic data processing

Thank you for your attention!

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