Current status of νSolve

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VLBI data analysis software

- New generation VLBI data analysis software
  - Increase in number of observations.
  - VLBI2010 introduce 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.
- **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.
- In this presentation we will cover the current status of the software.

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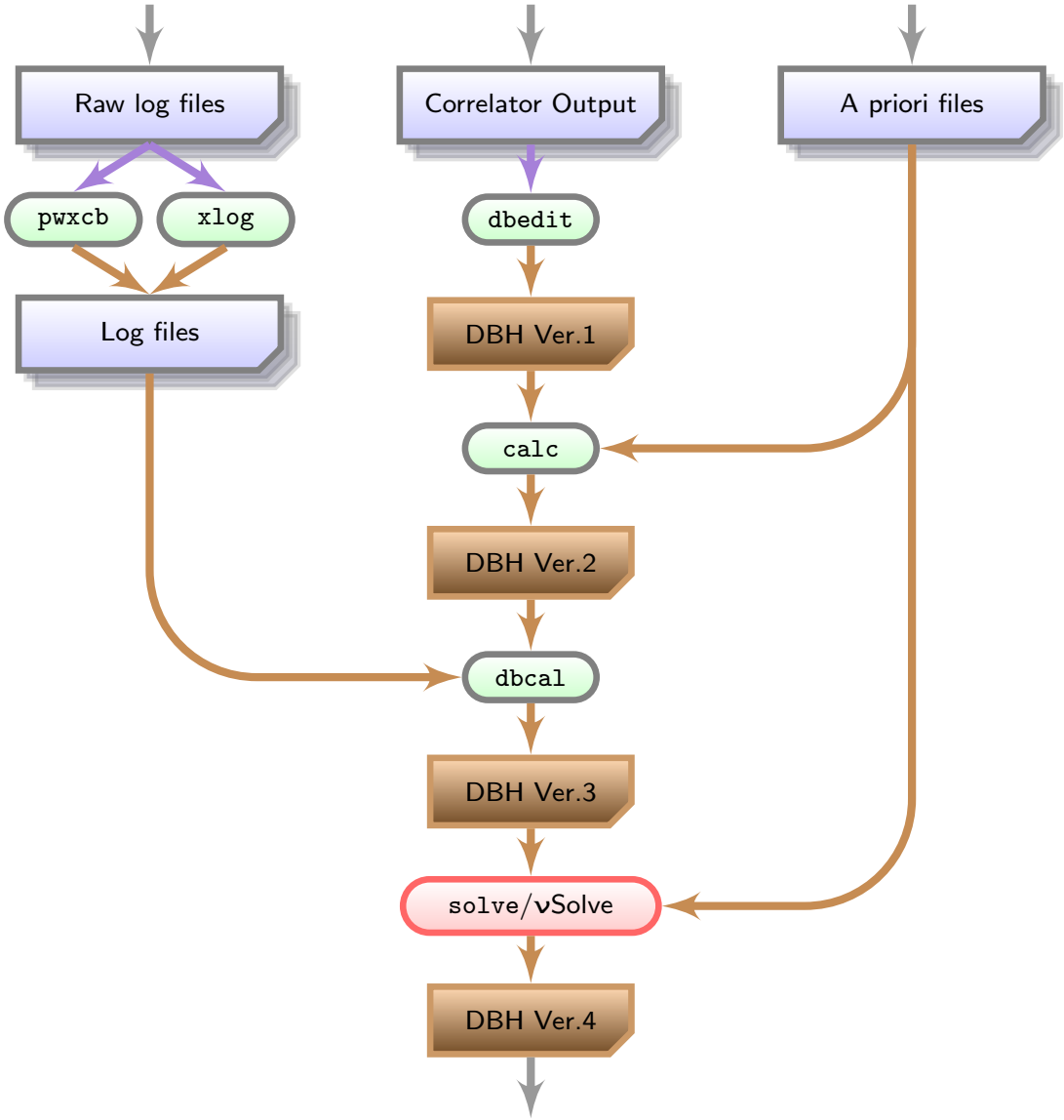
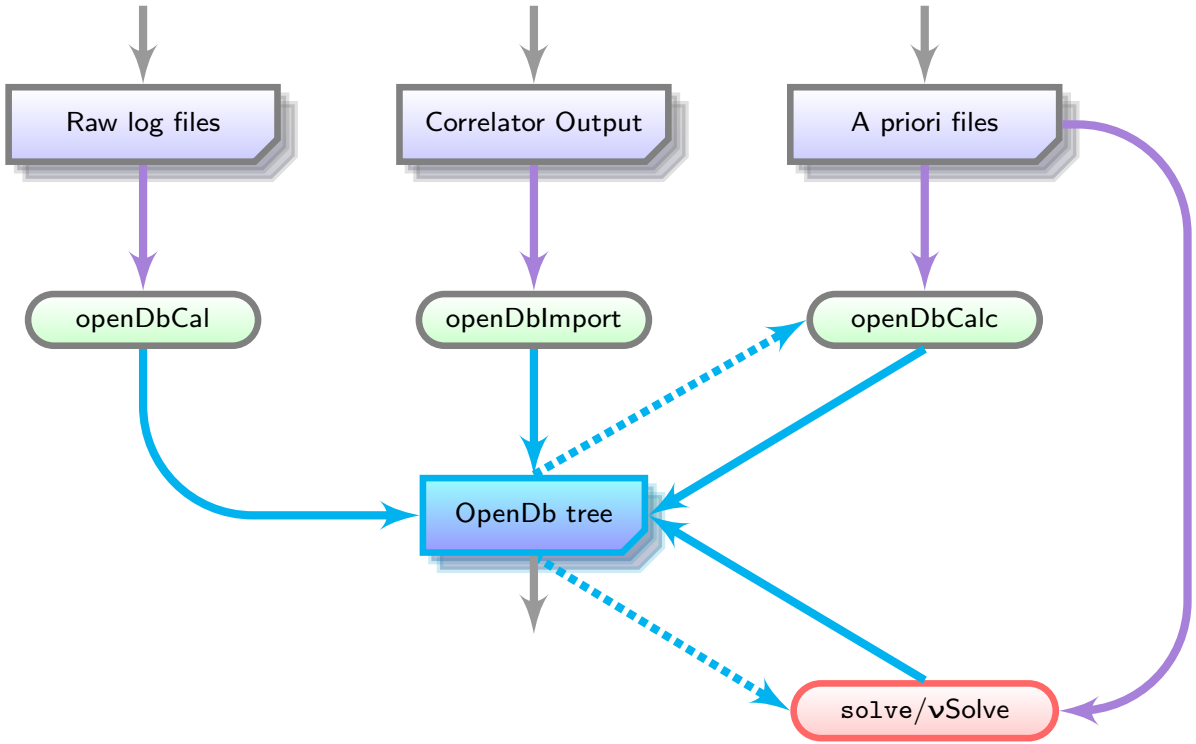
Geodetic VLBI data flow: current state



Geodetic VLBI data flow: forthcoming CALC/SOLVE release



Software development environment

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

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

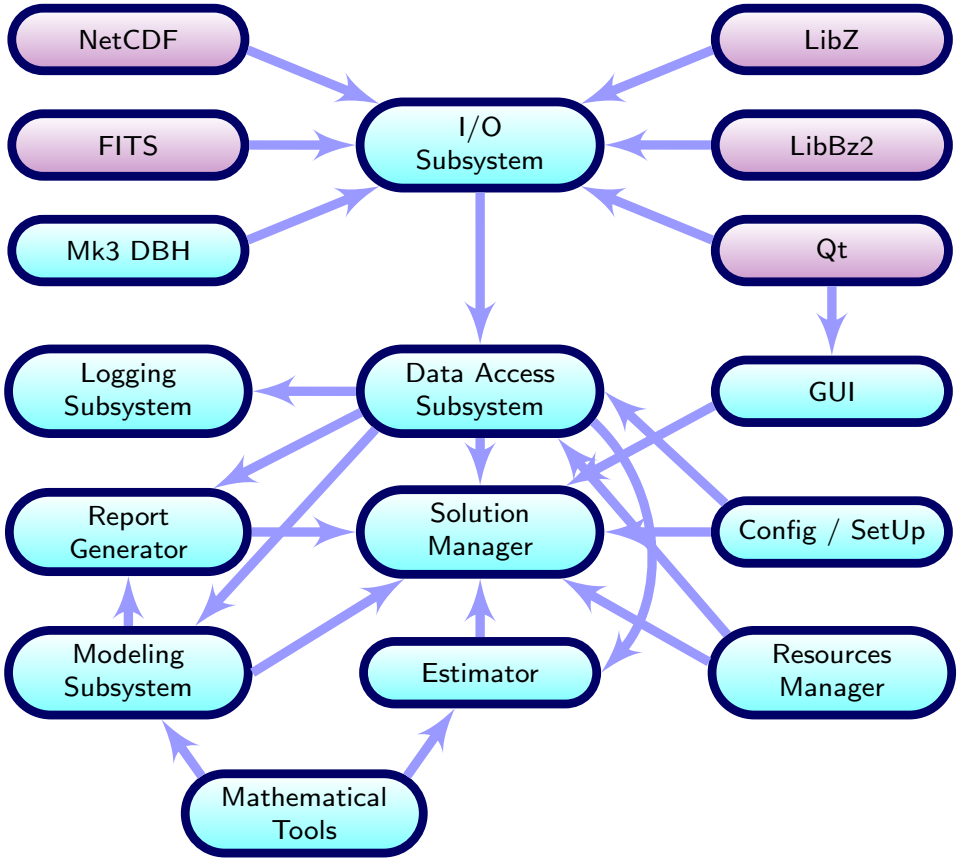
We distribute the software code and use **GNU Build System** to make it portable.

It uses the **Qt** library for high level data abstraction and system's **libc** and **libm** for low level system functions. For OpenDB 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 **vSolve** – a driver that calls the library and organizes work with an end-user (10% of source code).

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 OpenDB 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

General features

Operation

The software is able to:

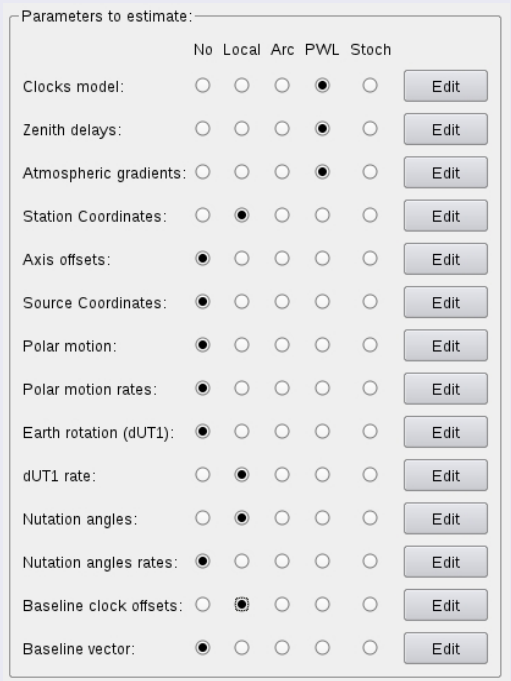
- Read/write files in Mk3 DBH format
- Read files in OpenDB format
- Display on plots various information that were stored in the files
- Process a single VLBI session and save results
- Estimate various parameters
- Detect and process clock breaks
- Resolve group delay ambiguities
- Perform ionospheric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

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 and their rates
- Baseline clock offsets
- Baseline vectors



Estimated parameters

Estimator

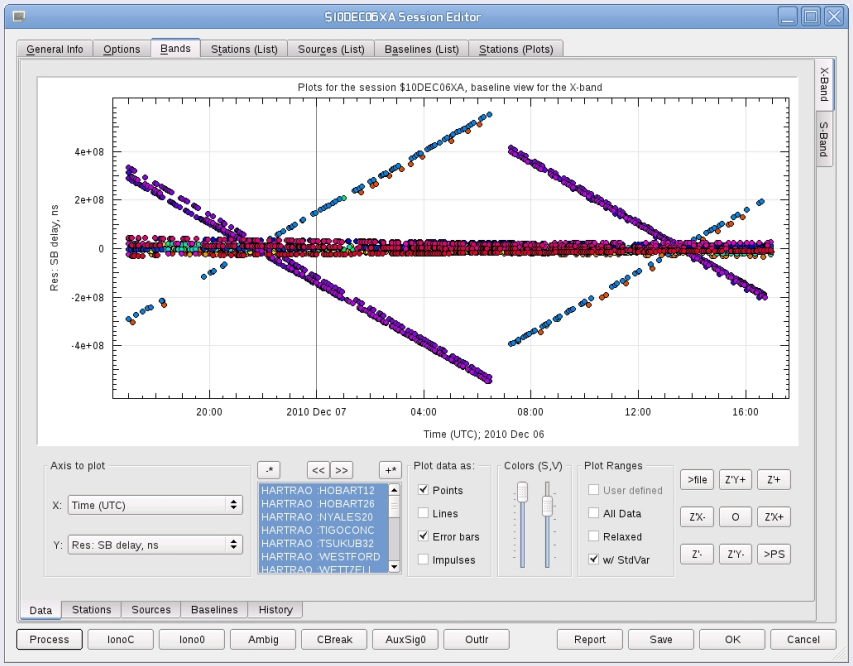
Types of parameters

- 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, coefficients of continuous linear function are estimated from data, an interval between nodes is specified by user
  - Stochastic parameters
- There is no limitations on length of arcs or step between nodes of piecewise linear functions.

Operations

Clock break processing

- To compensate a clock break, **vSolve** 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.

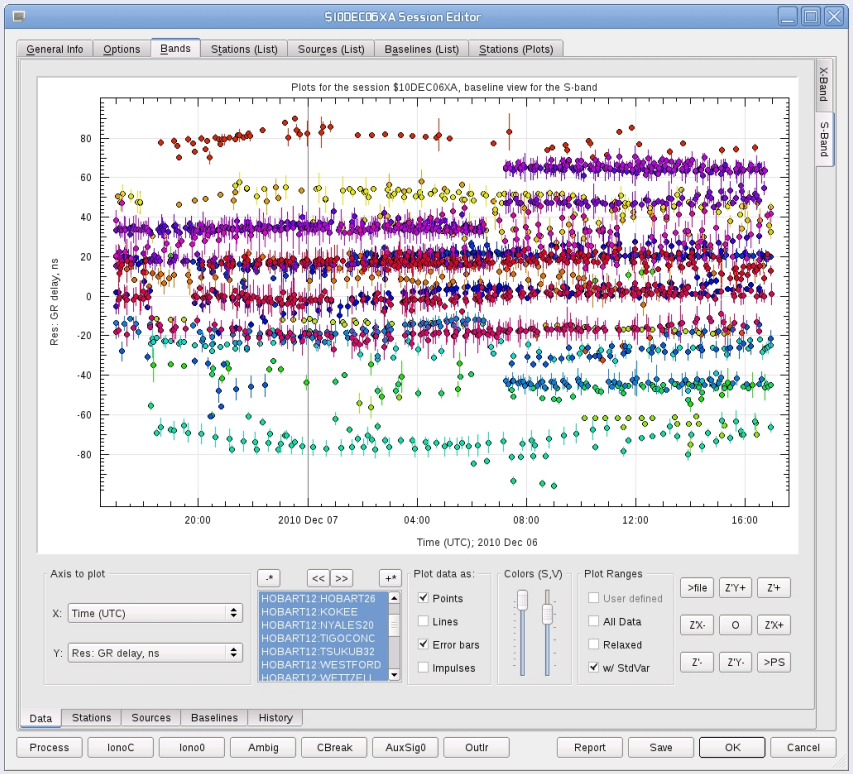


Example of an unresolved 1-second clock break on station NYALES20 during $10DEC06XA session

Operations

Ambiguity resolution

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

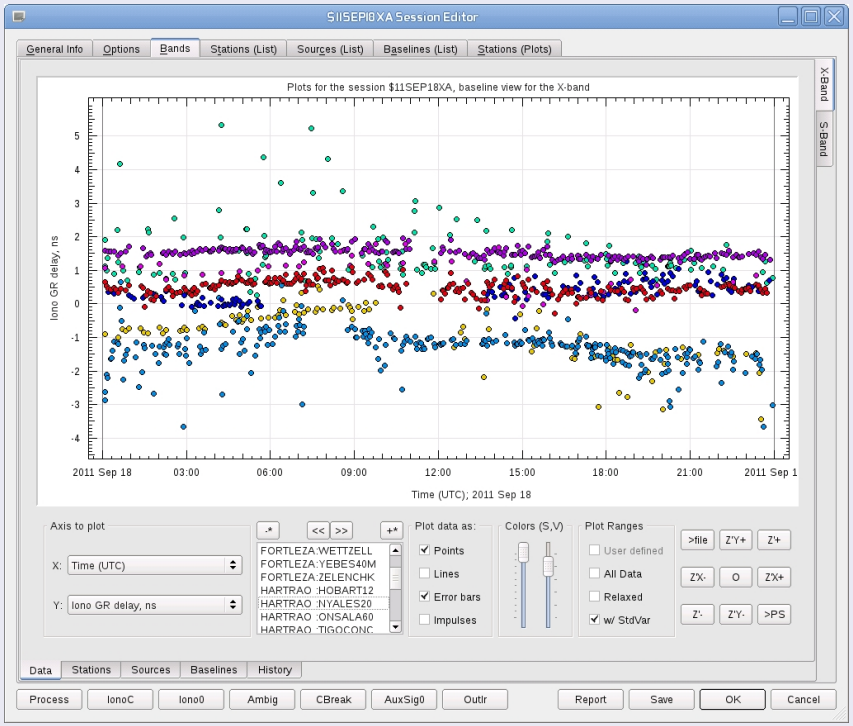


Group delay residuals with unresolved ambiguities

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.

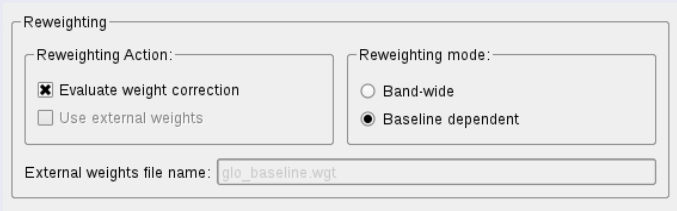


Impact of ionospheric effect on group delay residuals

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.

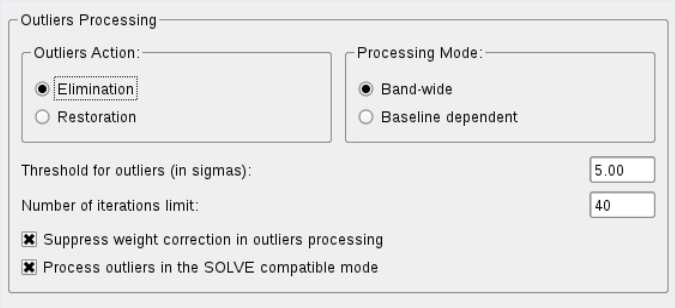


GUI controls of weight correction

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 informaiton 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

VLBI data analysis

Typical processing of a VLBI session

- Read observations
- Obtain single band delay solution
- Check for clock breaks
- Resolve ambiguities for both bands
- Check for clock breaks
- Evaluate ionosphere corrections
- Add to 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 estimated parameters UT1 rate and angles of nutation
- Calibrate weights of observations
- Eliminate outliers
- Iterate reweighting/outlier processing
- Save results

Next releases, plans for future

A first public release of **νSolve** is planned in the forthcoming release of CALC/SOLVE system.

After the public release we welcome users to provide comments and suggestions, that will improve the software.

The next release will be focused on the folowing issues:

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

Thank you for attention!

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