Seiji Manabe et al.: Astrometric and Geodetic Analysis System of VERA, IVS 2002 General Meeting Proceedings, p.372–376
http://ivscc.gsfc.nasa.gov/publications/gm2002/manabe

Astrometric and Geodetic Analysis System of VERA

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Abstract

VERA is a unique VLBI array both in scientific objectives and in innovative technologies. Its hardware is designed for accomplishing highest accuracy in determining relative positions of a pair of radio sources up to two degrees apart by phase-referencing VLBI. Each antenna is equipped with a dual-beam observation system. A system for calibrating difference in optical path length between the two beams is an indispensable component of the dual-beam observing system. The analysis software of VERA is required to handle properly the calibration data in order to remove instrumental errors as much as possible. Very high accuracy of antenna position determination and precise information on structures of reference sources are also required.

No existing software system meets all the requirements of VERA and a new one is under development. In the first step of the development, functions to meet VERA's requirements will be added to NRAO's AIPS. The reason to use AIPS as a platform is that phase-referencing observations will begin in this year and the reduction program must be ready before the observations. However, whether or not AIPS or AIPS++ is adopted as a platform of the VERA analysis software is still under investigation. A database for managing raw data from the Mitaka FX correlator is under development and will become available soon. Other databases that manage intermediate and final analysis results are in a designing phase. In this paper requirements to, design of and current status of the software are reviewed.

1. Requirements to the Software

VERA (VLBI Exploration of Radio Astrometry) is a VLBI array consisting of four dual-beam radio telescopes and the FX correlator at Mitaka. It aims at determining 3-dimensional positions and velocities of galactic maser sources associated with star forming regions and late-type stars. The accuracy goal in position determination is about 10 μas. The major requirements to the analysis software are listed below.

1. **High accuracy in position determination.** 10 μas is a target accuracy of a single determination of position of a maser source. Simulation results show that even higher accuracy can be expected in the determination of annual parallaxes. However, in order to realize this accuracy, accurate calibration data specific to VERA and their proper use are necessary.

2. **Establishment of a standard method and semi-automation of the analysis.** In order to accomplish the VERA's main scientific target, which is to reveal structure and dynamics of our galaxy, 150-200 days/year must be devoted to this project observation. This produces huge amount of data and the data analysis might be a bottleneck of VERA project unless fast and uniform reduction of data is operational. Thus, it is necessary to establish a standard method of reduction applicable to most of the *usual* radio sources.

3. **Construction of integrated data management system.** VERA's data consist of raw data from the correlator, intermediate results such as precise (u, v) and calibrated visibility, and right ascensions and declinations of individual maser features at individual observation

epochs. The raw data will be re-reduced with the improvement of adopted model parameters and analysis method. This may happen even 10 years after the observation. Therefore, a very stable, reliable and extendable data management system is indispensable.

4. **Determination of proper motions and annual parallaxes of maser sources.** It is not always simple to determine proper motions and annual parallaxes, even if positions of maser features are given at individual observation epochs. This is because lifetimes of individual maser features are not always long enough to trace their motions over a year and distinguish annual parallaxes from proper motions. In addition identifying individual maser features between observations at different epochs is not trivial. Furthermore, asymmetric and/or random motions of individual maser features in a maser spot may cause incorrect determination of motion of the maser spot. This error is not serious as long as statistical properties of motions of maser spots are concerned and internal motions of maser features are small enough compare to random motions of maser spots in our galaxy. However, since typical speed of internal motions of maser features are of the same order of peculiar velocities of stars, this might be serious for some maser sources. A lot of experiences in treating real data are necessary for semi-automating this process.

2. Strategy of the Development and Current Status

2.1. Development Environment

The Mitaka FX correlator, which has been primarily used for the VSOP project, is also used for VERA. It produces raw visibility and related calibration data in a form called CODA F/S. The CODA F/S is a flexible and self-descriptive structure of directories and files. The CODA F/S is designed for efficient use at the Mitaka correlator. Therefore, the use of CODA F/S as a basic platform of data management is natural and almost mandatory. Other format such as FITS can be used for data exchange.

As for the geodetic analysis, the software that was developed at NAOJ and covers from the bandwidth synthesis to the final global parameter fitting has been used. This system is also used for VERA.

The VERA hardware is in the phase of system adjustment and performance check. The first phase-referencing VLBI observation with the dual-beam receiving system is expected to take place in this year. The first version of the analysis software to obtain astrometric results has to become available by early 2003. Geodetic analysis will be working before the astrometric analysis because precise positions of the antennas are required for precision astrometry.

The main computer system is IBM's RS6000/SP whose operating system is AIX. Since this operating system is not very popular in the field of astronomy and geodesy, some effort is necessary for porting widely used free software such as AIPS++.

2.2. Data Flow and General Structure of the Software

Fig.1 shows VERA databases and programs to process them. The main body of the databases is raw observed data and logs. The catalogues and constants are also important and indispensable components for later use. Typical example is the case where positions of the antennas are revised and the past data have to be re-reduced. Details of the structure of the database of astrometric

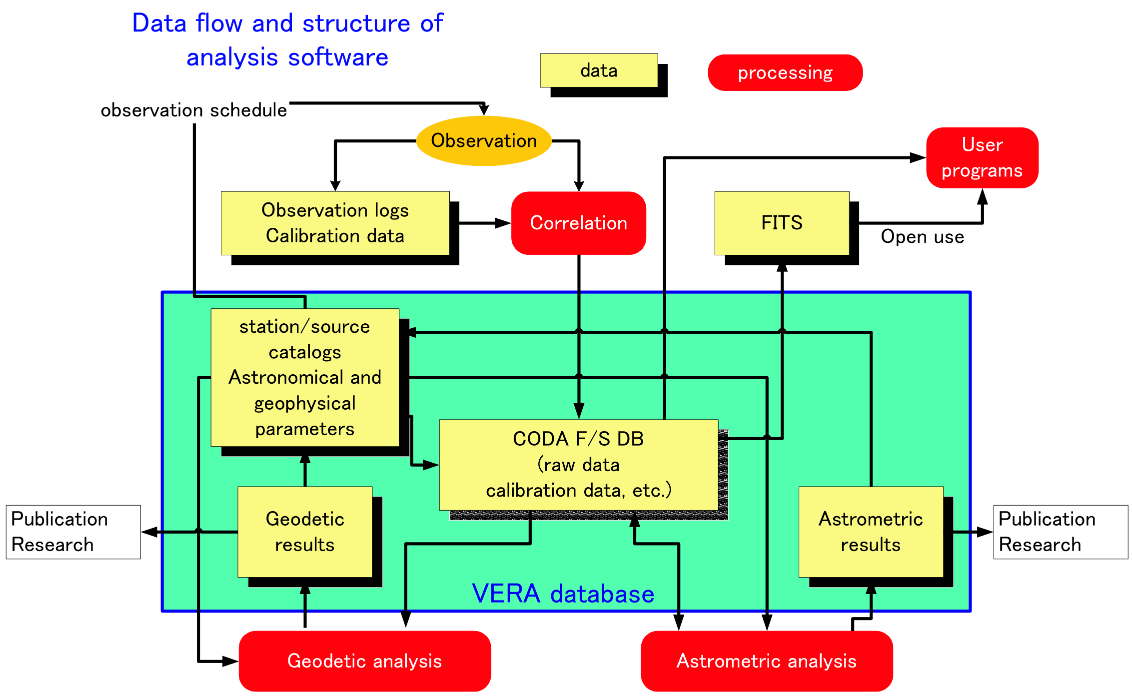

Figure 1. Data flow and processing program

results are shown in fig. 2.

2.3. Investigation of Applicability of Existing Software

There are some software packages for reduction of VLBI in the astrophysical field. Examples are NRAO's AIPS and CalTech's DIFMAP. If these packages are operationally usable for VERA, it is not necessary to add a new software. We are evaluating the astrometric accuracy of AIPS by using real and simulated data. The accuracy here concerns with algorithms of data processing and their implementation as program codes.

Capability of the existing software to handle VERA data is also investigated. Easiness of adding new functions specific to VERA such as the CODA F/S interface is important target of the investigation.

We have obtained an impression that AIPS can be used at least in experimental phase of data reduction. However, a lot more must be added for operational use.

2.4. Development of a Simulator

We are developing a program that produces simulated visibility. This program is used for checking accuracy of existing software, clarifying necessary performance of the system such as the calibration of the phase difference between the dual beams and mechanical stability of the antenna and necessary accuracy of geophysical and other parameters such as instantaneous positions of antennas and atmospheric propagation model, etc. A block diagram of the simulation program is

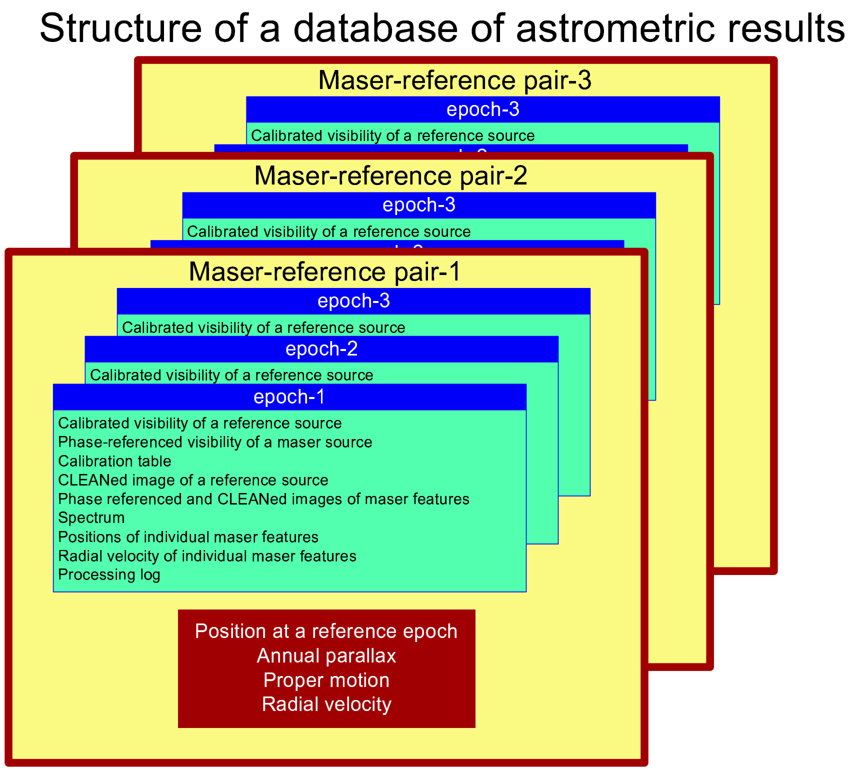

Figure 2. Structure of the database of analysis results

shown in fig. 3.

2.5. Catalogue of the CODA F/S

In order to efficiently manage huge amount of data from various kinds observations, a catalogue system for CODA F/S is being made. The major functions and specifications of the catalogue are as follows.

- **Retrieval** Project name, source name, station name, date of processing, processing status
- **Display** Retrieval condition, start and end epochs of observation, location of data including dissemination record, data amount, revision history, comments
- **Graphical data display** Data flagging status, fringe pattern
- **File system manupilation** Registration to the catalogue and deletion, migration from disk to tape library and vice-versa, FITS transformation and exportation,
- **Consistency check between datasets and catalogue**
- **User interface** Browsing and manipulating data through web browser. Program interfaces with Fortran, c, c++ and Java.
- **DBMS** PostgreSQL

This catalogue will become available in March, 2002.

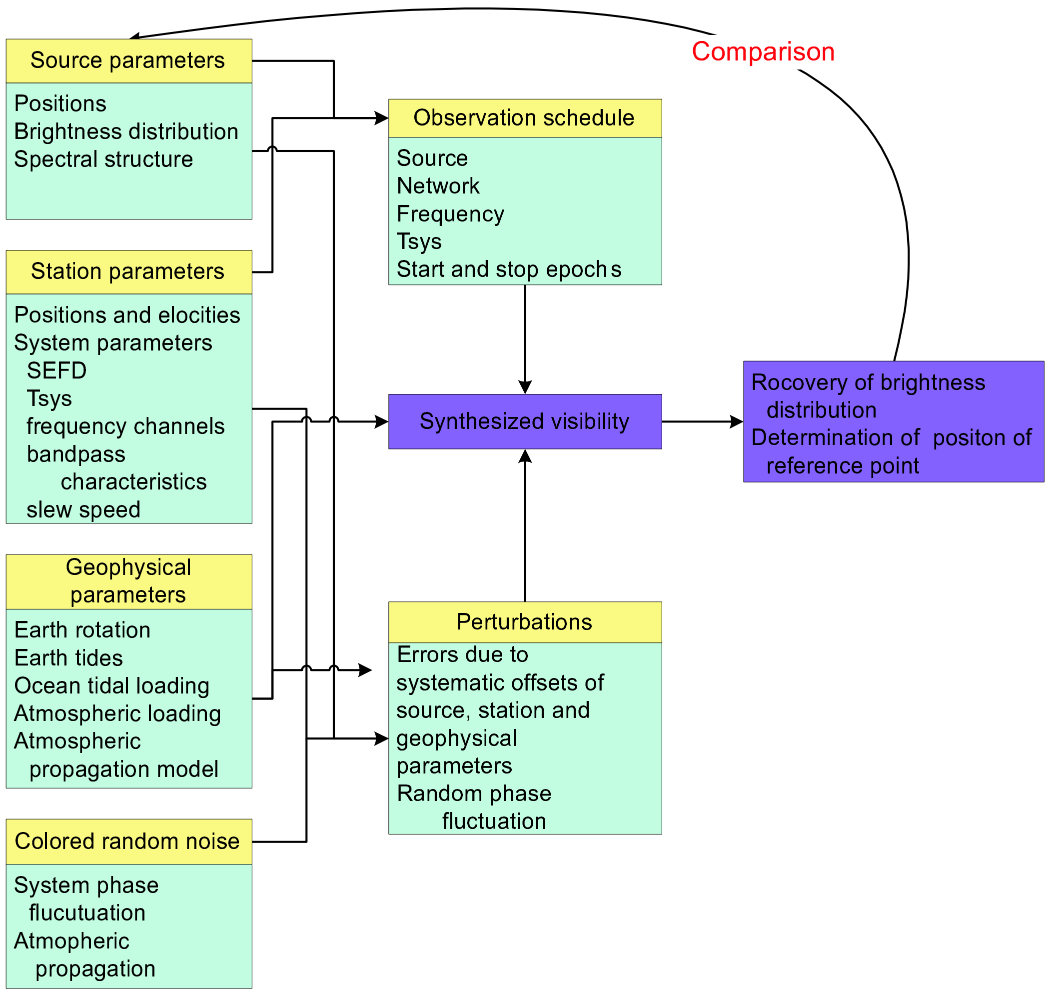

Figure 3. Block diagram of the simulation

2.6. Geodetic Analysis Software

Jike *et al.*(2002, [1]) has established a geodetic analysis system which derives geodetic parameters from FITS output of the Mitaka FX correlator. It is almost ready to analyze data of geodetic observations with VERA for determining positions of VERA antennas, although some discrepancies have been found in bandwidth-synthesized delays between the Mitaka FX correlator and the XF correlator of the Geographic Survey Institute. This problem has to be solved as soon as possible. In addition, capability of direct handling of CODA F/S in place of FITS is still needed to be implemented.

References

[1] Jike, T., S. Manabe, Y. Tamura, K. Shibuya, K. Doi, and the Antarctic VLBI Group, The Antarctic VLBI Experiments During JARE39 and Geodetic Analyses by the Mitaka FX Correlator, IVS 2002 General Meeting Proceedings, edited by N. R. Vandenberg and K. D. Baver, NASA/CP-2002-210002.