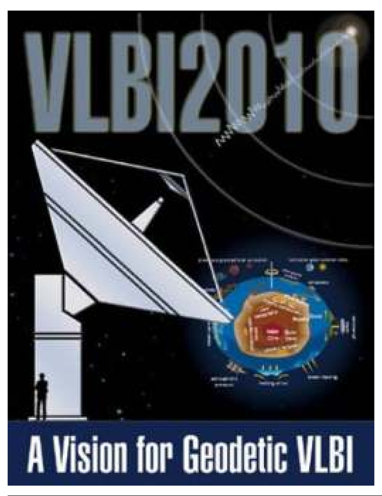


# V L B I 2 0 1 0


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## 1 Introduction

Very Long Baseline Interferometry (VLBI) is a vital technique in the realization and maintenance of the terrestrial and celestial reference frames (TRF and CRF). It uniquely provides the ICRF and the link between the ICRF and ITRF by providing the full set of Earth orientation parameters (EOP), in particular DUT1 and nutation. The current VLBI system was conceived and constructed mostly in the 1960's and 1970's. Aging antennas, increasing interference problems (RFI), obsolete electronics, and high operating costs make it increasingly difficult to sustain the current levels of accuracy, reliability, and timeliness.

To alleviate this situation, in 2003 the International VLBI Service for Geodesy and Astronomy (IVS) initiated Working Group 3 to define the next generation geodetic VLBI system, which has come to be called VLBI2010. The WG3 report is available at http://ivscc.gsfc.nasa.gov/about/wg/wg3/IVS_WG3_report_050916.pdf. This development went hand-in-hand with the gradual establishment of the Global Geodetic Observing System (GGOS) of the IAG. The IVS aligned the design goals for the VLBI2010 system with the GGOS goals and strives for global baselines to be accurate to 1 mm and stable to 0.1 mm/yr.

To realizethis demanding goal, the IVS VLBI2010 Committee investigated the various facets that the new system needs to have in order to fulfill the requirements. The major focus right now is on reducing the major error sources stemming from the atmosphere, the instrumentation, and the structure of the radio sources.

| | Current | VLBI2010 |
|---|---|---|
| antenna size | 5–100 m dish | ~ 12 m dish |
| slew speed | ~20–200 deg/min | ≥ 360 deg/min |
| sensitivity | 200–15,000 SEFD | ≤ 2,500 SEFD |
| frequency range | S/X band | ~2–15 (18) GHz |
| recording rate | 128, 256 Mbps | 8–16 Gbps |
| data transfer | usually ship disks, some e-transfer | e-transfer, e-VLBI, ship disks when required |

## 2 Increasing the Number of Observations per Day

Increasing the number of observations per day depends on three factors:

- Decreasing the length of time to slew from source to source
- Decreasing the time to acquire data while on a source
- Improving the scheduling algorithm

Although the steps taken to increase the number of observations have been successful, the effort has shown that more work needs to be done to optimize the sky coverage in the short (<10 minute) intervals corresponding to the atmospheric variability, perhaps at the expense of the total number of observations.

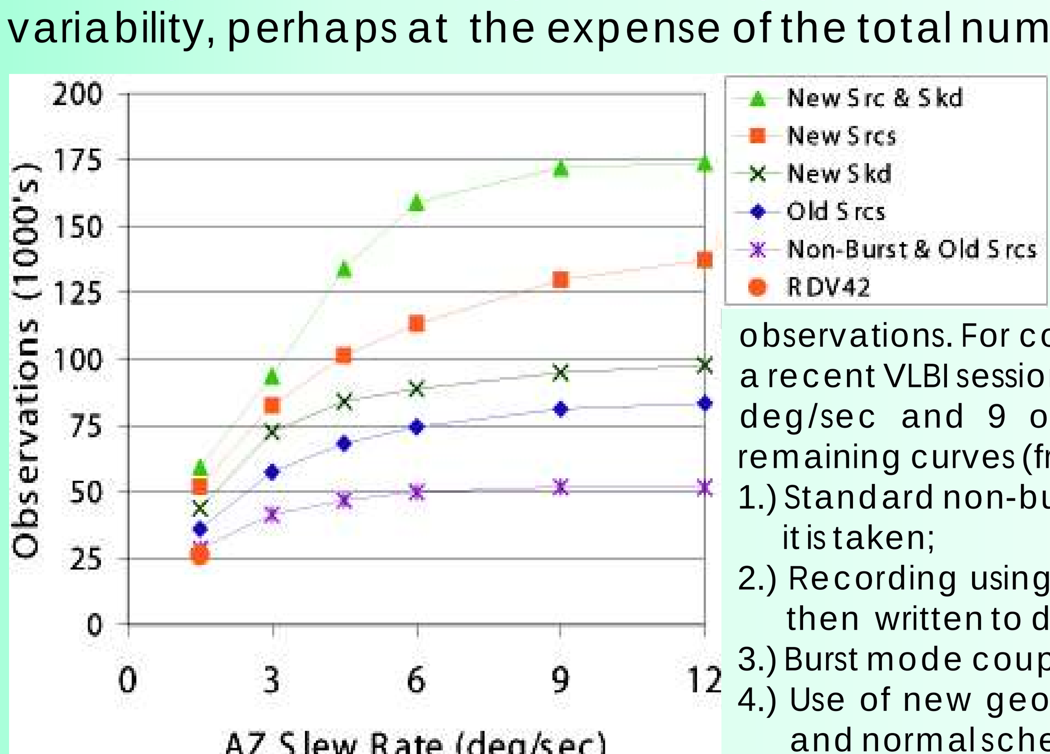


Figure 1.This figure displays the dependence of the number of observations with slew speed of the antenna. All schedules were gener-ated assuming identical 12 meter antennas. Improvements in hardware, software and observations. For comparison we include the results for RDV42, a recent VLBI session involving 10 VLBA stations (slew speed 1.5 deg/sec and 9 other stations (various slew speeds). The remaining curves (from bottom to top) are

1.) Standard non-burst mode observing: data is recorded as it is taken;
2.) Recording using "burst mode" where data is buffered and then written to disk;
3.) Burst mode coupled with improvements in obs. strategy;
4.) Use of new geodetic source list coupled with burst mode and normal scheduling;
5.) Burst mode and new sources and better scheduling.

## 3 Decreasing the Per Observation Measurement Error

Recent technological advances have made it economically feasible to simultaneously use several (four or more) frequency bands spread across a wide frequency range, e.g. 2 GHz to 15 GHz. Analysis shows that, with such systems, VLBI phase ambiguities can be reliably resolved, resulting in typical delay precision of about 2.5 ps (less than 1 mm). For comparison, with current group delay systems, per-observation delay measurement error is typically about 10 to 30 ps.

To demonstrate that this broadband delay concept will work in practice, NASA is supporting an R&D project to build a proof-of-concept "broadband" system and to evaluate its performance under real-world conditions. Major challenges for the concept include successful operation in the presence of RFI, realistic radio source structure, and uncalibrated instrumental offsets. The principal components of the new system are:

| | |
|---|---|
| Broadband dual linearly polarized feed: | 2 GHz to ~16 GHz (Figure 2) |
| Broadband low noise amplifier: | 2 GHz to ~12 GHz |
| Digital backend: | four 512 MHz channels each; 2 bits/sample |
| Mark5b+ recorder: | 2 gigabits per second |

Initial tests will be performed on the ~600 km baseline using the Westford (near Boston) 18m antenna and the GGAO (near Washington, D.C.) 5m antenna. The proof-of-concept system will record both linear polarizations from four 500 MHz bands that can be independently positioned in the frequency range 2 GHz to approximately 12 GHz. A prototype of the complete feed-to-recorder chain has been installed at both the Westford 18m and GGAO 4m antennas, and a successful VLBI experiment has been done at X-band.

Figure 2. ETS-Lindgren quadridge broad band feed inside heat shield attached to the 15K station of the cryogenic refrigerator. Dewar is to the right.

## 4 Simulations

As part of the development of specifications for the new VLBI2010 observing system, the IVS has been performing simulations to evaluate the geodetic performance of VLBI2010 networks. Monte Carlo simulations of different system specifications have been performed by geodetic analysis using simulated data consisting of troposphere, clock, and thermal noise delay contributions. These simulations allow us to investigate optimal network antenna locations, antenna sensitivities, slew rates and observing schedules. Figure 3 shows the comparison of the analysis of CONT05 data, which is the best VLBI contribution to date, and the result of the Monte Carlo simulations performed with a realistic parametrization of tropospheric, clock, and thermal noise delays. Also added to this plot is a simulation of a 16 station network with VLBI2010 specifications.

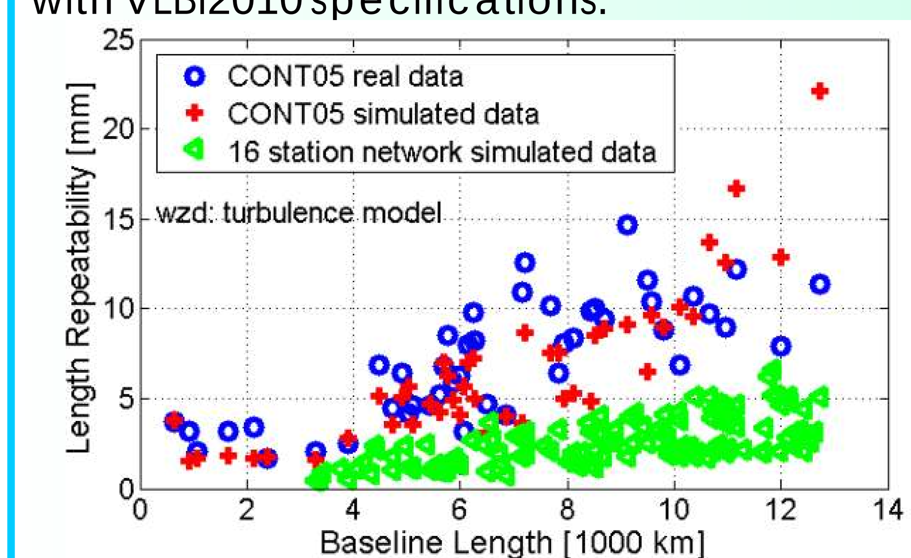


Figure 3. The blue dots show the real data analysis of CONT05. The green crosses show the analysis using the Monte Carlo simulator, with clock parameters of $1\times10^{-14}$ @ 50min and a turbulence model for the tropospheric parameters. The thermal noise is based on the real observation errors of each baseline observation. The red triangles show the simulation of a 16 station network of VLBI2010 antennas. The clock parameters are set to $2\times10^{-15}$@15min, the troposphere delays are simulated by the turbulence model, and a white noise of 4 psec is added as thermal noise.

## 5 Network Size

A series of Monte Carlo runs were performed to evaluate the relative performance of networks of different size. For this purpose, a series of theoretical networks were generated that have roughly uniform global coverage and use plausible locations (e.g. the sites are on land and are colocated with GPS). These simulations indicate that the VLBI2010 network could improve the determination of the TRF scale to roughly several parts in $10^{10}$ in a single session. Simulation and analysis of the depen-dence of EOP quality on the network size have shown an expected twofold improve-ment in both EOP precision and accuracy compared to existing regular IVS networks.

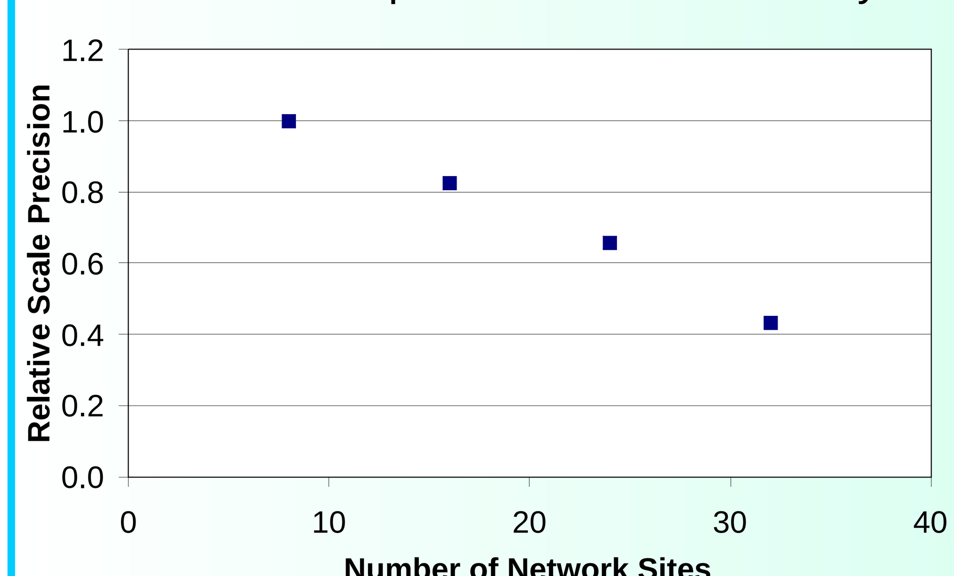


Figure 4. Terrestrial Reference Frame scale parameter precision from Monte-Carlo simulations. Precision is expressed relative to the precision of the 8-site network.

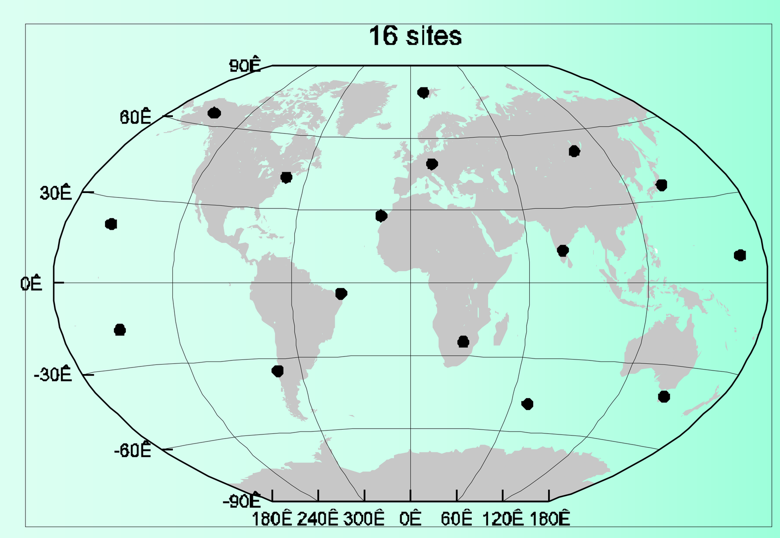


Figure 5. 16 station test network of VLBI2010 antennas

## 6 Source Structure Corrections

As we approach 1 mm precision, source structure becomes an ever more significant error component for geodetic VLBI. Furthermore, it significantly degrades our potential to use the proposed "broadband delay" technique to access VLBI's precise phase delay observable. As a result, it will be important to apply appropriate modeling to correct for such source structure errors.

With the new VLBI2010 observing scenarios that include larger networks and a mani-fold increase in the number of observations per session, UV coverage has improved to the point where precise VLBI images of the ICRF sources could be constructed on a daily basis directly from the geodetic observations, therefore enabling source structure corrections to be calculated. Simulations are currently underway to evaluate the potential of this approach.

## 7 Summary

As part of the IVS VLBI2010 renewal process, studies are being carried out to develop requirements for achieving 1 mm position accuracy on global length baselines. This is a work in progress. Highlights include:

- Studies show that faster slewing antennas, burst mode recording and improved scheduling algorithms yield a quantum increase in VLBI observations per session.
- Proof-of-concept tests are in preparation to demonstrate the broadband delay technique for achieving an order of magnitude improvement in delay precision.
- Monte Carlo simulators have been developed to evaluate the benefits of improved instrumentation and scheduling strategies.
- The Monte Carlo simulators are being calibrated against CONT05 real data.
- Monte Carlo results indicate that increased observation density and delay precision lead to position precisions in the range 1.5-3.5 mm. Better scheduling and analysis strategies are expected to lead to further improvements.
- Initial studies indicate that the increase in observation density and larger networks will enable active source structure corrections. Further simulations are underway.


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