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Geodetic Results from Mark 4 VLBI

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Abstract

We present geodetic results of a series of 30 VLBI experiments recorded in Mark 4 mode at rates of 128 and 256 Mbps. The formal uncertainties of UT1, polar motion, and nutation offsets derived from these experiments are better than the corresponding uncertainties from NEOS-A experiments by a factor of 1.3-2. Baseline length repeatability for the series of 32 experiments over a period of one year is about 0.9 ppb. For comparison, NEOS-A length repeatability is about 1.4 ppb. We will discuss optimal use of Mark 4 in the design of future observing networks.

1. Introduction

In 1990, the first demonstration of 1 Gbps recording was accomplished with a modified Mark 3 system. About a decade later, in June 2001, the first series of standard Mark 4 experiment sessions were correlated. In this paper, we will discuss results from the first 30 of the Mark 4 sessions. The milestones in Mark 4 development since 1990 are summarized below.

- 1990 - First lab demonstration of 1 Gbps recording with modified Mark 3A system
- 1992 - Start of Mark 4 correlator development at MIT Haystack Observatory
- 1993 - Formation of joint U.S.-European International Advanced Correlator Consortium for Mark 4 correlator development
- 1993 - Demonstration of first prototype Mark 4 data acquisition system
- 1995 - Commercial availability of upgrade of Mark 3A system to Mark 4
- 1995 - First prototype of Mark 4 ASIC correlator chip produced
- 1997 - First fringes with Mark 4 correlator
- 1999 - Four Mark 4 correlators put on line: USNO, Haystack Observatory, MPI (Germany) and JIVE (Netherlands)
- 2001 - Mark 4 correlator used to obtain first fringes with new disc-based Mark 5 data system
- 2001 - Correlated first series of standard Mark 4 experiment sessions

The Mark 4 VLBI hardware provides much more precise measurements due to an increase in recorded bandwidth by up to a factor of 16 from the standard Mark 3 data rate of 56 Mbps. This will be possible through a combination of the improved Mark 4 data acquisition system and the higher playback efficiency of the Mark 4 correlator. The Mark 4 correlator will be capable of supporting continuous data acquisition and simultaneously processing all 120 baselines from 16 stations at 1 Gbps/station. Currently the correlators are set up to process a maximum of eight stations.

The full data rate capability of 1 Gbps is not yet possible due to limitations of currently installed tape recording hardware at some VLBI stations and the cost of the increased number of required VLBI tapes. The full data rate will be possible once the Mark 5 system is implemented at VLBI sites in late 2002 or early 2003. Mark 5 is a magnetic disc-based data system that uses commercial off-the-shelf components. This type of system is possible because of the steady decrease in the cost of magnetic disc drives relative to the standard VLBI recording tapes.

We have analyzed the first 30 Mark 4 experiments that were observed during the period July 2000 to November 2001. These experiments were recorded in Mark 4 mode at rates of 128 Mbps or 256 Mbps. They were run with 2 different networks, CORE-1 (most at 256 Mbps) and CORE-3 (at 128 Mbps) shown in Figure 1. Generally, the increased Mark 4 data rate has allowed more observations to be made than with Mark 3. For example, the CORE-1 network stations observe at an average rate of 16 observations per hour compared with 10-12 observations per hour for the operational NEOS network.

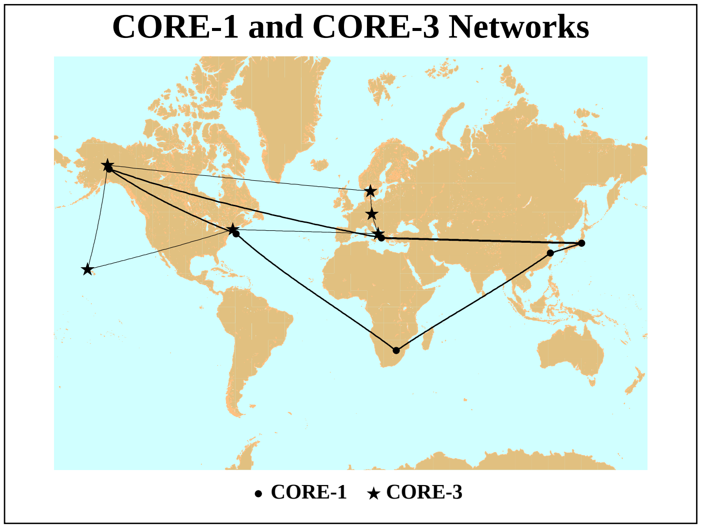


Figure 1. The CORE-1 network used Fairbanks, Hartebeestoek, Matera, Tsukuba, Westford, and Seshan. CORE-3 used Kokee, Gilcreek, Matera, Westford, Wettzell, and Onsala.

In the following we discuss the quality of these experiments including the baseline length precision and the formal Earth orientation parameter (EOP) uncertainties. We then discuss possibilities for future observing with Mark 4.

2. Baseline Length Repeatability

We have computed the baseline length repeatabilities for several series of experiments: the Mark 4 experiments, the NEOS-A experiments from 1997 to 2001, and the CORE experiments (A and B series) from 1997 to 2000. Repeatabilities are generally better for the Mark 4 experiments. As function of baseline length, the length repeatabilities for baselines with at least 10 observations are shown above and were fit as:

$$wrms(Mark4) = [(2.0mm)^2 + (0.90ppb)^2]^{1/2}$$

$$wrms(NEOS) = [(1.7mm)^2 + (1.45ppb)^2]^{1/2}$$

$$wrms(CORE) = [(1.8mm)^2 + (1.50ppb)^2]^{1/2}$$

One can derive approximate values for the site position precision by decomposing the baseline length error into average local station vertical and horizontal errors,

$$\sigma_L^2 = (2 - f_L)\sigma_H^2 + f_L\sigma_V^2,$$

where σ_L is the baseline length error, σ_V is the average site vertical error, σ_H is the average site horizontal error, $f_L = L^2/2R^2$, L is the baseline length, and R is the Earth's radius. The average station vertical error is ~8 mm for the Mark 4 series and ~13 mm for both the NEOS and CORE series.

3. Earth Orientation Parameter Uncertainties

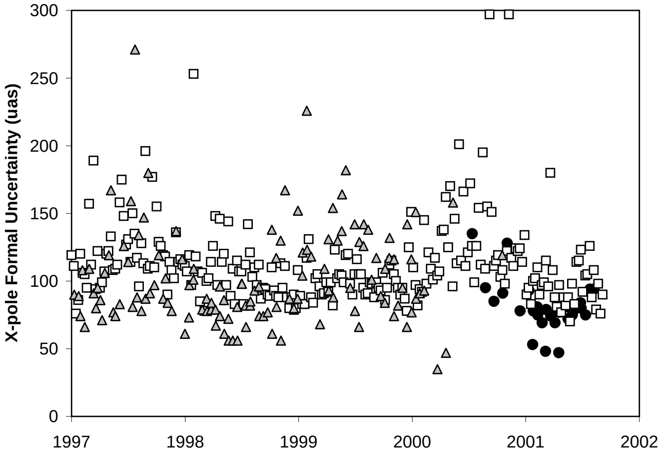


Figure 2. X-pole formal uncertainties for Mark 4 (black circles), NEOS (open squares), and CORE A+B (triangles).

The formal uncertainties of polar motion, UT1, and nutation offsets from the Mark 4 experiments are generally better than uncertainties from the NEOS-A or CORE-A and CORE-B series of VLBI experiments. Figure 2 compares the X-pole formal uncertainties for these series of experiments from 1997 to 2001. Plots for the other EOP components are similar. One can see that the Mark 4 points (clearly for the sessions in 2002) are mostly at the lower edge of the envelope of all the values plotted. The lowest three Mark 4 points are for the CORE-1 network, which has better geometry from global coverage than the CORE-3 network.

The median formal uncertainties given in Table 1 give a measure of the average performance of any given session. Larger values of the uncertainties for a given network session are usually caused by loss of data, either from specific station problems or not being able to schedule a station.

Table 1. Median EOP Formal Uncertainties

Session Type	X (μas)	Y (μas)	UT1 (μs)	ψ sinϵ (μas)	ϵ (μas)
Mark 4	80	66	2.6	65	67
CORE A+B (1997-2000)	91	79	3.2	70	72
NEOS-A (1997-2001)	107	86	4.4	81	78

4. Future Observing with Mark 4

We have been investigating different strategies of observing to take advantage of the increased data rate of Mark 4. An obvious way of improving the precision and accuracy of EOP measurements is to increase the number of stations in the observing network. The global coverage of the stations must of course also be optimized within the practical limitation of the actual locations of VLBI telescopes. Increasing the number of antennas provides better observing geometry and better local sky coverage of observations. To study this, we made simulations for observing schedules with different sized networks from 6 to 16 stations. For observed sessions, the simulation uncertainties are usually within 10-30% of observed formal uncertainties, depending on the performance of a session.

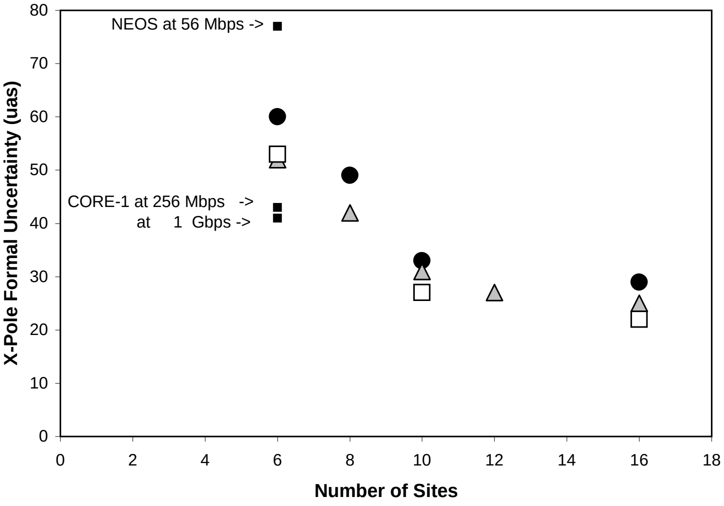


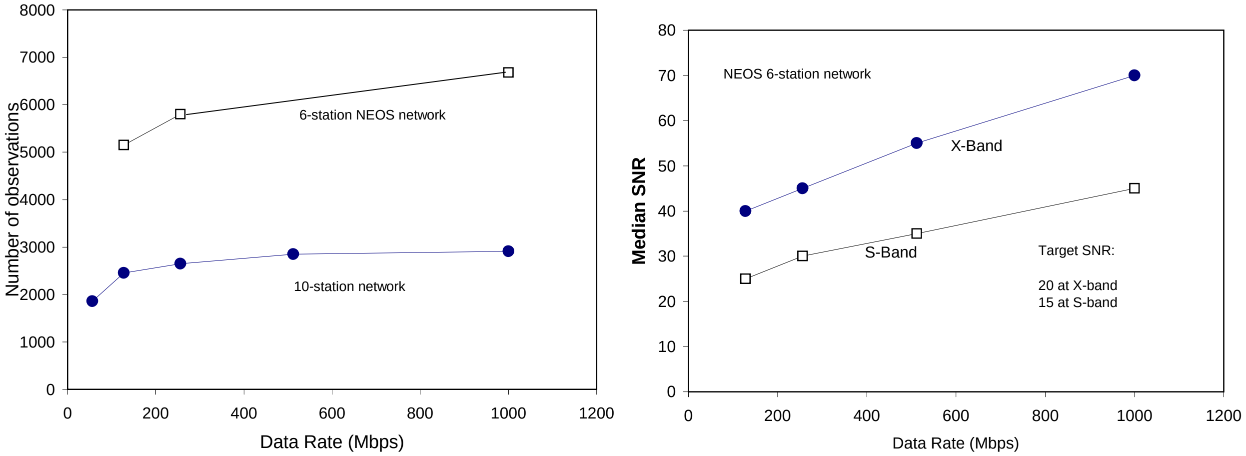
Figure 3. Simulated X-pole formal uncertainties for Mark 4 at data rates of 128 Mbps (black circles), 256 Mbps (triangles), and 1 Gbps (open squares).

Figure 3 shows the X-pole formal uncertainties from simulations of experiment sessions varying the network size and experiment data rate. Generally, one can see that EOP uncertainties decrease with the number of antennas. The series of networks starts with the NEOS-A 6-station network (Algonquin, Kokee, Fortaleza, Fairbanks, Nyalesund, and Wettzell) and then stations are added to make larger networks. The improvement with more than 10 sites is limited. Points are shown for these networks observing at data rates of 128 Mbps, 256 Mbps, and 1 Gbps. Formal precision improvement beyond 256 Mbps diminishes rapidly because of antenna slewing time. For instance, at 1 Gbps, observing time is only 15-20%. Several additional points are shown. The precision for the 6-station NEOS network improved by about 30% in going from 56 Mbps to 256 Mbps. Network dependence can be seen from the difference between the 6- station NEOS and CORE-1 networks, where CORE-1 is a significantly larger network than NEOS-A.

In Figure 4, we have plotted on the left side the number of observations as a function of data rate for the 6-station NEOS network and for the 10-station network The number of observations does not increase much beyond 256 Mbps. Despite this, the right-hand plot in Figure 4 shows that the median SNR of the observations nearly doubles in going from 128 Mbps to 1 Gbps.

It is not clear how to best use Mark 4. One possibility is to use the increased sensitivity of Mark 4 to observe weaker sources and exploit larger source catalogs (for example, the new VLBA Calibrator Survey of ~1400 sources). This would improve sky coverage and increase the number of observations and would provide more information about the spatial and temporal variation of tropospheric delay. Alternatively, experiments could be scheduled to get much higher SNR observations, which would allow phase delay solutions to be done so that one could take advantage of the much more precise phase delays to possibly determine and correct instrumental errors. The

R&D experiment series for 2002 will include this type of experiment to investigate this.



Observations in 24 hour session at different data rates.

Median session SNR at different data rates.

Figure 4. Dependence of number of observations and SNR on data rate.

5. Acknowledgements

We thank Nancy Vandenberg for running many Mark 4 simulation schedules and Alan Whitney for providing information regarding the Mark 4 development history.