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VLBA Impact on Geodesy and Astrometry

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Abstract

Large global solutions with and without VLBA sessions are compared to assess the impact of the VLBA. VLBA sessions comprise ~30% of all the normal geodetic/astrometric VLBI observations, and are found to make significant improvements in the TRF and CRF and to contribute significantly to the measurement of the long period nutation terms.

1. Introduction

Geodetic usage of the VLBA began in 1989, with the inclusion of Pie Town in occasional Mark III sessions. Increasing geodetic/astrometric use continued for several years, as more antennas became available. These early sessions were all correlated at the Haystack or USNO Mark III correlators. Beginning in 1995, geo/astro sessions using the full VLBA plus a few Mark III stations were started, along with their correlation on the new VLBA correlator. In 1997, the RDV sessions were begun, consisting of 6 yearly sessions, using the full VLBA and up to ten Mark IV stations. Early on in their usage, the VLBA antennas were recognized for their greater sensitivity and phase stability. Though not routinely done, the 8 continental US VLBA stations could be phase connected in nearly all of the RDV and earlier sessions. The geo/astro community now has nearly 9 years of full VLBA and VLBA-correlated sessions, In view of its recognized high quality, it seems like a good time to take an objective look at what contribution the VLBA has made to the gedetic/astrometric programs. To make this analysis, a Solve global solution was run to match the latest GSFC quarterly solution, but with all effects of the VLBA removed. This meant removing all RDV and most earlier VLBA sessions. For some of the earliest sessions, with just one or two VLBA stations and several Mark III stations, we just excluded the VLBA sites. The VLBA Calibrator Sessions (VCS1 and VCS2) [1] [2] were not included in either solution. The basic statistics of the two solutions, with and without the VLBA, are shown below in Table 1. The VLBA sessions represent about 30% of all the normal geodetic/astrometric VLBI observations, but less obvious is their effect on the terrestrial and celestial reference frames.

Table 1. Solution Statistics with/without the VLBA

	Without VLBA	With VLBA
No. Observations (millions)	2.98	4.28
No. Sources	879	910
No. Stations	138	148
No. Baselines	1044	1327

2. Impact on the Terrestrial Reference Frame

At first glance, it seems that the VLBA represents only a small fraction of the 148 VLBI stations in the TRF, but most of these are inactive sites. In reality, the VLBA represents nearly 30% of the active geo/astro VLBI sites, and they are among the most accurately determined sites, greatly adding to the stability of the TRF in the North America, Caribbean, and Pacific regions. Further, use of the VLBA with other worldwide Mark III/IV sites has greatly strengthened the worldwide TRF. Baselines with a VLBA antenna at one or both ends show an average repeatability of 0.8 parts-per-billion, compared to 1.5 ppb for all baselines. In Table 2, we list the horizontal site position and velocity formal errors from the two solutions for the VLBA and the 14 Mark IV stations used in VLBA sessions. Participation in VLBA sessions has improved the TRF positions and velocities for most of these Mark IV sites by typically 10-40%. Standing out anomolously are GGAO, which has been used almost exclusively in the RDVs, so its improvement is much more dramatic; and TIGO which has been used in only the last few RDVs, so it shows little improvement yet.

3. Impact on the Celestial Reference Frame

Though the regular VLBA sessions add only 31 additional sources, they greatly improve the source position determinations for most sources between -30 and +90 degrees declination. Figures 1 and 2 show the distribution of right ascension and declination uncertainties for all sources north of -30 degrees. Inclusion of the VLBA sessions results in a dramatically narrower distribution of errors. But we need to ask whether this improvement is just the result of the increased number of observations. If the VLBA data were equivalent in quality to the Mark III/IV data, then we would expect the source formal errors to decrease at a rate proportional to the square root of the number of observations. But if the quality is greater, then the formal errors should decrease faster. For 484 sources with more than 10 Mark III/IV observations, we find the average square root (giving all sources equal weight) of the ratio of the number of observations (Mark III/IV+VLBA divided by Mark III/IV-only) to be 1.946. This compares to average ratios of the formal errors (Mark III/IV-only divided by Mark III/IV+VLBA) of 2.184 in Declination and 2.673 in R.A. Thus, the implication is that the VLBA source data is higher in quality than the Mark III/IV data, most significantly in R.A. This can be attributed to the improved geometry of the RDV sessions, particularly in longitude, and the greater sensitivity and phase stability of the VLBA systems.

If we include the 12 VLBA calibrator sessions from VCS1 and VCS2 [1] [2], then the total number of geodetic/astrometric sources increases to 2290, a 150% increase. This increases the number of sources known to better than 1 n-radian from 615 to 2011, and there is now at least one well known calibrator within 4 degrees of any target source over 90% of the sky north of -40 degreees declination. This is, of course, most significant for radio astronomy phase referencing, where nearby calibrators are needed. Most of the new sources are too weak for the regular Mark IV 24-hr and 1-hr Intensive sessions, but undoubtably, many will contribute towards the next definition of the ITRF.

Table 2. Horizontal Site Formal Errors

	Position With/Without VLBA (mm)	Velocity With/Without VLBA (mm/yr)
GGAO7108	.41 / 2.6	.12 / .71
GILCREEK	.25 / .36	.03 / .04
HARTRAO	.58 / .68	.13 / .15
KOKEE	.40 / .60	.06 / .09
MATERA	.34 / .42	.06 / .07
MEDICINA	.36 / .46	.07 / .08
NOTO	.37 / .45	.08 / .09
NRAO20	.24 / .40	.07 / .09
NYALES20	.29 / .37	.04 / .04
ONSALA60	.31 / .39	.05 / .06
TIGOCONC	8.7 / 9.2	1.30 /1.43
TSUKUB32	.62 / .73	.12 / .13
WESTFORD	.23 / .38	.03 / .05
WETTZELL	.31 / .40	.05 / .06
BR-VLBA	.22 / —	.03 / —
FD-VLBA	.24 / —	.04 / —
HN-VLBA	.24 / —	.04 / —
KP-VLBA	.25 / —	.04 / —
LA-VLBA	.23 / —	.03 / —
MK-VLBA	.42 / —	.07 / —
NL-VLBA	.22 / —	.03 / —
OV-VLBA	.24 / —	.04 / —
PIE TOWN	.24 / —	.03 / —
SC-VLBA	.36 / —	.07 / —

4. Impact on EOP/Nutation

Table 3 shows the relative performance of the current session types in EOP and nutation, taken from a recent GSFC EOP submission. It can be seen that the RDVs produce the most accurate determination of all five Earth orientation parameters. With only 6 sessions per year though, the usefulness of the greater precision in UT1 and pole positions is limited. One of the greatest strengths of the VLBA/RDV sessions lies in the nutation measurements, where high frequency is not needed. The RDV nutations are over twice as precise as in the regular weekly (R1 and R4) or monthly (R&D) sessions. This makes them ideal for studying and monitoring the longer term nutation components, such as the free core nutation and possibly the free inner core nutation.

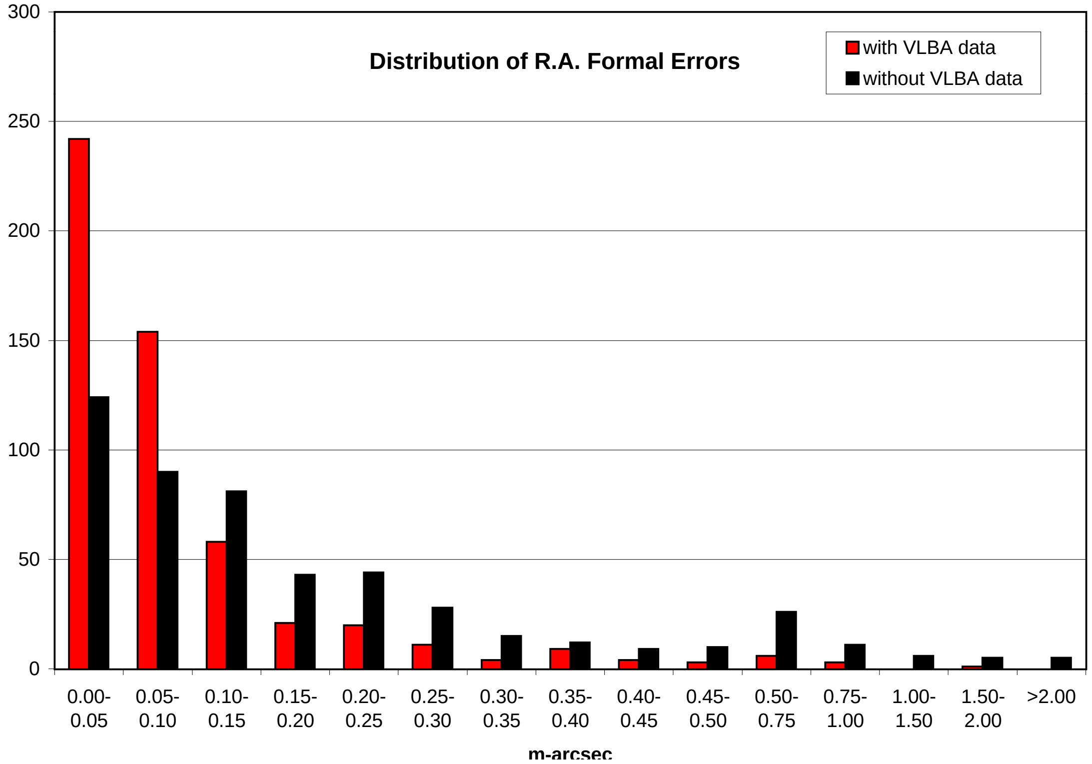

Figure 1. Distribution of formal errors in Right Ascension for the two solutions for all sources between -30 and +90 degrees declination.

Table 3. EOP/Nutation Formal Errors

	No.	Xpole μasec	Ypole μasec	UT1 μsec	Psi μasec	Eps μasec
RDV	41	29.9	30.7	1.59	59.1	24.0
R1	103	56.5	56.5	2.00	125.0	51.3
R4	102	85.7	70.8	2.95	169.7	68.2
R&D	16	70.9	66.9	2.57	147.3	61.8
Cont02	14	49.2	39.4	1.75	95.5	40.8

5. K/Q Session Contributions

Four K/Q sessions and one K-band survey session have been run on the VLBA over the last two years to begin building up a higher frequency reference frame. This frame will be needed in the near future for more precise spacecraft navigation at Ka band. A K/Q collaboration group is currently working on building up the basic catalog, investigating systematic effects, and selecting ecliptic sources for the next round of Mars missions. The VLBA has been invaluable in this effort, and it is unlikely that it could be undertaken at this time without the VLBA. Also, because of the

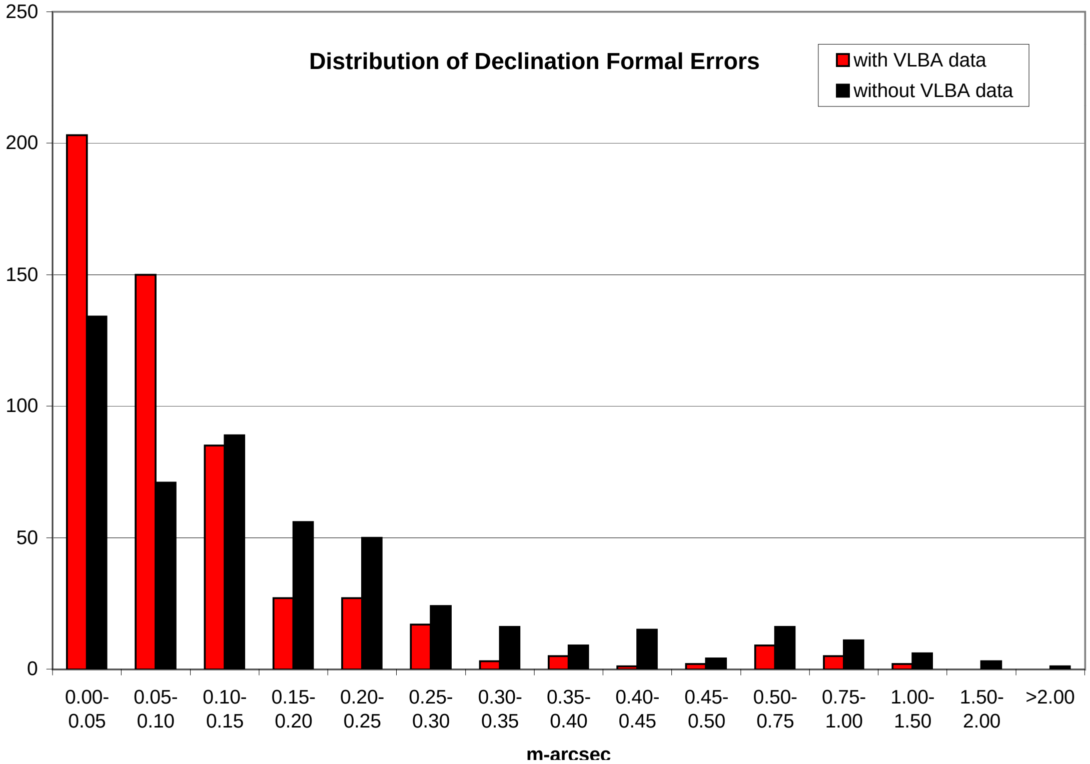

Figure 2. Distribution of formal errors in Declination for the two solutions for all sources between -30 and +90 degrees declination.

increasing interference at S-band, attempts are underway to establish a Ka/X geodetic frequency standard [3] as an alternate or replacement for X/S.

References

[1] Beasley, A.J., D. Gordon, A.B. Peck, L. Petrov, D.S. MacMillan, E.B. Fomalont, C. Ma, The VLBA Calibrator Survey–VCS1, Ap. J. Supplement, 141, 13–21, 2002.

[2] Fomalont, E.B., L. Petrov, D.S. MacMillan, D. Gordon, C. Ma, The Second VLBA Calibrator Survey: VCS2, Ap. J., 126, 2562–2566, 2003.

[3] Jacobs, C., G. Lanyi, C. Naudet, Standard Observing Bands: Is Now the Time To Replace S/X with X/Ka?, this volume, 2004.