VERA Status Report

VERA Observatory,
National Astronomical Observatory of Japan

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Contents

1 Introduction

This document summarizes the current observational capabilities of VERA (VLBI Exploration of Radio Astrometry), which is operated by National Astronomical Observatory of Japan (NAOJ). VERA is a Japanese VLBI array to explore the 3-dimensional structure of the Milky Way Galaxy based on high-precision astrometry of Galactic maser sources. VERA array consists of four stations located at Mizusawa, Iriki, Ogasawara, and Ishigaki-jima with baseline ranges from 1000 km to 2300 km (see, Figure 1). The construction of VERA array was completed in 2002, and it is under regular operation since the fall of 2003. From 2007, VERA is open to international users. This document is intended to give astronomers necessary information for proposing observations with VERA.

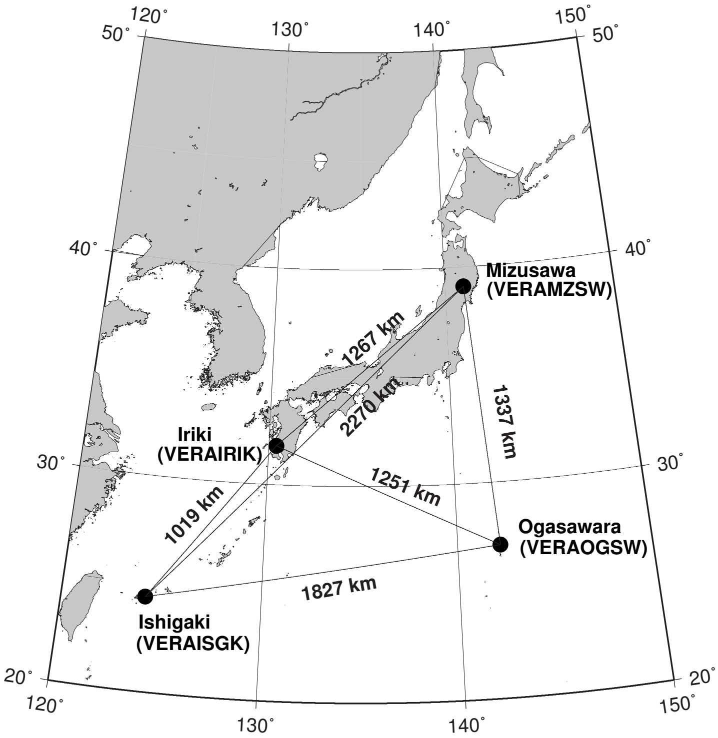

Figure 1: Array configuration of VERA.

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Most unique aspect of VERA is "dual-beam" telescope, which can simultaneously observe nearby two sources. While single-beam VLBI significantly suffers from fluctuation of atmosphere, dual-beam observations with VERA effectively cancel out the atmospheric fluctuations, and then VERA can measure relative positions of target sources to reference sources with higher accuracy based on the 'phase-referencing' technique.

2.1 Array

VERA array consists of 4 antenna site in Mizusawa, Iriki, Ogasawara, and Ishigaki-jima, with 6 baselines (see, Figure 1). The maximum baseline length is 2270-km between Mizusawa and Ishigaki-jima, and the minimum baseline length is 1019-km between Iriki and Ishigaki-jima. The maximum angular resolution expected from the baseline length is about 1.2 mas for K band (22 GHz) and about 0.6 mas for Q band (43 GHz). The geographic locations of each VERA antenna are summarized in Table 1. Figures 2 show examples of *uv* plane coverage.

Table 1: Geographic locations and motions of each VERA antenna

Site	East Longitude [° ′ ″]	North Latitude [° ′ ″]	Ellipsoidal Elevation [m]	Elevation [m]
Mizusawa	141 07 57.199	39 08 00.725	116.5	75.7
Iriki	130 26 23.597	31 44 52.435	573.5	541.5
Ogasawara	142 12 59.807	27 05 30.487	273.1	222.9
Ishigaki	124 10 15.582	24 24 43.828	65.0	38.4

Site	X (m)	Y (m)	Z (m)	IVS2[a]	IVS8[b]	CDP[c]
Mizusawa	–3857241.8292	3108784.8088	4003900.5255	Vm	VERAMZSW	7362
Iriki	–3521719.6126	4132174.6724	3336994.2267	Vr	VERAIRIK	7364
Ogasawara	–4491068.7882	3481544.8109	2887399.5913	Vo	VERAOGSW	7363
Ishigaki	–3263994.7692	4808056.2948	2619949.1828	Vs	VERAISGK	7365

[a]IVS 2-characters code, [b]IVS 8-characters code
[c]CDP (NASA Crustal Dynamics Project) code

Site	ΔX (m/yr)	ΔY (m/yr)	ΔZ (m/yr)
Mizusawa	0.0036	0.0019	–0.0083
Iriki	–0.0142	–0.0120	–0.0176
Ogasawara	0.0381	0.0201	0.0087
Ishigaki	–0.0354	0.0059	–0.0472

The coordinate system of epoch 2006.0

Table 2: Baseline Lengths between each VERA antenna site

ΔL (m/yr)\L (m)	MIZ	IRK	OGA	ISG
MIZ	—	1266754.1137	1336884.8025	2270415.5968
IRK	–0.0117	—	1251036.5201	1018524.2546
OGA	–0.0355	–0.0680	—	1826711.0010
ISG	0.0151	0.0269	–0.0542	—

Baseline lengths, L, in meter (*top right*) and velocity, ΔL, (*bottom left*) in m/yr for each VERA antenna pair.

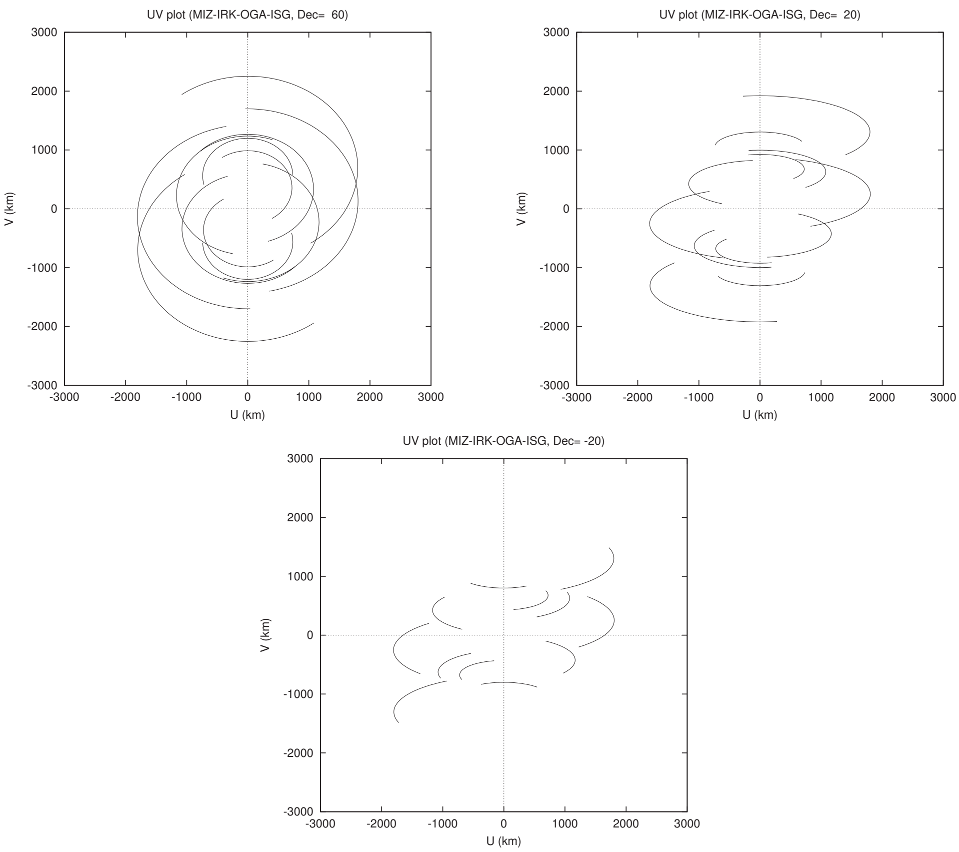

Figure 2: *UV* coverage (±3000 km) expected with VERA four antennas from an observation over elevation of 20°. Each panel show *UV* coverage for the declination of 60° (*top left*), 20° (*top right*), and –20° (*bottom*).

2.2 Antennas

All the telescopes of VERA have the same design, being a Cassegrain-type antenna on AZ-EL mount. Each telescope has a 20-m diameter dish with a focal length of 6-m, with a subreflector of 2.6-m diameter. The dual-beam receiver systems are installed at the Cassegrain focus. Two receivers are set up on the Stewart-mount platforms, which are sustained by steerable six arms, and with such systems one can simultaneously observe two adjacent objects with a separation angle between 0.32 and 2.2 deg. The whole receiver systems are set up on the field rotator (FR), and the FR rotate to track the apparent motion of objects due to the earth rotation. Table 3 summarizes the ranges of elevation (EL), azimuth (AZ) and field rotator angle (FR) with their driving speeds and accelerations. In the case of single beam observing mode, one of two beams is placed at the antenna vertex (separation offset of 0 deg).

2.2.1 Aperture Efficiency

The aperture efficiency of each VERA antenna was measured during the winter season in 2005-2006. The observation toward Jupiter with five position scan was performed using each antenna, and the aperture efficiency was estimated assuming that the brightness temperature of Jupiter is 160 K in the K band. The results are summarized in

Table 3: Driving Performance of VERA 20-m Antennas

Driving axis	Driving range	Max. driving speed	Max. driving acceleration
AZ[1]	–90° ∼450°	2.1°/sec	2.1°/sec^2
EL	5° ∼85°	2.1°/sec	2.1°/sec^2
FR[2]	–270° ∼270°	3.1°/sec	3.1°/sec^2

[1]The north is 0° and the east is 90°.
[2]FR is 0° when Beam-1 is at the sky side and
Beam-2 is at the ground side, and CW is positive when an antenna is seen from a target source.

Table 4. The latest value of the aperture efficiency will be measured again by the VERA group before the next season.

Table 4: Aperture Efficiency of VERA 20-m Antennas

Site	Band	Date	η_A (%)	HPBW (arcsec)	Elevation (deg)	Num. of Scan	θ^a (arcsec)
MIZ	K	Apr. 22, 2006	46.7 ± 2.7	151.7 ± 7.6	31-35	9	42.9
IRK	K	Apr. 13, 2006	45.2 ± 1.9	150.4 ± 10.2	41-42	8	42.5
OGA	K	Nov.2002/Feb.2003	44.8 ± 3.8	150^b	67-71	4	40.4/45.4
ISG	K	Apr. 28, 2004	49.5 ± 2.3	152.6 ± 6.9	64-75	17	39.3

[a]Assumed apparent diameter for Jupiter
[b]Assumed value

The elevation dependence of aperture efficiency for VERA antenna was also measured from the observation toward maser sources. Figure 3 show the relations between the elevation and the aperture efficiency measured for Iriki station. The aperture efficiency in low elevation of $\leq$ 20 deg decreases slightly, but this decrease is less than about 10%. Concerning this elevation dependence, the observing data FITS file include a gain curve table (GC table), which is AIPS readable, in order to calibrate the dependence when the data reduction.

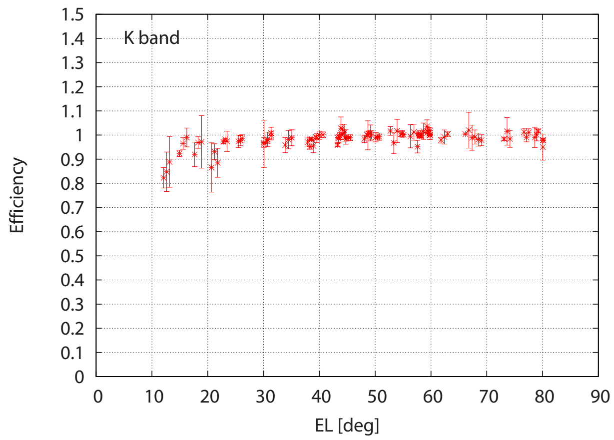

Figure 3: The elevation dependence of the aperture efficiency at K band (on Feb 8, 2005) for Iriki antenna. The efficiency of vertical axis is relative value to the measurement at EL = 50°.

The aperture efficiency was also measured at various separation angle of dual-beams in order to evaluate the dependence of aperture efficiency on dual-beam separation angle. Figure 4 show the relations between the beam separation angle and the aperture efficiency measured for Iriki antenna. It appears that the aperture efficiency decreases slightly as the separation angle increases. For the calibration of the separation angle dependence, a gain curve table (GC table) which includes the separation angle dependence of the aperture efficiency is attached to the observed data FITS file.

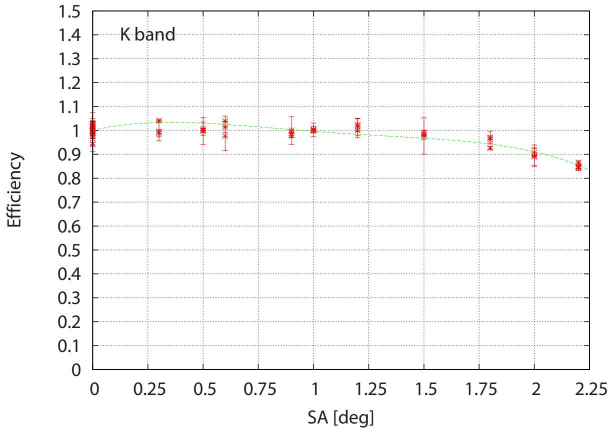

Figure 4: The dependence of the aperture efficiency on the separation angle between dual-beams at K band for Iriki antenna (on Mar 4, 2004). The efficiency of vertical axis is relative value to the measurement at the separation angle of 0°. The curved line indicates the quartic polynomial fitting.

2.2.2 Beam Pattern and Size

Figure 5 shows the beam patterns in the K band. The side-lobe level is less than about –15 dB, except for the relatively high side-lobe level of about –10 dB for the separation angle of 2.0 deg at Ogasawara station. The side-lobe of the beam patterns have an asymmetric shape, but the main beam have a symmetric gaussian shape without dependence on separation angle. The measured beam sizes (HPBW) in the K band based on the data of the pointing calibration are summarized in Table 5. The main beam sizes show no dependece on the dual-beam separation angle.

Table 5: Beam Size of VERA 20-m Antennas

Site	Band	HPBW[AZ] (arcsec)	HPBW[EL] (arcsec)	Num. of data point	Date
MIZ	K	147.93 ± 7.96	151.35 ± 9.73	596	Mar. 2006
IRK	K	152.79 ± 9.56	153.93 ± 10.11	674	Nov.-Dec. 2005
OGA	K	148.41 ± 9.49	150.34 ± 11.12	619	Feb.-Mar. 2006
ISG	K	149.30 ± 11.84	151.27 ± 14.13	697	Mar. 2006

Each error indicates a standard deviation (1σ).

2.2.3 Pointing Accuracy

In each VERA antenna, observations to check a pointing accuracy were carried out, and the pointing offset were calibrated. Pointing offsets for all sky direction were measured based on five-point scans in the azimuth and elevation direction using strong maser sources with known positions. Observed pointing offsets were parameterized with

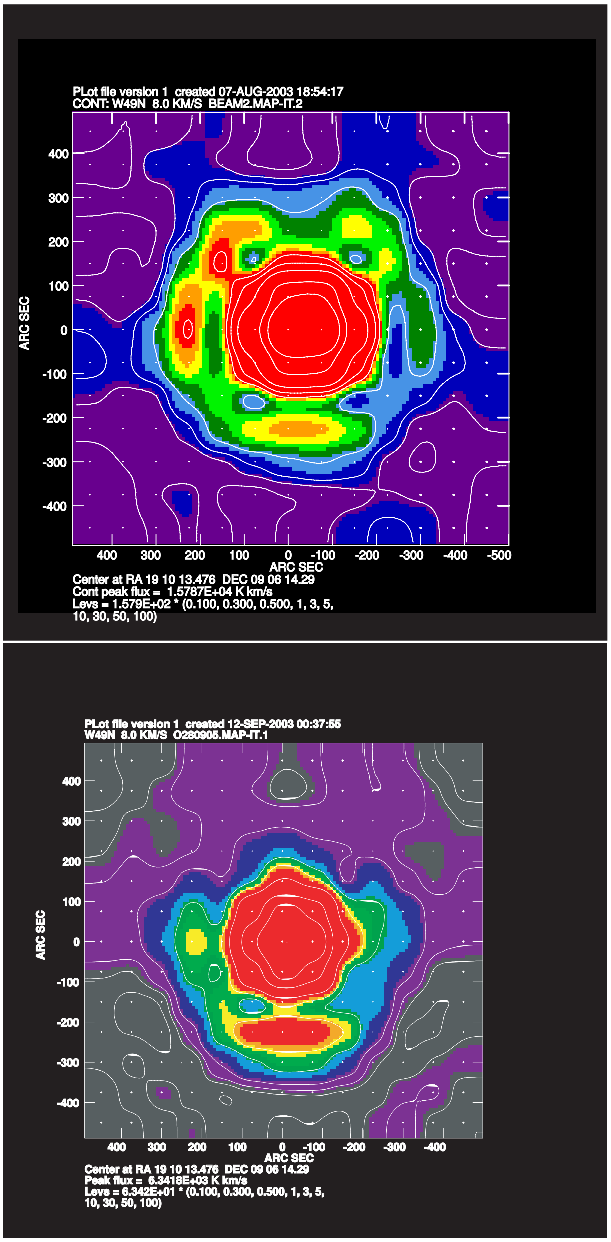

Figure 5: The beam patterns of Beam-A in the K band. Top and bottom panels were the results for the separation angle of 0° at Iriki, and for the separation angle of 2.0° at Ogasawara, respectively. These are derived from the mapping observation of strong H_2O maser toward W49N, which can be assumed as a point source, with grid spacing of 75″.

the models described in the equation (1) and (2), and are now corrected to improve the pointing accuracy. In the equations (1) and (2), A_1-A_8 are standard pointing instrumental parameters for AZ-EL mounting telescope, and A_9-A_{12} are parameters which are introduced to describe higher order effects.

$$\begin{aligned}
\delta Az &= A_1 \sin(Az)\sin(El) - A_2\cos(Az)\sin(El) + A_3\sin(El) + A_4\cos(El) + A_5 + \\
&\quad A_9\sin(2Az)\sin(El) - A_{10}\cos(2Az)\sin(El) + \\
&\quad A_{11}\sin(2Az)\cos(El) - A_{12}\cos(2Az)\cos(El) \qquad (1)\\
\delta El &= A_1\cos(Az) + A_2\sin(Az) + A_6 + A_7\cos(El) + A_8\sin(El) + \\
&\quad A_9\cos(2Az) - A_{10}\sin(2Az) \qquad (2)
\end{aligned}$$

The pointing accuracy of each VERA antenna, after the correction of the pointing instrumental error, are summarized in the Table 6. The residual pointing offsets are shown in the Figure 6.

Table 6: Pointing Accuracy of VERA 20-m Antennas

Site	Band	Date	σ^a	$\sigma_{AZ}{}^b$	$\sigma_{EL}{}^c$
MIZ	K	Mar. 2006	11.666	8.087	14.381
IRK	K	Dec. 2005	6.957	6.493	7.393
OGA	K	Mar. 2006	8.934	7.054	10.483
ISG	K	Mar. 2006	9.378	6.522	11.549

[a]Standard deviation
[b]Standard deviation for azimuth
[c]Standard deviation for elevation

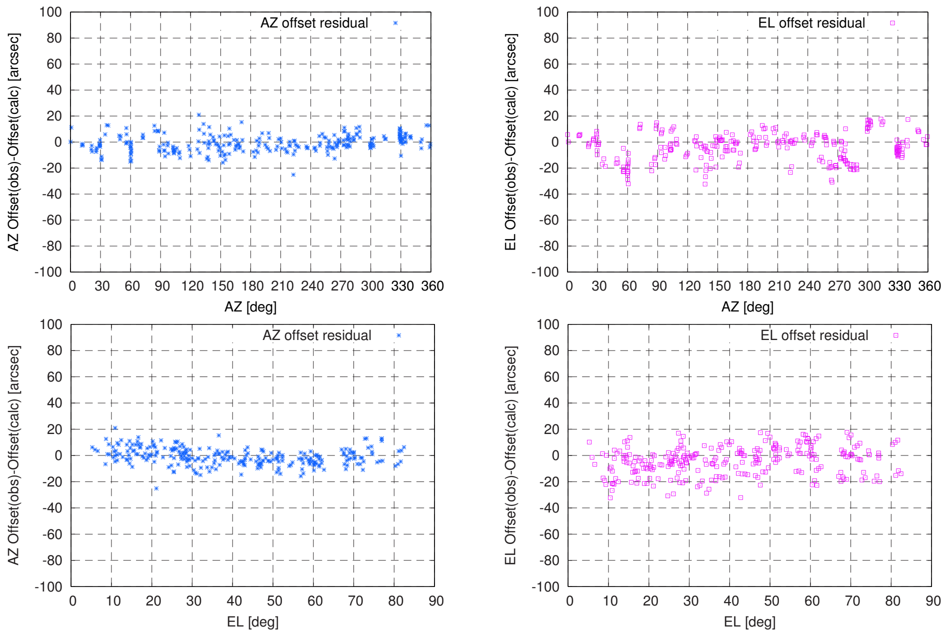

Figure 6: Pointing residuals in the K band in Ishigaki antenna. Top and bottom panels show the relation the azimuth and elevation to the pointing residual of azimuth (*left*) or elevation (*right*), respectively. Measurements were made in Mar 2006.

For dual-beam observations with large separation angle, there is an additional pointing offset with $\sim$ 15 arcsec that shows sinusoidal variations with FR angle, as shown in Figure 7. This poiting error is not fully calibrated.

2.2.4 Sky Line

Figure 8 show a skyline for the VERA antenna site. While mechnically-possible EL driving range is from 5 to 85 deg, due to the sky line effect, the lowest observable elevation is as high as 20 deg depending on the stations and the directions. Observers are requested to take care of the skyline effect if low declination sources are to be observed.

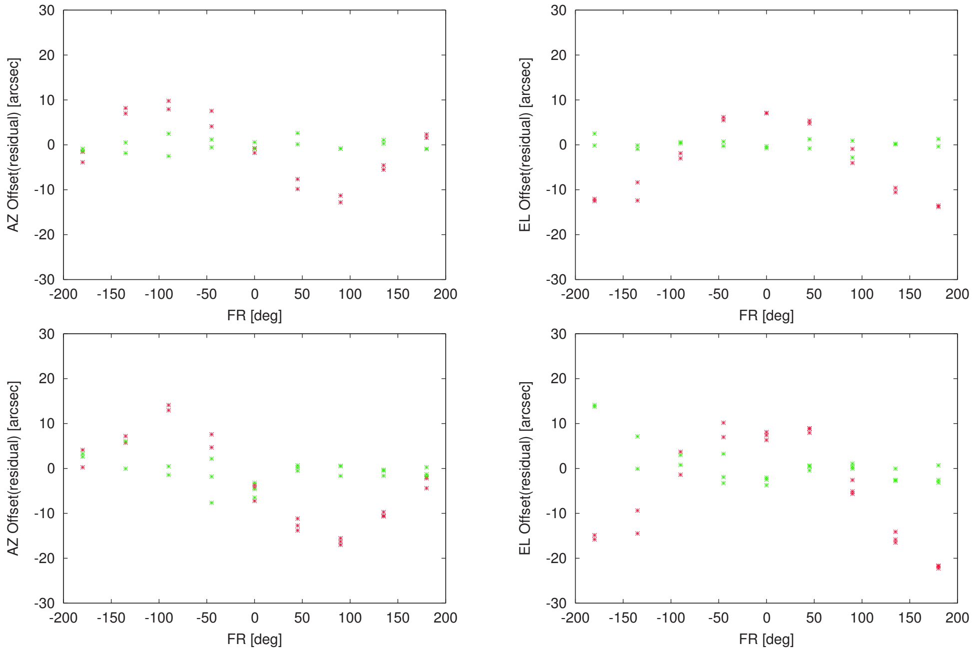

Figure 7: Pointing offset of Beam A against dual-beam separation angle in the K band at Iriki station. Red cross indicate the tracking error with the dual-beam offset, and green cross indicate the tracking error without the dual-beam offset (Beam A is placed at the antenna vertex). These panels show dependency on the field rotator angle (FR) of the azimuth offset (*left panel*) and the elevation offset (*right panel*). Top and bottom panels show the relations for the separation angle of 1.0 deg (on the observation of W3 OH) and 2.0 deg (on the observation of W49N), respectively.

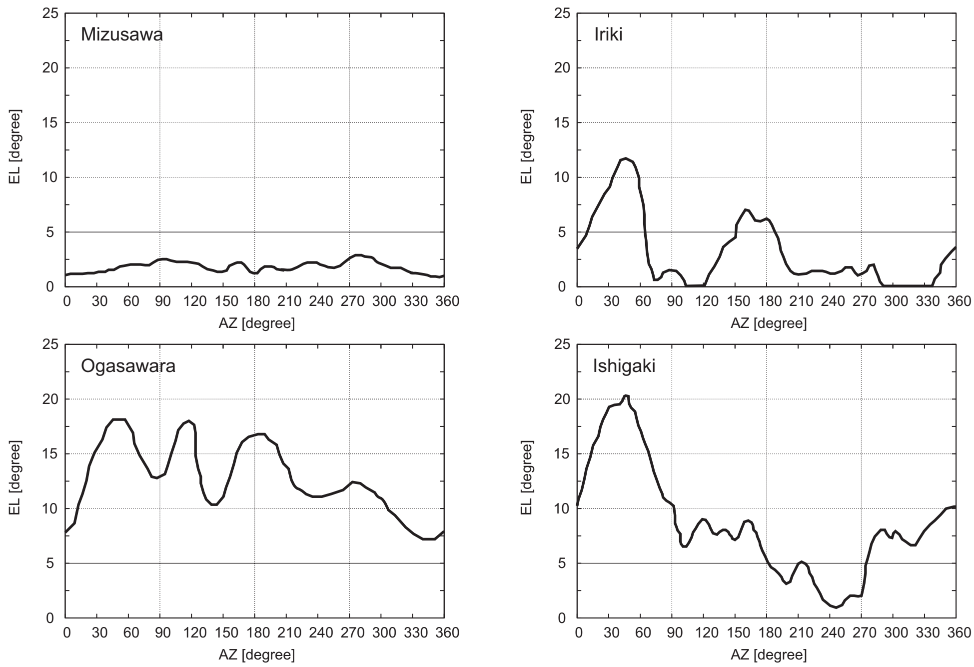

Figure 8: Sky Line for each VERA antena. The azimuth of 0 deg is the north. Mechanically-possible EL range is from 5 deg to 85 deg.

2.3 Receivers

Each VERA antenna has the receivers for 4 bands, which are S, X, K, and Q bands. For the common use in 2007, only K band (22 GHz) is open for observing. The low-noise HEMT amplifiers in the K and Q bands are enclosed in the cryogenic dewar, which is cooled down to 20 K, to reduce the thermal noise. The range of observable frequency and the typical receiver noise temperature ($T_{\rm RX}$) at each band are summarized in the Table 7 and Figure 9.

Table 7: Receivers

Band	Frequency Range [GHz]	$T_{\rm RX}{}^a$ [K]	Polarization
K	21.5-23.8	30-50	LCP
Q	42.5-44.5	70-90	LCP

[a]Receiver noise temperature

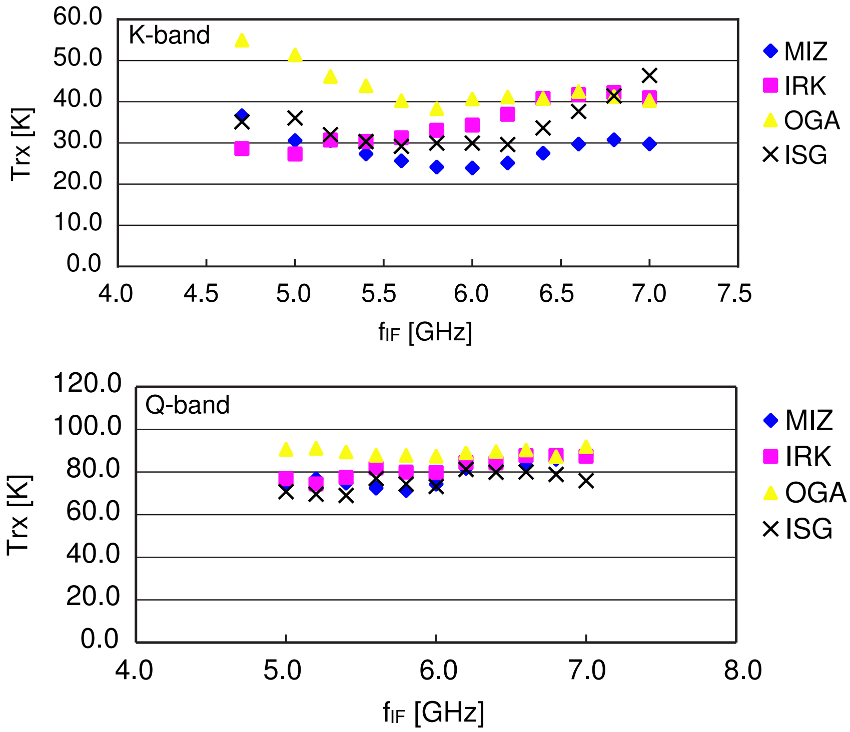

Figure 9: Receiver noise temperature for each VERA antenna. Top and bottom panels show measurements in the K and Q bands, respectively. Horizontal axis indicate a IF (intermediate frequency) at which $T_{\rm RX}$ is measured. To convert it to RF (radio frequency), add 16.8 GHz at K band and 37.5 GHz at Q band to the IF frequency.

After the radio frequency (RF) signals from astronomical objects are amplified by the receivers, the RF signals are mixed with standard frequency signal generated in the first local oscillator to down-convert the RF to an intermediate frequency (IF) of 4.7 GHz–7 GHz. The first local frequencies are fixed at 16.8 GHz in the K band and at 37.5 GHz in the Q band. The IF signals are then mixed down again to the base band frequency of 0–512 MHz. The frequency of second local oscillator is tunable with a possible frequency range between 4 GHz and 7 GHz. The correction of the

Doppler effect due to the earth rotation is carried out in the correlation process after the observation. Therefore, basically the second local oscillator frequency is kept to be constant during the observation. Figure 10 shows a flow diagram of these signals for VERA.

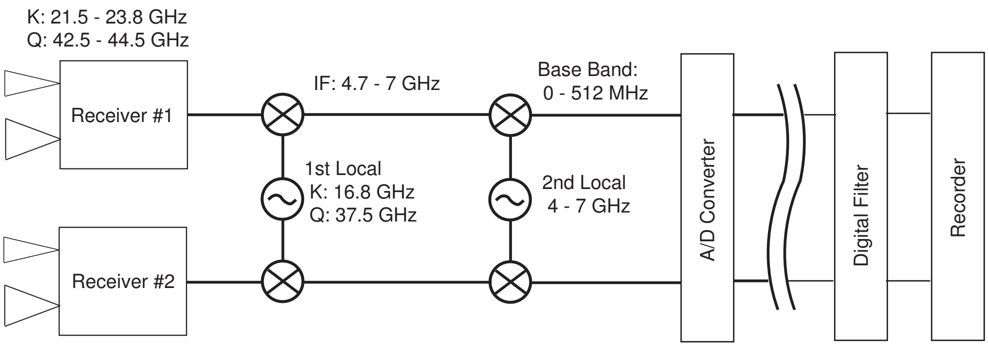

Figure 10: Flow diagram of signals from receiver to recorder for VERA.

2.4 Digital signal process

A/D (analog-digital) samplers convert the analog base band outputs (0–512 MHz $\times$ 2 beams) to digital form. The A/D converters carry out the digitization of 2-bit sampling with the bandwidth of 512 MHz, and the data rate is 2048 Mbps for each beam.

Since the total data recording rate is limited to 1024 Mbps (see the next section), only part of the sampled data can be recorded onto magnetic tape. The data rate reduction is done by digital filter system, with which one can flexiblly choose number and width of recording frequency bands. Observers can select modes of the digital filter listed in the Table 8.

Table 8: Digital Filter Mode for VERA

Mode	Rate (Mbps)	Num. CH[a]	BW/CH[b] (MHz)	CH[c]	Beam	Total BW[d] (MHz)
VERA1	1024	2	128	1	A	256 - 384
				2	B	256 - 384
VERA7	1024	16	16	1	A	256 - 272
				2	B	128 - 144
				3	B	144 - 160
				4	B	160 - 176
				5	B	176 - 192
				6	B	192 - 208
				7	B	208 - 224
				8	B	224 - 240
				9	B	240 - 256
				10	B	256 - 272
				11	B	272 - 288
				12	B	288 - 304
				13	B	304 - 320
				14	B	320 - 336
				15	B	336 - 352
				16	B	352 - 368
VERA10	1024	16	16	1	A	256 - 272
				2	B	256 - 272
				3	A	272 - 288
				4	B	272 - 288
				5	A	288 - 304
				6	B	288 - 304
				7	A	304 - 320
				8	B	304 - 320
				9	A	320 - 336
				10	B	320 - 336
				11	A	336 - 352
				12	B	336 - 352
				13	A	352 - 368
				14	B	352 - 368
				15	A	368 - 384
				16	B	368 - 384

In VERA7 and VERA10, any two CH can be simultaneously recorded on the DIR100M system

[a]Total number of channels

[b]Bnadwidth per channel in MHz

[c]Channel number

[d]Total Bnadwidth in MHz

2.5 Recorders

VERA has two types of high speed magnetic tape recorders. These data recording systems are the DIR1000M developed for the VSOP (VLBI Space Observatory Program), and the DIR2000 which is newly developed for the VERA. The recording speed of each recorder is 128 Mbps in the DIR1000M system and 1024 Mbps in the DIR2000 system. Because of 2-bit sampling, the total bandwidths are 32 MHz in the DIR1000M system and 256 MHz in the DIR2000 system. The recording time per roll of tape are 2 hrs in the DIR1000M system and 80 mins in the DIR2000 system.

2.6 Correlators

The correlation processes is carried out by the FX correlator located at NAOJ Mitaka campus. The correlator system is originally developed for VSOP, and is modified for VERA's dual-beam observation. The maximum number of antenna station that can be correlated at the same time is 5 for the DIR2000 system, and 10 stations for the DIR1000M system. Thus, the correlator can process at once the data recored by DIR2000 with VERA four station, or the data recored by DIR1000M with VERA, Nobeyama 45-m telescope, and Kashima 34-m telescope. The correlator cannot process 'mixed' correlation between the data recorded by DIR1000M and those by DIR2000. In the correlator output, the maximum number of spectral point per antenna are 1024 points across all channels for DIR1000M, and 2048 points across all channels of 2-beams for DIR2000. The time resolution of the correlator output is usually set to be 1 second, but the high time resolution (down to 25 milliseconds) is also avaialble upon requests (though the total amount of output data becomes larger).

2.7 Calibration

2.7.1 Delay and Bandpass Calibration

The time synchronization for each antenna is kept within 0.1 μsec using time referred to GPS and high stability frequency standard provided by the hydrogen maser. To correct for clock parameter offsets with better accuracy, bright continuum sources with accurately-known positions should be observed at usually every 60–90 mins during observations. The calibration of frequency characteristic (bandpass calibration) can be also done based on the observation of bright continuum source.

2.7.2 Gain Calibration

Each VERA antenna has the chopper wheel of the hot load (black body at the room temperature), and the system noise temperature can be obtained by measuring the ratio of the sky power to the hot load power (so-called R-Sky method). The hot load measurement can be made before/after any scan. Also, the sky power is continuously monitored during scans, so that one can trace the variation of system noise temparature.

2.7.3 Phase Calibration

To calibrate the instrumental phase error caused the path length difference in dual-beams, four artificial noise sources (NS) are installed on the feedome base (above the main reflector). During observations, the artificial noise (reflected by sub-reflector) is injected to dual-beam receivers and correlated on real-time to calculate the phase difference between dual-beams. Typical phase residuals of the dual-beam calibration system are 0.2 mm for using one NS and 0.12 mm for using four NSs. Dual-beam phase calibration data are also attached to the observed data in a readable format with AIPS.

2.8 Geodetic Measurement

Geodetic observations are performed as part of the VERA project observations to derive accurate antenna coordinates. The geodetic VLBI observations for VERA are carried out in the S/X bands (2 GHz/8 GHz). The most up-to-date geodetic parameters are derived through geodetic analyses. The results of the geodetic measurement are summarized in Tables 1 and 2. The epoch of the coordinates is at 2006.0.

In order to maintain the antenna position accuracy, the VERA project has three kinds of geodetic observations. The first is participation in JADE (JApanese Dynamic Earth observation by VLBI) organized by GSI (Geographical Survey Institute) in order to link the VERA coordinates to the ITRF2000 (International Terrestrial Reference Frame 2000). Basically Mizusawa station participate in JADE nearly every month. Based on the observations for four years, the 3-dimentional positions and velocites of Mizusawa station are determined with accuracies of 7-9 mm and about 1 mm/yr in ITRF2000 coordinate system. The second kind of geodetic observations is monitoring of baseline vectors between VERA stations by internal geodetic VLBI observations. Geodetic positions of VERA antennas relative to Mizusawa antenna are measured from geodetic VLBI observations every two weeks. From simple linear-fitting of the two-year geodetic results, the relative positions and velocities are obtained at the precisions of 1-2 mm and 0.8-1 mm/yr. The third kind is continuous GPS observations at the VERA sites for interpolating VLBI geodetic positions. Daily positions can be determined from 24 hour GPS data. The GPS data can be also used to estimate the tropospheric delay, which is difficult to predict based on tropospheric models.

3 Observing Proposal

Although the aimed positional accuracy of VERA (10 μas) has not yet been achieved, the measurements of annual parallax have been successfully done for some sources at K band. Hence, for 2006 observing season, K-band dual-beam mode is opened to international users.

Total observing time up to 400 hrs will be available for the common-use observing time in 2007. The observation with 6 elements array (VERA + Nobeyama 45-m and Kashima 34-m) is also available, with observing time of 100 hrs at maximum. Accepted observations will be scheduled from January to December in 2007. However, note that the observable season for Nobeyama 45-m telescope is limited from winter to spring season (from January to May and at December) in 2007.

3.1 Proposal Submission

Observing proposals for VERA are invited for the observing period from January to December in 2007. The application deadline is on "**November 3, 2006**" for this season. Proposals will be reviewed by referees, and observing time is scheduled by the VERA Time Allocating Committee of the NAOJ on the basis of the scientific merits of the proposed research. As for the proposal submission, detailes can be found at the VERA homepage,

`http://veraserver.mtk.nao.ac.jp/restricted/index-e.html`.

Any questions on proposal submission should be sent to "`veraprop@miz.nao.ac.jp`". If an applicant wants to have a collaborator from the VERA group member for extensive support, the VERA group can arrange the collaborator (after the acceptance of proposal).

3.2 Observation Mode

In this year's common-use, K band (22 GHz) single/dual-beam mode is available. The observation using the six antenna included Nobeyama 45-m and Kashima 34-m in addition to VERA four antennas is also available. However, note that the observation with Nobeyama 45-m and Kashima 34-m should be done in single-beam mode.

3.3 Angular Resolution

The angular resolution that is expected from baseline length (D) is provided by λ/D for a wavelength of λ. Thus, the expected angular resolutions for K band (22 GHz) and Q band (43 GHz) are estimated at about 1.2 mas and about 0.6 mas, respectively. The synthesized beam size strongly depend on UV coverage, and is actually larger than the values mentioned above because the baseline projected on UV plane become shorters than the distance between antennas.

3.4 Sensitivity

When a target source is observed, a noise level $\sigma_{\rm bl}$ for each baseline can be expressed as

$$\sigma_{\rm bl} = \frac{2k}{\eta} \frac{\sqrt{T_{\rm sys,1} T_{\rm sys,2}}}{\sqrt{A_{e1} A_{e2}} \sqrt{2B\tau}}, \tag{3}$$

where k is Boltzmann constant, η is quantization efficiency (~ 0.88), $T_{\rm sys}$ is system noise temperature, A_e is antenna effective aperture area which include aperture efficiency, B is the bandwidth, and τ is on-source integration time. Because of the coherence loss due to the atmospheric fluctuation, the noise level expected by equation (3) is not generally attained for the observation with the integration time over 3 mins (in the K band). Thus, for finding fringe within a coherence time, the integration time τ cannot be longer than 3 minitues. When a continuum source is observed with the digital filter mode of 'VERA1' in good weather condition of winter season, the noise level estimated by the equation (3) is $\sigma_{\rm bl}$=23 mJy, assuming that aperture efficiency $\eta_A \sim 50\%$, $B = 128$ MHz, $\tau = 120$ sec, and $T_{\rm sys} = 200$ K. Thus the minimum flux which can be detected for each baseline is 160 mJy for $S/N = 7$. For VLBI observations, signal-to-noise ratio (S/N) of at least 5 and usually 7 is generally required for finding fringes. On the other hand, when a maser source is observed with the 'VERA7' mode under above conditions, the noise level is $\sigma_{\rm bl}$=1.5 Jy, assuming that $B = 31.25$ KHz (512 spectral channels with 16 MHz bandwidth) for the VERA7 mode. Thus the minimum detectable flux for each baseline is 10.2 Jy for $S/N = 7$. A noise level for each parameter is also expressed as follows,

$$\sigma_{\rm bl} = 23 \times \left(\frac{T_{sys,1}}{200\ K}\right)^{1/2} \left(\frac{T_{sys,2}}{200\ K}\right)^{1/2} \left(\frac{B}{128\ MHz}\right)^{-1/2} \left(\frac{\tau}{120\ sec}\right)^{-1/2} \text{mJy}. \tag{4}$$

On the dual-beam observation, a continuum source or a maser source which is brighter than the above baseline sensitivity should be observed as reference source by one of the two beams. If the user observes a source which is weaker than the above sensitivity limit, it is necessary to carry out the long time integration with phase-referencing to brighter sources. After successful phase-referencing, signal-to-noise ratio is improved as $\propto \sqrt{\tau}$.

Figure 11 show the receiver noise temperature and the system noise temperature at the zenith for K band, at Mizusawa station. Here the receiver temperature includes the temperature increase due to the feedome loss and the spill-over effect. In Mizusawa, typical system temperature in the K band is $T_{\rm sys} = 150$ K in fine weather of winter season, but sometimes rises above $T_{\rm sys} = 300$ K in summer season. The system temperature at Iriki station shows a similar tendency to that in Mizusawa. In Ogasawara and Ishigaki-jima, typical system temperature is similar to that for summer in Mizusawa site, with typical optical depth of $\tau_0 = 0.2 \sim 0.3$.

3.5 Astrometric Observation

In an astrometric observation, the observation using dual-beams with DIR2000 recorder system is recommended because of higher sensitivity than that with DIR1000M system. Also, it is strongly recommended to observe pair sources with small separation angle (i.e., less than 1 deg) at high elevation. This will reduce the postion errors caused

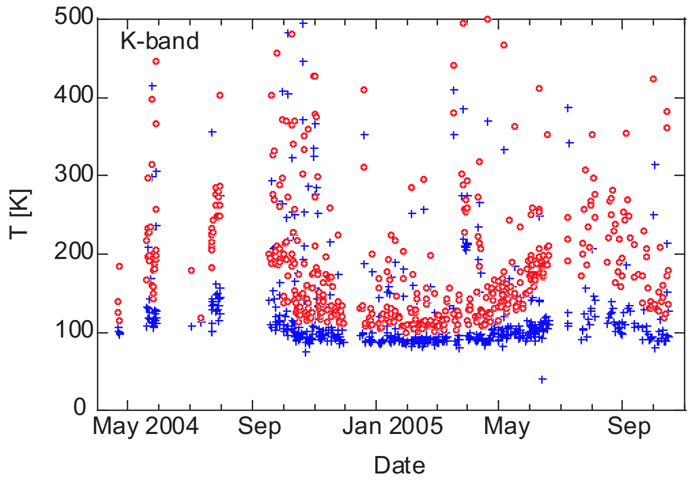

Figure 11: The receiver noise temperature (*crosses*) and the system noise temperature (*open circles*) at the zenith in the K band with Mizusawa antenna.

by the residuals in atmospheric zenith delay, which is difficult to predict accurately. Generally, users are encouraged to carefully carry out data reduction in consultation with a contact person in the VERA project group.

3.6 Calibrator Infomation

The VLBA calibrator survey of the National Radio Astronomy Observatory (NRAO) is very useful to search for a continuum source which can be used as a reference source to carry out the delay, bandpass, and phase calibrations. The source list of this calibrator survey can be found at the following VLBA homepage,

`http://www.vlba.nrao.edu/astro/calib/index.shtml`.

The calibrator source for phase-referencing should be brighter than the detection limit described in the previous section. For delay calibrations and bandpass calibrations, calibrators with 1 Jy or brighter are recommended.

Regarding H_2O maser source list, "the Arcetri Catalog of H_2O maser sources" (Valdettaro et al. 2001, A&A, 368, 845) is very useful. However, we note that the flux of H_2O maser source is highly variable, and also that it is probable that the correlated flux is significantly smaller than that the catalog flux because of resolving-out problem with long baslines. We also note that a positional accuracy of a few arcsec is usually needed for correlation process, but some of the maser sources in the cotalog have larger position uncertainty.

3.7 Nobeyama 45-m and Kashima 34-m Telescopes

The array with the six antennas including Nobeyama 45-m telescope at Nobeyama Radio Observatory (NRO), NAOJ, and Kashima 34-m telescope at Kashima Space Research Center, National Institute of Information and Communication Technology (NICT), is also available. The observable season for Nobeyama 45-m telescope is limited from winter to spring season (from January to May and at December) in 2007. The user can see at the following homepage about the performance of both antennas,

http://www.nro.nao.ac.jp/~nro45mrt/NEW45M/45OPENUSE/index.html
http://www2.nict.go.jp/w/w114/stsi/34m/antenna-34m/index.html.

Whether these antennas are joined in the proposed observation or not is judged by Time Allocating Committee of VERA and NRO based on a scientific standpoint of observing proposal and availablity of observing time. Note that the recorder systems at Nobeyama 45-m and Kashima 34-m are only DIR1000 (with recording speed of 128 Mbps).

Table 9: Performance of Nobeyama 45-m and Kashima 34-m Telescope

Antenna	Nobeyama 45-m	Kashima 34-m
Aperture diameter (m)	45	34
Beam size (arcsec)^a	73	96
Aperture efficiency (%)^a	63	57
Frequency (GHz)^a	20.0–24.0	21.8–23.8
$T_{\rm sys}$ (K)^{a,b}	100	160
EL driving range (deg)	12–80	7–88
Recorder system	DIR1000	DIR1000

^{a}In case of the K band
^{b}Typical system noise temperature in good condition

3.8 Date Archive

The users who proposed the observations will have an exclusive access the data for 18 months after the correlation. After that period, all the observed data in the VERA common-use observation will be released as archive data. Thereafter, archived data will be available to any user upon request. This policy is applied to each observation, even if the proposed observation is comprised of multi-epoch observations in this season.

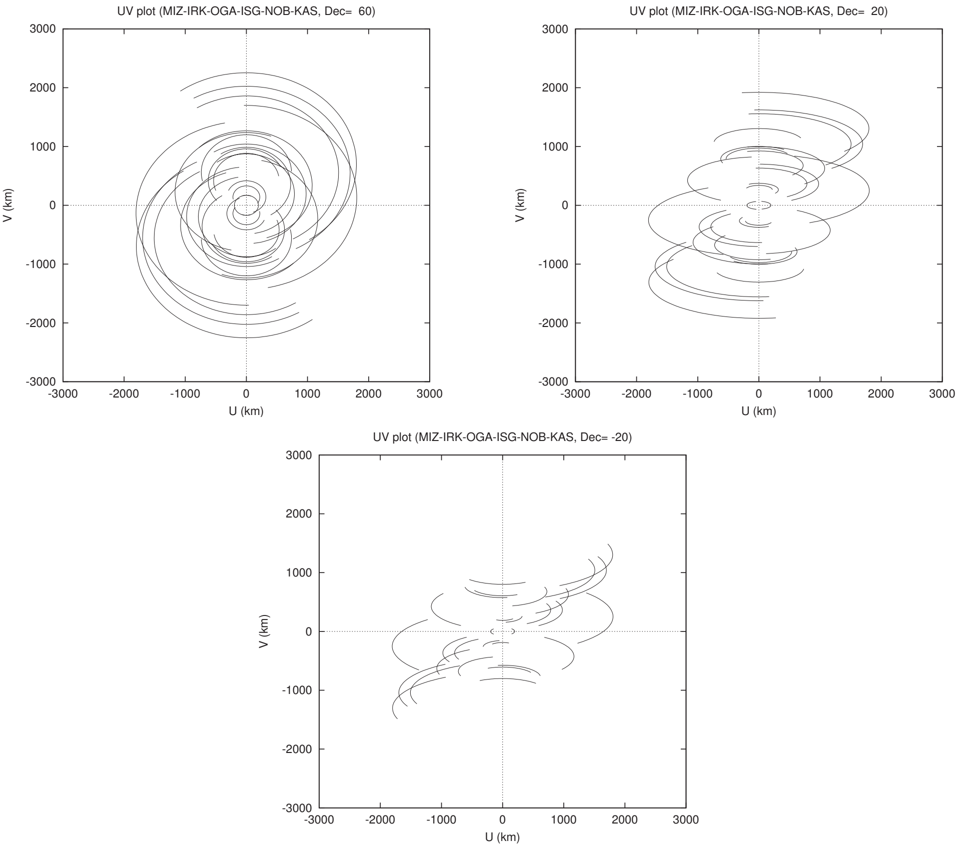

Figure 12: *UV* coverage expected with the array of the six antennas, VERA four antennas, NRO 45-m, and Kashima 34-m telescopes, from an observation over elevation of 20°. Each panel show *UV* coverage for the declination of 60° (*top left*), 20° (*top right*), and –20° (*bottom*).

4 Observation and Data Reduction

4.1 Preparation

After the acceptance of proposals, users are requested to prepare the observing schedule file before the observation date. The observer is encouraged to consult a contact person in the VERA project group (which will be asigned after the proposal accpectance) to prepare the schedule file under the support of the contact person.

4.2 Observation and correlation

VERA group take full responsiblity for observation and correlation process, and thus basically proposers will not be asked to take part in observations or correlations. After the observation and the correlation, the correlated data will be sent to the user in the FITS format by the digital 4-mm magnetic tape (DDS, DDS3) or DVD. Because the raw data on the magnetic tapes will be erased within 3 months, the user should contact the VERA group member within that period if the user needs re-correlation or correlation under different settings (e.g., with different tracking position).

4.3 Data Reduction

At present, the users are encouraged to reduce the data using the AIPS. The observation data and calibration data will be provided to the users in a format which AIPS can read.

- As for the amplitude calibration, the VERA's correlation data in FITS format have the system temperature measured by the R-sky method and the information (gain-curve table) of the dependence of aperture efficiency on antenna elevation and separation of dual-beam. If the user wants a weather information, the informations of the temperature, pressure, and humidity during the observation can be provided.

- The calibration data for the dual-beam instrumental phase is provided to the users as text file which can be read as the SN table of AIPS. This text file can be imported using the task "TBIN" of AIPS, and the data is calibrated using the task "CLCAL" of AIPS.

- Apriori delay calculation at correlation is not accurate enough for astrometric measurements, and this will be corrected for later with delay-recalculation tools that have higher precision. Basically these corrections will be made before the data are sent to proposers. Please ask a contact person in the VERA project group to check the status of delay recalculation in your data when you receive the data.

In case of questions or problems, users are encouraged to ask the contact person in the VERA group for supports. Also, please check the VERA homepage, where rhe latest information about data reduction will be shown.

4.4 Further Information

The users can contact any staff member of the VERA by E-mail (see, Table 10).

Table 10: Contact Persons

Name	E-mail address	Related Instrument
H. Kobayashi	hideyuki.kobayashi@nao.ac.jp	Project Director, Antenna, Correlator
N. Kawaguchi	kawagu.nori@nao.ac.jp	Total systems, Receiver, Digital instrument
O. Kameya	kameya@miz.nao.ac.jp	Antenna site in general
K. Shibata	k.m.shibata@nao.ac.jp	Operation, Schedule management
Y. Tamura	tamura@miz.nao.ac.jp	Geodetic measurement
T. Hirota	tomoya.hirota@nao.ac.jp	Performance for each antenna
M. Honma	honmamr@cc.nao.ac.jp	Phase calibration, Data analysis

Some documents for the VERA, including user guides and proposal application forms, are accessible on the VERA homepage:

`http://veraserver.mtk.nao.ac.jp/index.html`.