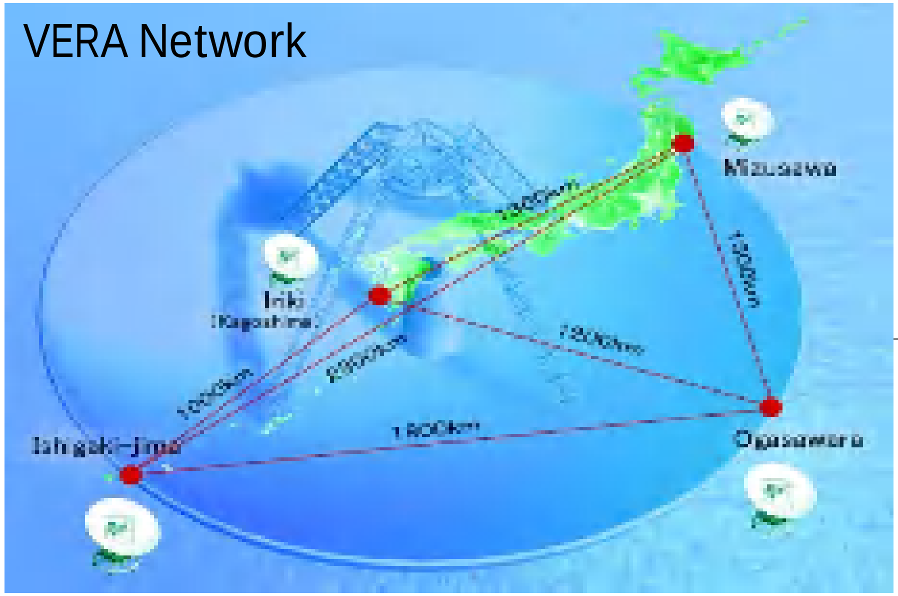
VERA K-band Geodetic VLBI Experiment Using Newly Developed High Speed Sampler and Recorder

Takaaki JIKE

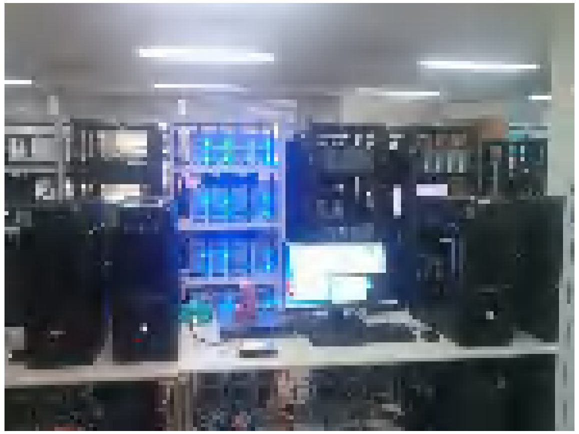
National Astronomical Observatory of Japan

9th IVS GM, HartRAO, Johannesburg, Republic of South Africa



VERA is a Japanese VLBI array aimed for obtaining 3-dimensional map of our Galaxy. With phase-reference VLBI technique, VERA will measure distances and motions of radio sources in our Galaxy with -9th powers of 10 accuracy, unveiling the true structure of our Galaxy.

In 2014, the 1-Gbps recording system replaced to OCTADISK HDD data storage system. Recording time is 80 hours/unit.



Unvarnished view of the Mizusawa Correlation Room. From 2015, the newly developed software correlator starts correlation operating in Mizusawa. Core engine of correlator is GICO3 developed by NICT.

VERA is carrying out the geodetic VLBI observations with two purposes.

1, Fixing of the VERA network to TRF

Participation of VERA-Mizusawa in IVS sessions (T2, AOV, & JADE)

2, Monitoring of VERA network form with mm error (H:2-3mm, V:4-5mm)

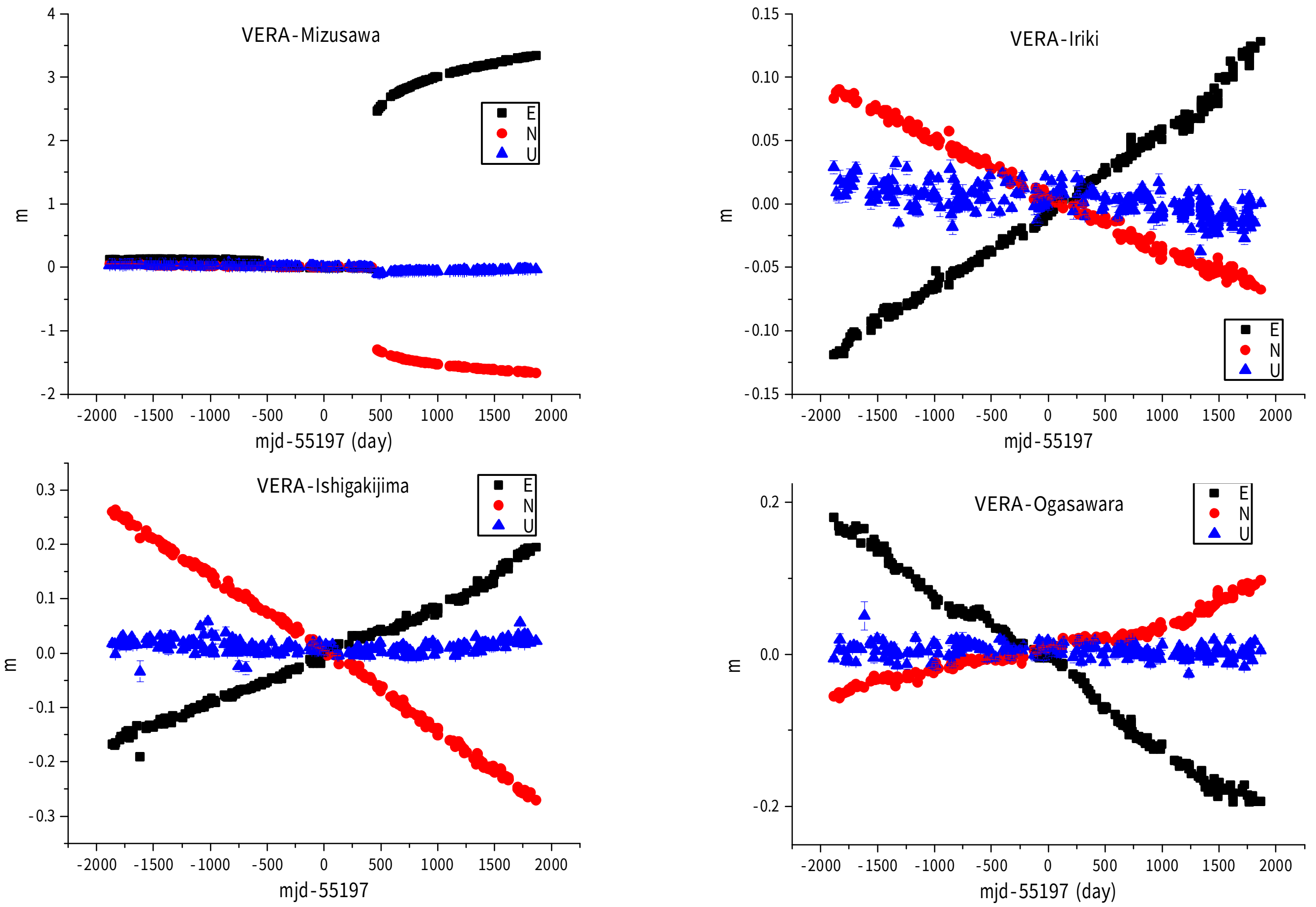
VERA Internal geodetic VLBI using K-band

This report is related with the second purpose.

Specification of VERA K-band Internal Geodetic Observation

Specifications of observation	Specification peculiar to VERA
Number of scan / session	800 or more (VERA only), or 500 (with KVN)
Sampler & Sampling mode	ADS1000, 1024MHz-2bit-1stream
Digital Filter mode	16MHz bandwidth - 2bit - 16stream, 32MHz interval
Received Radio Frequency	22800-23328MHz
Data Storage System	DIR2000H (till 2014), OCTADISK (2015 and after)
Recording rate	1024Mbit/second
Correlation	Mitaka FX (till 2014), Mizusawa Software (2015 and after)

The current result of the VERA Internal Geodetic VLBI Observations



- These plots are expressed on the H-V coordinates system and relative to the coordinate origin on Jan.-1, 2010.
- Linear movement velocity of Mizusawa is fixed to result of the global VLBI solution (GSI 2015a).
- The typical error of each result is 1mm in horizontal and 4mm in vertical component, but the instability among the results is larger.
- Velocity changes are seen in time series. SSE, co-seismic step, post seismic creeping, etc.

Approach for improving the accuracy of the estimated geodetic parameter

Is it possible to improve the reliability of estimated antenna coordinates to 2-3 mm?

1. Make time density of observation high.
2. Use of reliable geophysical-models to analysis, and selection of simple structure radio sources for observation
3. Improve the stability of VLBI observation system.
4. Acquisition of more precise and more accurate observed delay. The error of observed delay aims to be a few millimeters (<5-6 Pico-seconds average).

- Widening of the observed frequency bandwidth by using new high speed sampler – recording system.

← OCTAD (High speed sampler and DBBC)

Specifications
Maximum sampling rate: 10384Mbps
Quantifying bit number: 2bit or 3bit
Output: 10GbE
10GbE channel number: 4 stream (max)
10GbE application layer protocol: VDIF

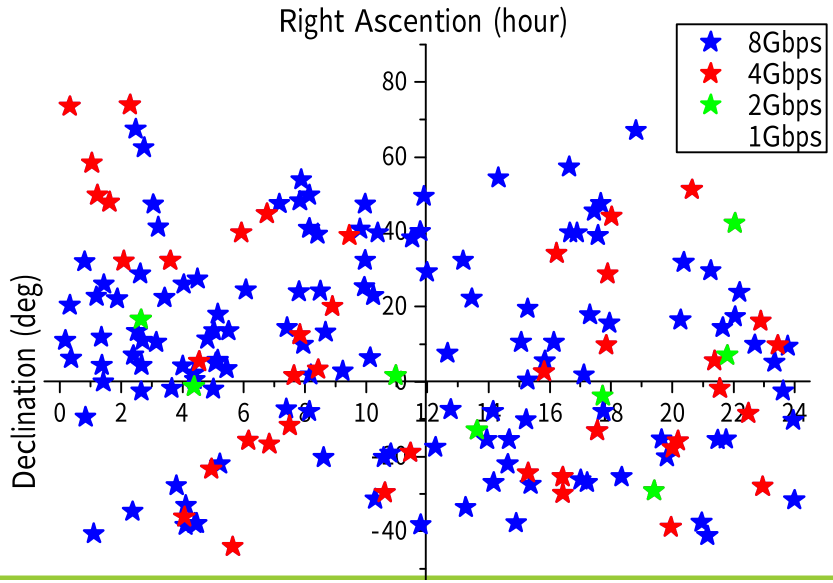
Digital BBC mode: 8MHz-32ch, 16MHz-32ch, 512MHz-4ch, and more mode……, correspondence also in VGOS is possible.

Widening of recording bandwidth and Prediction of fringe detection performance

Sampling mode Recording rate	Minimum SNR	Minimum flux density (Jy) necessary to fringe detection with Minimum SNR	Number of fringe-detectable radio sources (Even if EL = 6 degree)
512MHz-2bit 1 Gigabit/sec	280	4.54	0
1024MHz-2bit 2 Gigabit/sec	170	2.02	8
2048MHz-2bit 4 Gigabit/sec	65	0.80	44
4096MHz-2bit 8 Gigabit/sec	45	0.28	170

Performance of present VERA geodetic observation system

Radio sources list: P. Charlot, et.al: The celestial reference frame at 24 and 43GHz. II . Imaging, Astronomical Journal, 139:1713-1770, 2010 May, doi:10.1088/0004-6256/139/5/1713



Simulation Setting:

- Four VERA stations observe a radio source simultaneously.
- Used Frequency Band is K-band.
- Maximum Theoretical Observed Delay Error = 10 Pico sec
- Cutoff Maximum Duration Length = 120 sec
- Structure Effect: 0 <= variation of delay < 10 Pico sec
  structure index = (always 1) or (1 and sometime 2)
- Cutoff Lower Angle of Elevation = 6 degree

Widening of the recording bandwidth is indispensable in order to secure the number of radio sources.

Distribution of fringe-detectable radio sources in the Celestial sphere

3 Mode Recording Test Observation

In order to verify the betterment effect of the estimation parameter by widening of record bandwidth

Date: 06:00 Jan.27 – 06:06 Jan.28 (UT), 2016. Sky Condition : Mizusawa is fine, but Ishigakijima is rainy.

Number of scans: 490 times/baseline/24hour (VERA+KVN session), Predicted minimum SNR / scan: 38

Baseline & Length: Mizusawa-Ishigakijima, 2280Km, Frequency Band: K-band,

Radio sources: selected from the radio sources list of last pages,

Since the failure occurred to the optical digital data transfer system in Ishigakijima in the middle of the session, the observed delays after 19:00 are unusable for analysis.

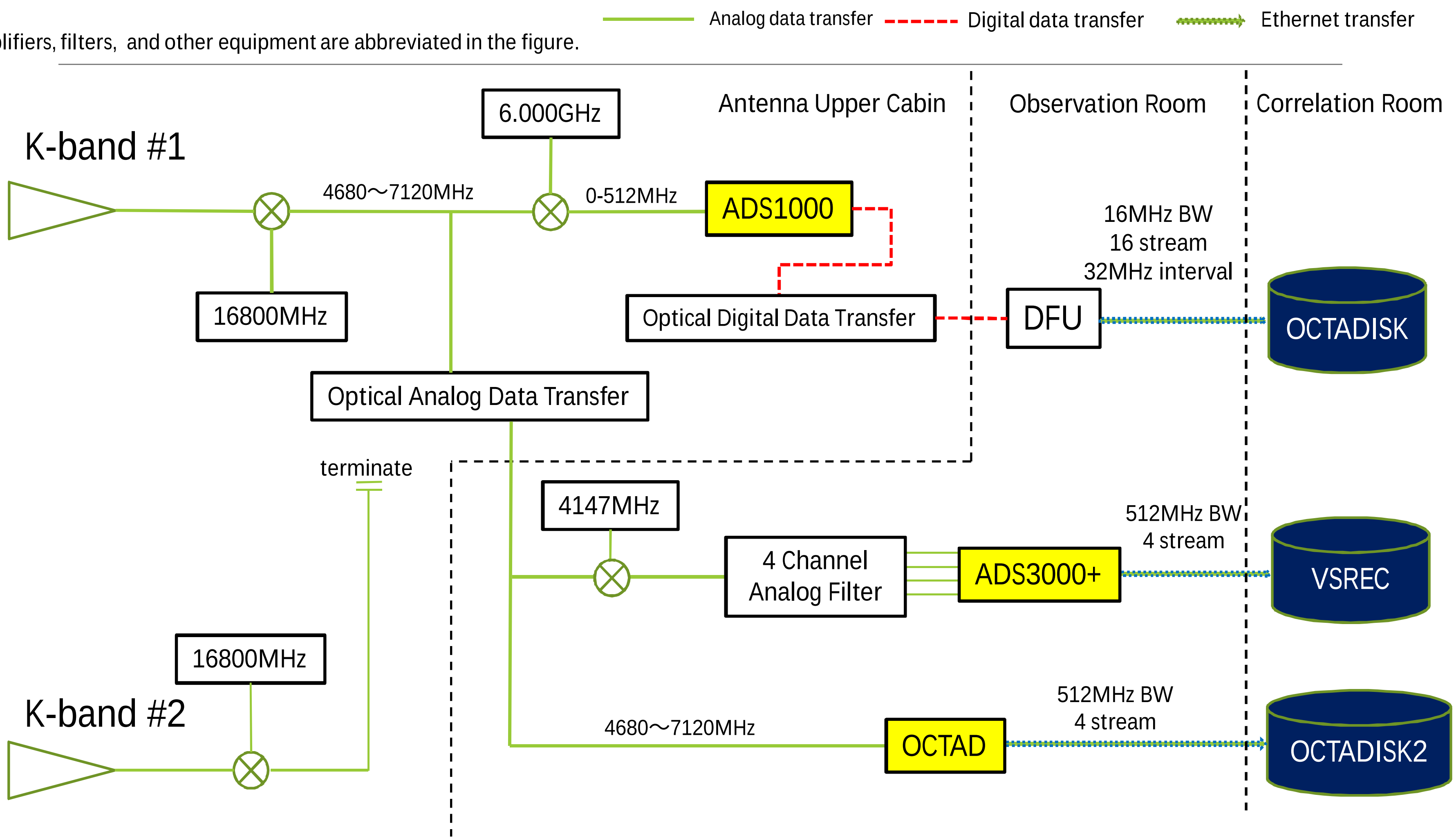
Number of Observed delays used for analysis: 255

Use 3 data acquisition system in order to compare solutions mutually:

Test name	Sampler	Filter Mode (MHzBW-bit-stream)	Recorder	Minimum Frequency (MHz)	Recording Bandwidth (MHz) & Recording Rate (Mbps)	Effective Bandwidth (MHz)
1G-bps	ADS1000	16-2-16	OCTADISK	22700	256 & 1024	147.51
2G-bps	ADS3000+	512-2-1	VSREC	21971	512 & 2048	147.80
8G-bps	OCTAD	512-2-4	OCTADISK2	21459	2048 & 8196	591.21

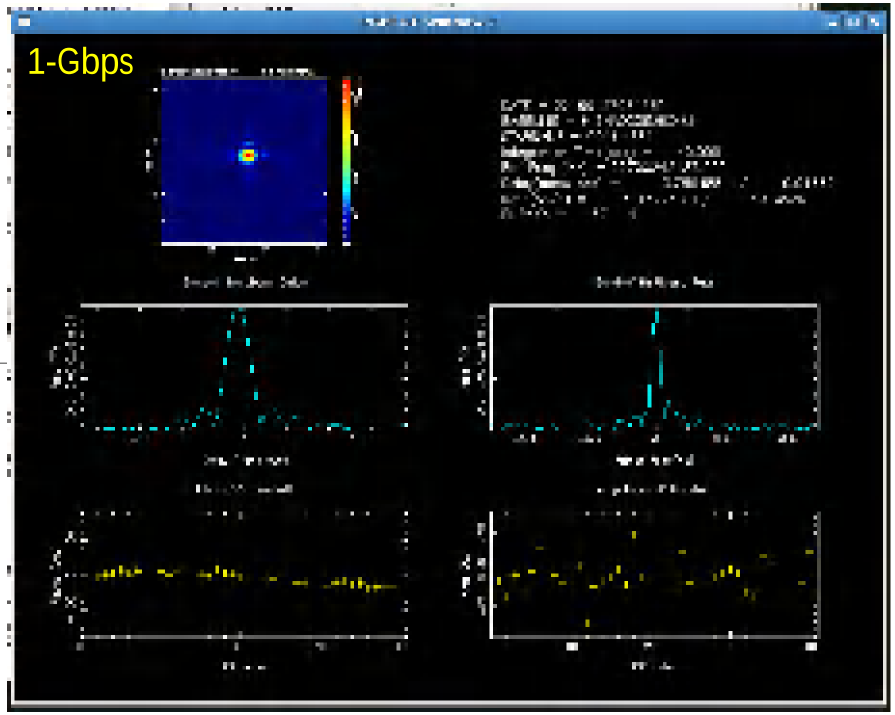
The System Configuration of the Test Observation in Mizusawa

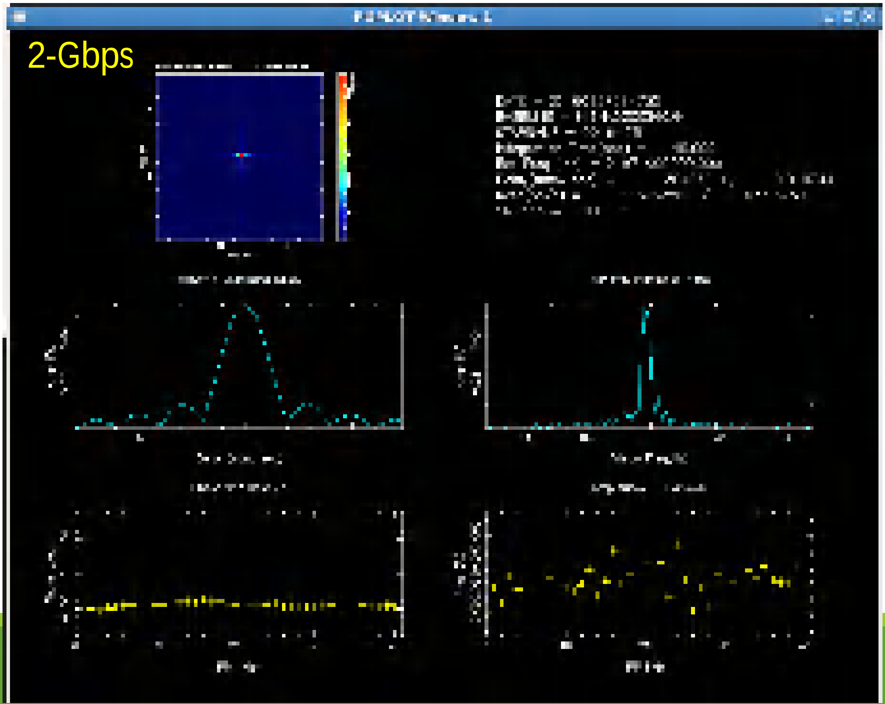
Amplifiers, filters, and other equipment are abbreviated in the figure.

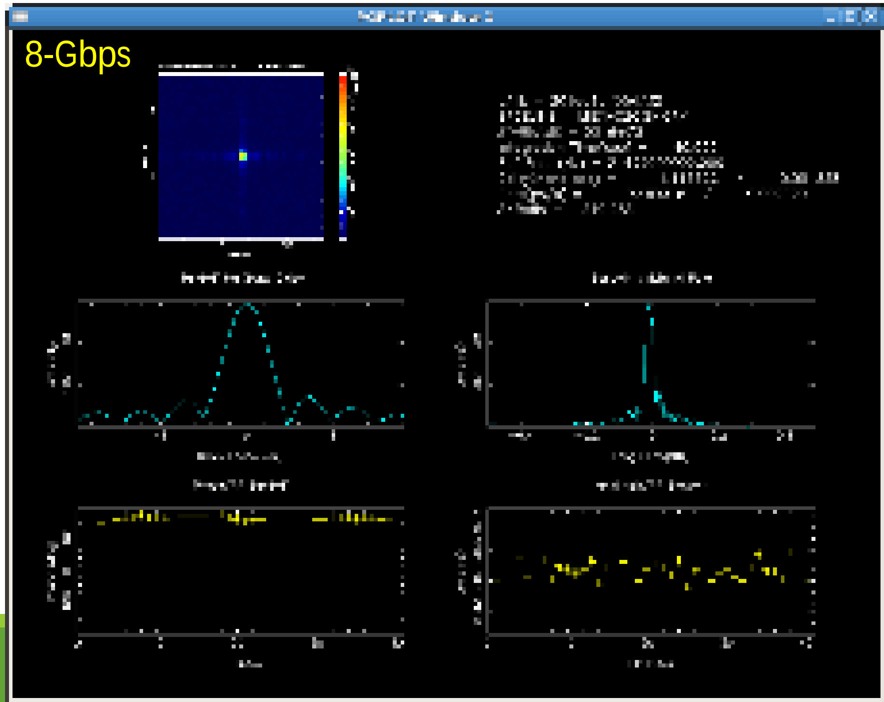


Result of Fringe Search at same scan

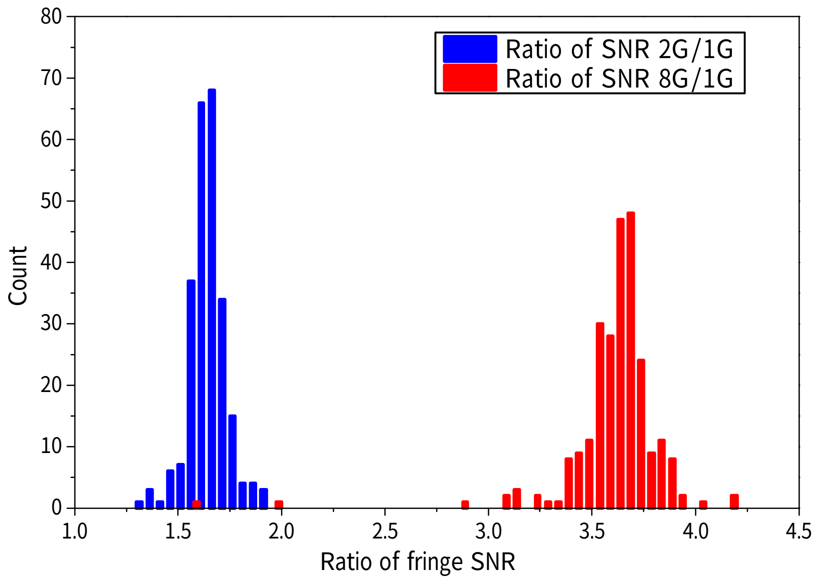
Rec Rate	Delay Error (Pico second)	SNR
1-Gbps	18.8	57.1
2-Gbps	10.7	100.2
8-Gbps	1.2	219.3

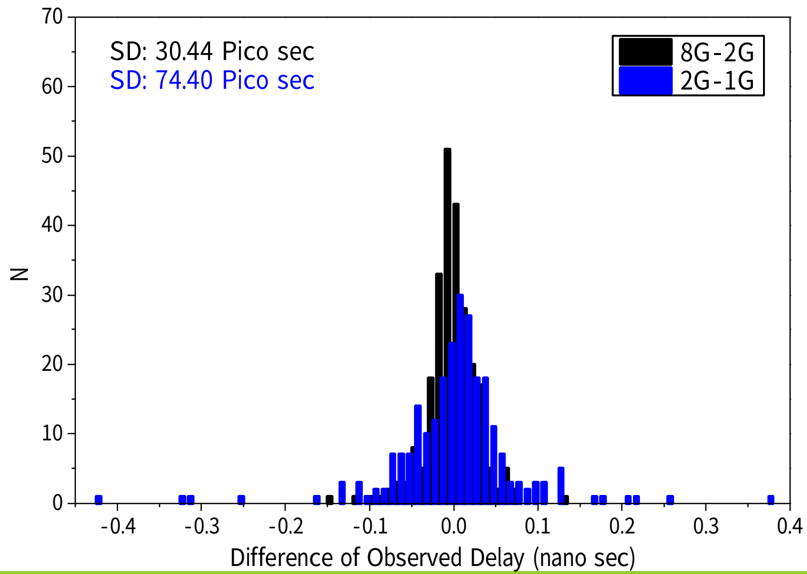






Distribution of SNR, Observed Delay Difference





	2-Gbps/1-Gbps	8-Gbps/1-Gbps
Theoretical Ratio of SNR	1.45	2.88

Result of delay search	2-Gbps/1-Gbps	8-Gbps/1-Gbps
Ratio of averaged SNR	1.77	3.72

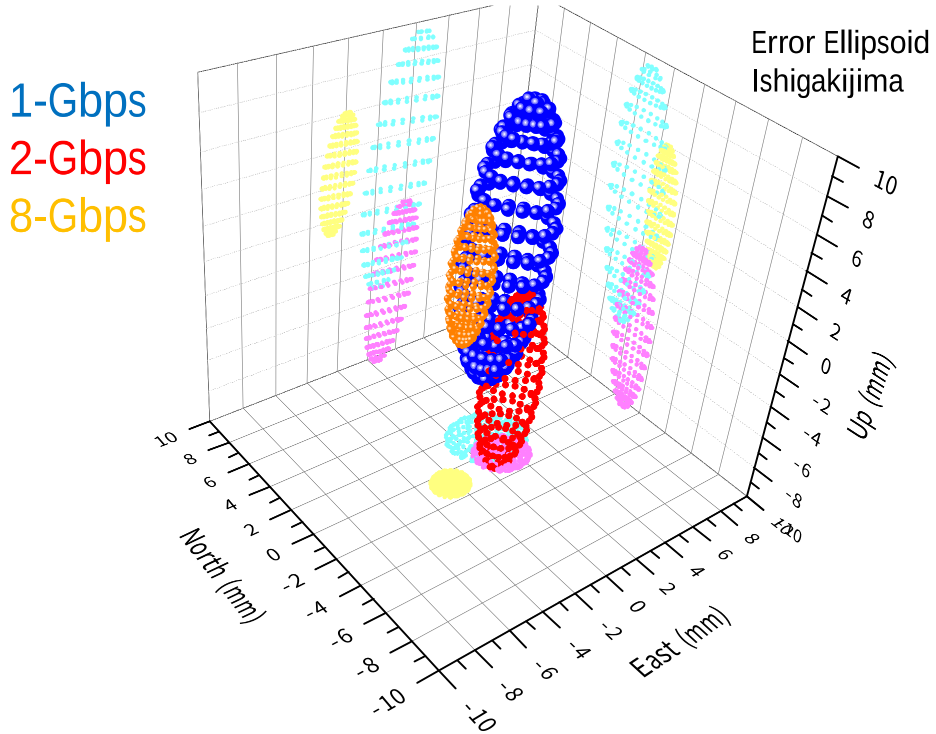
- Probably, in the signal transfer system of 1-Gbps, coherence loss is larger than the ideal value.

Scatter of delay becomes small with a widening of recording bandwidth and/or increasing of SNR.

Result of rapid geodetic estimation

Offset from an initial coordinate value

Unit=mm	U-D	E-W	N-S
1-Gbps	2.1	1.5	1.0
2-Gbps	-5.3	1.4	-0.4
8-Gbps	2.6	-2.3	-0.8



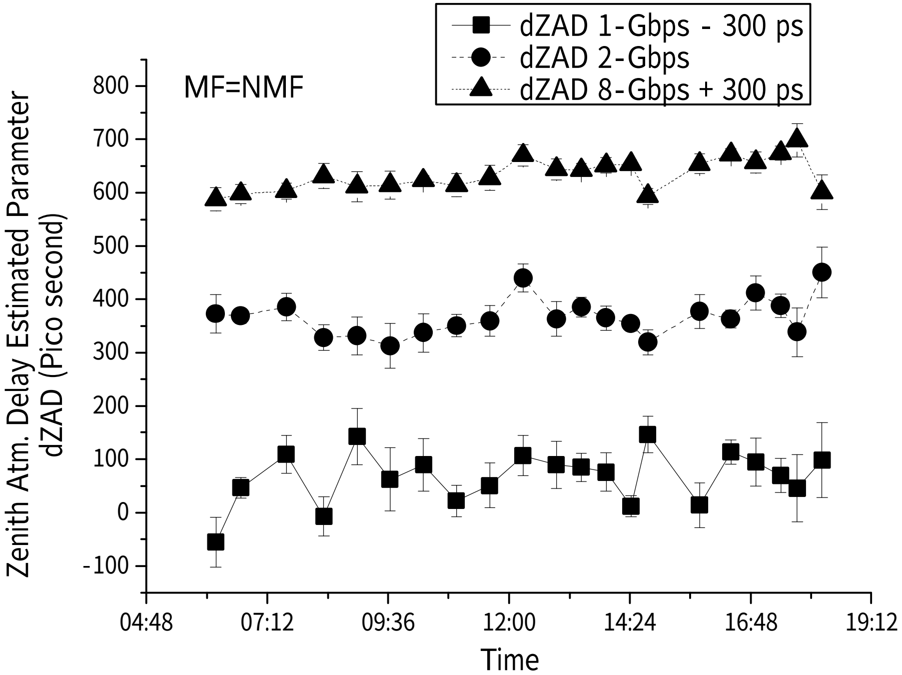
Estimated Error

	1-Gbps	2-Gbps	8-Gbps	2G/1G	8G/1G
R.M.S. of Post-fit-residuals (Pico second)	32.2	23.0	14.0	0.71	0.43
Sample Standard Deviation (Pico second)	2.4	1.7	1.0	0.70	0.42
Degree of Freedom	177	185	186		
Error of Baseline Length (mm)	8.6	6.0	4.1	0.69	0.48
R.M.S. of Observed Delay Error (Pico second)	34.7	21.0	3.3	0.61	0.10
Delay Rejection Criterion (Pico second)	159.6	115.3	71.5		

The ability of delay estimation is not used effectively for analysis. What are the causes?

- The instability of the observation system?, Time variation of inter-band phase characteristic?
- Fitting function (Quadratic) of fringe peak search processing?, Skewness of the delay resolution function?
- Precision of the physical models, correction of tau_ion, etc are not enough to the magnitude of delay error?

Time Series of Estimated dZAD



	Average (Pico second)	Standard Deviation (Pico second)
1-Gbps	367.17	38.25
2-Gbps	366.89	26.86
8-Gbps	334.20	18.73

- The error bar and time variation is small as the observed delay error becomes small.
- The error of estimated Zenith Atm. Delay correction (dZAD) is about 6 times as large as the R.M.S. of observed delay error in 8-Gbps.
- If the Atmospheric Propagation Delay Model can trace a delay with more high accuracy, It is likely that dZADs are estimated with more high accuracy.
- And, also it will be effective to make time density of the number of scans high for estimate dZAD.
- Does stabilization of the dZAD solutions contribute to the stability of the antenna coordinates solutions? It is necessary to confirm.

Summary and near future aiming

- Test observation was carried out with 3 data acquisition system, whose sampling and recording mode are differ respectively,

  1: 32MHz-2bit-16stream, 1-Gbps, 2: 1024MHz-2bit-1stream, 2-Gbps, 3: 1024MHz-2bit-4stream, 8-Gbps.

- As compared with 1-Gbps recording, SNR of the fringe increased by 1.5 times in 2-Gbps, and increased by 3.5 times in 8-Gbps. The R.M.S. of the observed delay error reached 3 Pico seconds in 8-Gbps, thanks to widening of record bandwidth. Scatter of delay was also reduced.

- The magnitude ratio of geodetic solution error is 2.0, 1.4, and 1.0 in 1-Gbps, 2-Gbps, and 8-Gbps. The stability of Zenith Atmospheric Delay solution was also increased.

Future aims are:

- Test observation with 800 or more scans/24h.
- Repeating test observations in order to confirm the stability of estimated antenna coordinates.
- Establishment of regular operation by 8-Gbps recording.
- Use of OCTAD for international VLBI observation in VERA-Mizusawa.
- Applying of the external atmospheric propagation delay, estimation of ionospheric delay simultaneously with delay estimation, etc.

Thank you for your attention.