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Recent Activities of Tsukuba Correlator/Analysis Center

Kensuke Kokado [1], *Shinobu Kurihara* [1], *Ryoji Kawabata* [1], *Kentaro Nozawa* [2]

[1] *Geospatial Information Authority of Japan*

[2] *Advanced Engineering Service Co.,Ltd*

Contact author: Kensuke Kokado, e-mail: `kokado@gsi.go.jp`

Abstract

The Geospatial Information Authority of Japan (GSI) has been a member of IVS and taken charge of a Network Station and an IVS Correlator since 1998. In addition, GSI became an IVS Operational Analysis Center in January 2010.

The Tsukuba Correlator takes charge of correlation work for approximately 100 IVS-INT02 (INT2) sessions and 10 Japanese domestic sessions every year. In 2011, the number of INT2 sessions dramatically increased, because INT2 sessions were observed twice a day during the weekend from April 2011 to January 2012 due to the change in position of the Tsukuba 32-m antenna by the 2011 earthquake off the Pacific coast of Tohoku. The role of the Tsukuba VLBI Analysis Center is to produce ultra-rapid dUT1 measurements, sessions with the goal of obtaining a dUT1 solution within 30 minutes after the end of the observation session. The data processing system at the Tsukuba Correlator and Analysis Center was dramatically improved to achieve rapid data processing. It enabled us to shorten the data processing time to one-sixth and to process the IVS VLBI data in near real-time.

In 2011, we processed the ultra-rapid dUT1 measurements with the Onsala or Wettzell stations from INT2 sessions or IVS 24-hour sessions, such as R1, RD or T2 sessions. The most successful sessions for ultra-rapid dUT1 measurement was the CONT11 sessions which were a campaign of 15 days of continuous VLBI sessions. During these sessions, we succeeded in estimating continuous dUT1 solutions in near real-time for 15 days.

1. Tsukuba VLBI Correlator

1.1. Processed Sessions at Tsukuba VLBI Correlator

The Tsukuba Correlator takes charge of correlation work for 100 INT2 sessions and 10 Japanese domestic sessions every year. The sessions processed at the Tsukuba Correlator in 2011 are shown in Table 1. It shows that the number of INT2 sessions is more than 150. INT2 sessions are normally performed to estimate dUT1 values on the Tsukuba-Wettzell baseline every weekend. However, a big earthquake occurred in east Japan on March 11, 2011, and the position of the Tsukuba 32-m antenna dramatically moved east. The dUT1 value could no longer be estimated correctly until the new station position was determined accurately, so the baseline of the INT2 sessions changed from Tsukuba-Wettzell to Kokee-Wettzell after the earthquake. The INT2 sessions using the Kokee-Wettzell baseline ended in January 2012. Meanwhile, the sessions using the Tsukuba-Wettzell baseline restarted in April 2011. Therefore, INT2 sessions were observed twice a day each weekend from April 2011 to January 2012, and the number of INT2 sessions dramatically increased.

1.2. System Component

The system components of the Tsukuba Correlator are shown in Table 2. We use K5/VSSP utility programs developed by the National Institute of Information and Communications Technology (NICT) and some management programs for correlation. These programs are installed on a lot of general purpose servers. In 2012, we have three management servers, 39 data servers, and 32 correlation servers. The file system between the servers has been based on Network File System (NFS) since 2007, and we improved the system from NFS to Lustre File System in 2011.

Table 1. Processed IVS sessions at the Tsukuba Correlator in 2011.

Session Code	Stations	Number of Sessions
INT2	Ts, Wz	82
INT2	Kk, Wz	73
JAXA	Ts, Ai, Cc, Ud	1
JADE	Ts, Ai, Cc, S3, Vm, Vs, K1, Kg	8
Ts: TSUKUB32, Wz: WETTZELL, Kk: KOKEE, Ai: AIRA Cc: CHICHI10, Ud: USUDA, S3: SINTOTU3, Vm: VERAMZSW Vs: VERAISGK, K1: KASHIM11, Kg: KOGANEI		

Table 2. System components at the Tsukuba Correlator.

<table>
<tr><th colspan="3">K5/VSSP Software Correlation System</th></tr>
<tr><td>Software</td><td colspan="2">K5/VSSP utility programs (developed by NICT)
Some management programs (Parnassus etc..)</td></tr>
<tr><td rowspan="3">Servers</td><td>Management Servers</td><td>3 servers</td></tr>
<tr><td>Data Servers</td><td>39 servers</td></tr>
<tr><td>Correlation Servers</td><td>32 servers</td></tr>
<tr><td>File System
between Servers</td><td colspan="2">Network File System (NFS)
(2007—2011)
Lustre File System
(since 2011)</td></tr>
</table>

2. Tsukuba VLBI Analysis Center

The role of the Tsukuba VLBI Analysis Center is to produce ultra-rapid dUT1 measurements from IVS VLBI sessions. The goal is to obtain a dUT1 solution within 30 minutes after the end of the observation session.

The sessions analyzed in 2011 are shown in Table 3. INT2 sessions are performed every weekend, and we can obtain one dUT1 solution per session. In 2011, we tried to produce ultra-rapid dUT1 measurements from all of the INT2 sessions. The IVS 24-hour sessions were R1, RD, or T2 sessions in which the Tsukuba and Onsala stations participated. With these sessions, we can obtain several tens of dUT1 solutions over 24 hours. The main sessions for ultra-rapid dUT1 measurement in 2011 were the CONT11 sessions, which were a campaign of 15 days of continuous VLBI sessions. We were able to obtain continuous dUT1 solutions for 15 days from this campaign. The special experiments for ultra-rapid dUT1 measurement were scheduled for optimizing dUT1 estimation using the Tsukuba-Onsala baseline, and they were not regular IVS sessions. We were able to obtain more precise dUT1 solutions from these experiments.

In addition, a special experiment for ultra-rapid EOP measurement was implemented using the Tsukuba-Onsala and Tsukuba-Hobart baselines. The goal of the experiment was to estimate X/Y (polar motion) and dUT1 parameters in near real-time.

Most of the solutions estimated by these sessions or experiments were used for rapid EOP solutions calculated by the United States Naval Observatory (USNO).

Table 3. Processed sessions at the Tsukuba VLBI Analysis Center in 2011.

Session/Experiment	Solutions	# sessions
INT2	One dUT1 solution per session	155
IVS 24-hour sessions	Continuous dUT1 solutions for one day	15
CONT11	Continuous dUT1 solutions for 15 days	1
Special experiments	Continuous dUT1 or EOP solutions for several hours	2

3. Improvement of Data Processing System in 2010-2011

3.1. New Distributed Data Processing System for Correlation

The Tsukuba Correlator improved the data processing system in 2011. The improved system is shown in Figure 1. In the new system, we have mainly four kinds of servers for several tasks such as processing management, correlation, data management, and data storage.

The management server manages the correlation processes performed on several correlation servers reading IVS schedule files. The number of job commands for correlation which the management server sends to the correlation server can be selected with a management program written in perl. We determine the number of job commands in accordance with the specification and the number of correlation servers.

When the management server sends the job command to the correlation server, the correlation server searches for the VLBI data indicated in the received job command. All of the VLBI data is stored in the shared directory built by the Lustre File System.

The data access between the data servers and the correlation servers is managed by the Metadata server on the Lustre File System. The data access rate among several servers is not decreased. Due to an increase in the number of data accesses, in the case of the previous system based on NFS, we could not increase the number of servers due to the weakness of NFS. The Lustre File System is superior to NFS as a file system for distributed data processing. We succeeded in shortening the processing time for correlation by introducing the Lustre File System.

3.2. Comparison Results Between Old and New System

The comparison results of the data processing time of the new correlation system with the Lustre File System and the old system with NFS is shown in Table 4. We implemented the verification test of the new system using data from the Japanese domestic session “JD1109”. In the case of the new system, we could use 15 servers as correlation servers and execute 46 correlation processes at the same time. In the old system, we could not increase the number of the correlation servers to more than 12 due to the weakness of NFS. Even if we had increased the number of servers on the old system, the processing time would not have been shortened. The new system uses more

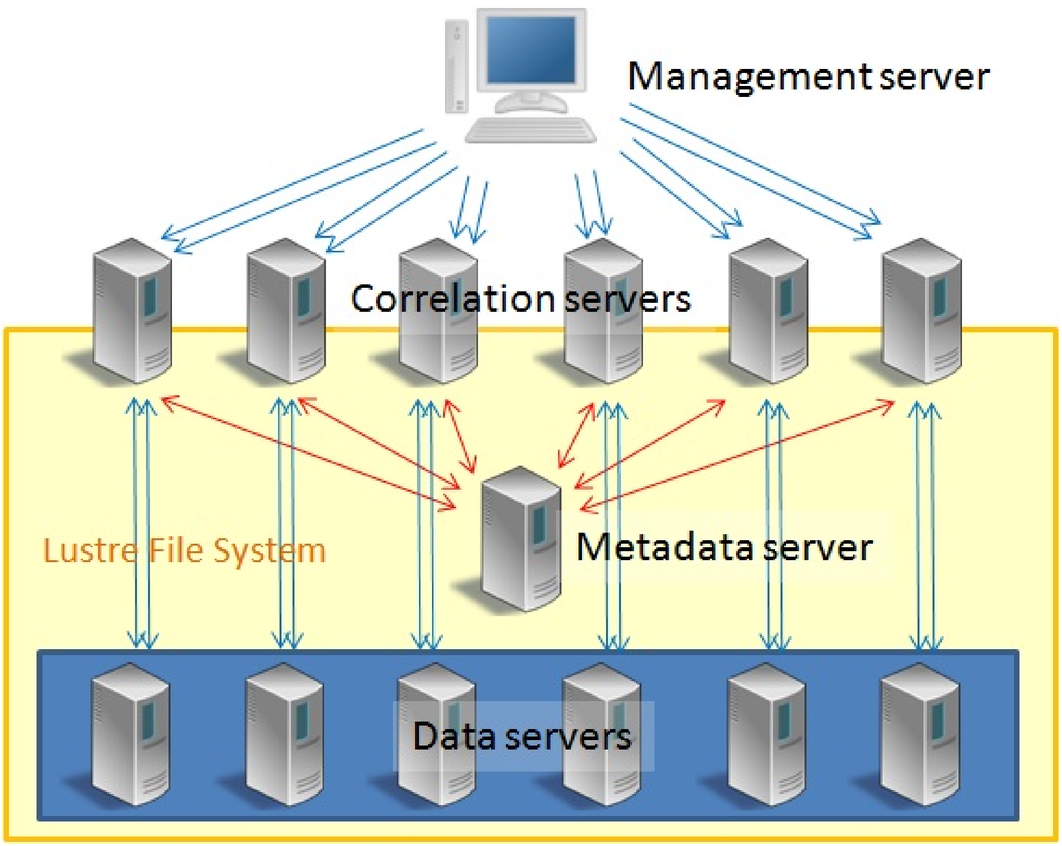

Figure 1. New distributed data processing system.

correlation servers than the old system. Therefore, we succeeded in shortening the processing time to one-sixth.

Table 4 shows the data processing time for only one baseline. The total processing time for JD1109 is shown in Table 5. In the case of this session, five stations participated and we had to correlate the data of seven baselines.

Although the data processing time was different for each baseline, the total processing time with the new system was about 4.6 hours. This means that the Tsukuba Correlator has the capacity to complete the correlation of a 24-hour VLBI session in only several hours. In the case of a 1-hour INT2 session, the total processing time would be less than five minutes. This also means that we can correlate VLBI data faster than the sampling rate of VLBI sessions. This processing capacity enabled us to perform ultra-rapid dUT1 measurement during the CONT11 sessions.

4. Ultra-rapid dUT1 Measurement

4.1. Data Processing for Ultra-rapid dUT1 Measurement

Most of the experiments for ultra-rapid dUT1 measurement in 2011 were implemented on the Tsukuba-Onsala baseline. Figure 2 shows the data processing system for ultra-rapid dUT1 measurement on the Tsukuba-Onsala baseline.

Table 4. Data processing time for the TSUKUB32-CHICHI10 baseline from JD1109.

Session Code	JADE1109 (Domestic session)	
Processed Baseline	TSUKUB32-CHICHI10	
# Scans	202	
Processing System	NEW	OLD
# Correlation Servers	15 servers	12 servers
Maximum number of data processes	46	12
File system between servers	Lustre File System	NFS
Processing time	25	145

Table 5. Data processing time for all baselines from JD1109.

Processed baseline	# Scans	Processing time (min.)
TSUKUB32-CHICHI10	202	25
TSUKUB32-SINTOTU3	95	12
TSUKUB32-VERAMZSW	170	20
TSUKUB32-VERAISGK	149	18
CHICHI10-VERAMZSW	163	63
CHICHI10-VERAISGK	146	59
VERAMZSW-VERAISGK	137	77
TOTAL	1062	274 (about 4.6 hours)

At first, VLBI observation is performed at both stations, and the VLBI data is sampled with Mark 5A at Onsala and K5 at Tsukuba. The Onsala data is transferred to the Tsukuba Correlator using PC-EVN equipment in real-time and quickly converted to K5 format. The data recorded with K5 at Tsukuba is also transferred to the Tsukuba correlator, but not in real-time. The data is transferred during antenna slew time between VLBI observations.

The Tsukuba Correlator correlates the transferred and converted K5 data immediately after the data becomes available. After the data for enough scans is correlated, the automatic analysis program runs. For the analysis, we use the new analysis software "C5++" developed by NICT of Japan. All of the data processing is managed by one management server and operated automatically without any operators.

4.2. Ultra-rapid dUT1 Measurement during CONT11

We tried ultra-rapid dUT1 measurement during CONT11 using the data processing system described above. 14 stations participated in the CONT11 sessions, and the Onsala and Tsukuba stations tried to implement ultra-rapid dUT1 measurements. For the 15 days of CONT11, the data were transferred to the Tsukuba Correlator via high-speed network in real-time, and dUT1 solutions were calculated during the observing sessions. This approach enabled us to obtain 15 days of continuous dUT1 values during the sessions.

The flow of the data processing for the ultra-rapid dUT1 measurements during CONT11 is shown in Figure 3. When the VLBI session starts, the recorded data of the first scan is transferred

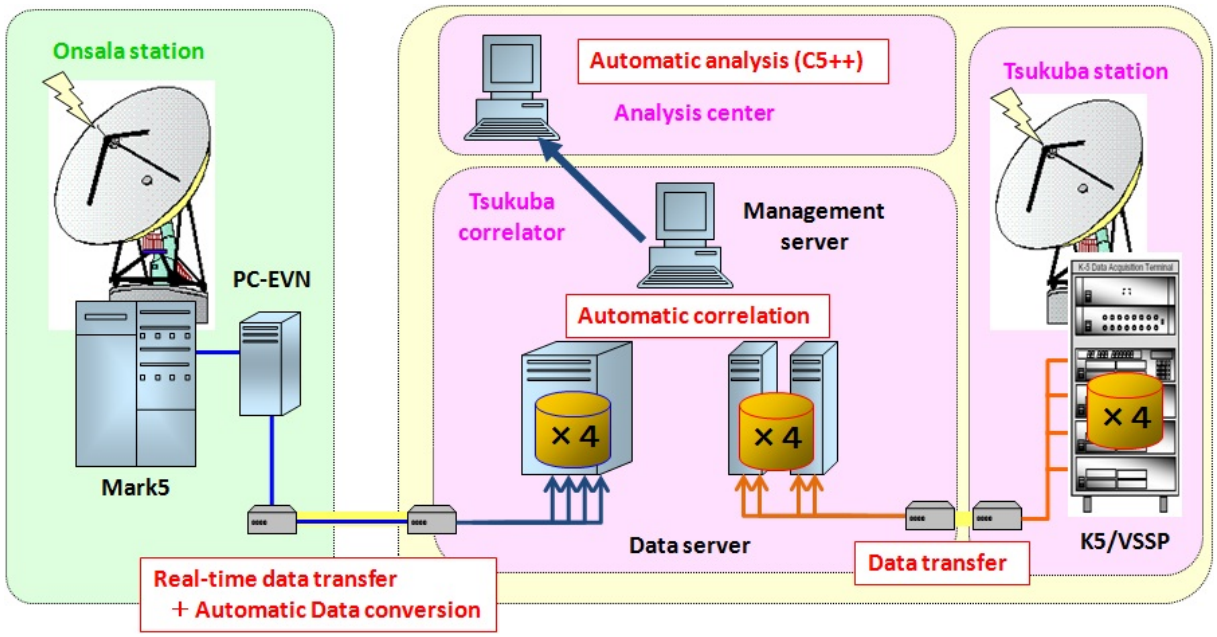

Figure 2. Data processing system for ultra-rapid dUT1 measurement.

to the Tsukuba Correlator and converted to K5 format data. After the conversion, correlation and bandwidth synthesis start. In the first scan, we search for fringes and determine the clock offset and rate for all of the correlation. As the result of the data processing, the result files of bandwidth synthesis is created within a few minutes after the end of the observation of each scan. Data analysis is performed when the bandwidth synthesis for enough scans to estimate a dUT1 solution are completed. During the CONT11, we tried two modes of analysis. The first mode is "6-hour sliding window mode" and the second one is "30 scan sliding window mode".

In the case of the 6-hour sliding window mode, we perform the first analysis when the bandwidth synthesis for the scans from the first six hours of the session is completed. After that, the analysis is done for every scan, using the bandwidth synthesis results for the scans from the prior six hours. In this mode, the number of scans used in analysis is not constant, because the antenna slew times and the durations of the scans differ.

Another analysis mode is the 30 scan sliding window mode. In this mode, we perform the first analysis when the bandwidth synthesis for the first 30 scans of the session is completed. After that, the analysis is done for every scan using the prior 30 scans. In the 30 scan mode, the time period of the 30 scans is different for each scans analysis. It depends on the observation schedule.

4.3. Results of Ultra-rapid dUT1 Measurement during CONT11

We succeeded in the 15 days of continuous dUT1 measurement except the period when some troubles happened with antenna operation or data transfer. The dUT1 values estimated in "6-hour sliding window mode" are shown in Figures 4 and 5. Figure 5 shows the dUT1 values on September 27, and there is approximately 100 microsecond difference between the observed and predicted values. The predicted values are from usno_finals estimated by USNO. If we submitted the observed value to the IVS Data Center immediately after the estimation and USNO used the

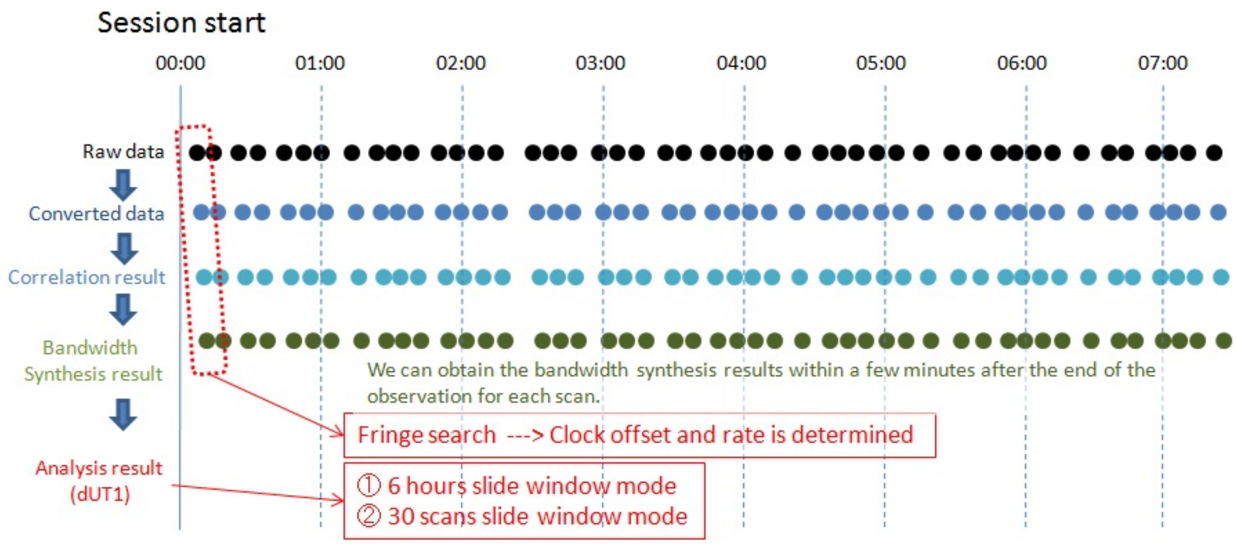

Figure 3. Flow of data processing for an ultra-rapid dUT1 measurement.

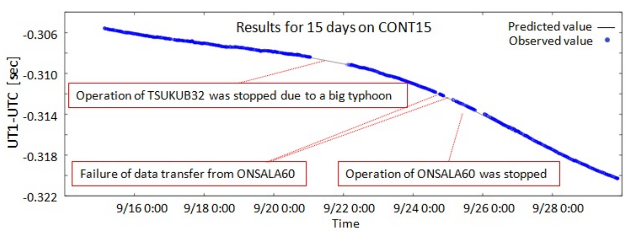

Figure 4. dUT1 values for 15 days (6-hour mode).

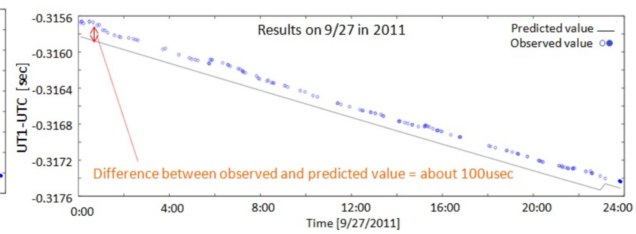

Figure 5. dUT1 values on Sep. 27 (6-hour mode).

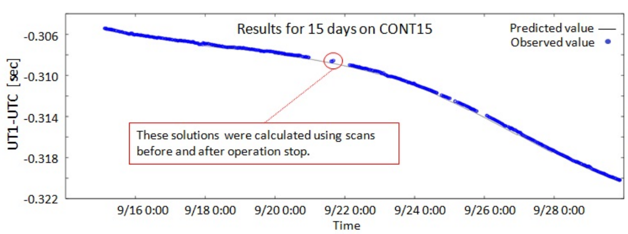

Figure 6. dUT1 values for 15 days (30 scans mode).

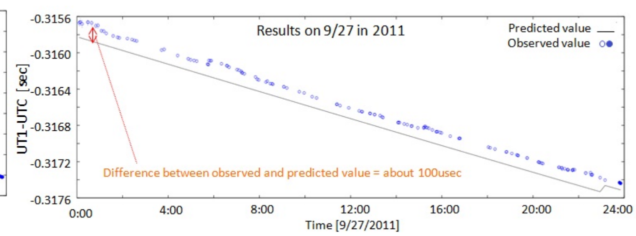

Figure 7. dUT1 values on Sep. 27 (30 scans mode).

dUT1 value to calculate the predicted value, the accuracy of the predicted value would be higher than ever before.

Figures 6 and 7 show the results of "30 scan sliding window mode". It is almost the same as the results of 6-hour slide window mode, but there are additional solutions on September 21. These solutions were calculated using 30 scans before and after a stop in observing. It is not desirable for dUT1 estimation to use scans recorded on different days, so we have to improve the management program for the analysis.

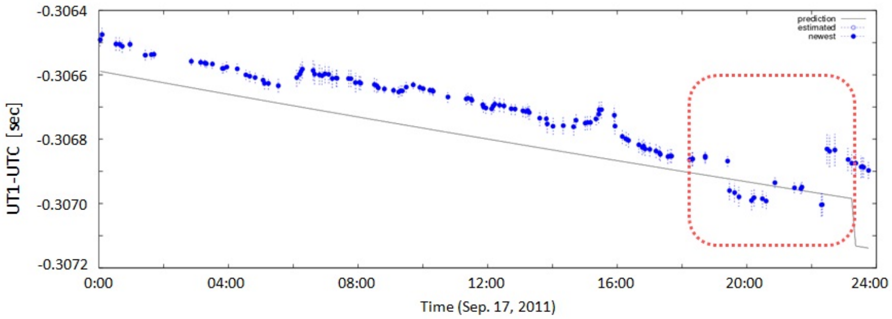

Figure 8. dUT1 values on Sep. 17 (30 scans mode).

Figure 8 shows another problem. In 30 scan sliding window mode, the dUT1 results irregularly changed as shown in the box. It seems that the fluctuation happened when a bad scan was included in the analysis. We have to improve the program to remove bad scans from the data analysis.

Figure 9 shows a histogram of the data processing time for dUT1 measurement. The processing time means the time between the end of the observation for each scan and completion of correlation. As shown in Figure 9, approximately 68% of the scans were correlated within 30 minutes after the end of the observing session. Sometimes a data transfer error or bandwidth synthesis error happened, so we could not complete the correlation within 30 minutes for about 30% of the scans. Even if some errors happened in data processing and caused a processing delay, we could recover from the error and make up for the delay because the data processing is faster than the observation sampling rate. The new data processing system with the Lustre File System enabled the rapid data processing.

All of the data processing was performed automatically, and some errors happened outside of working hours. Therefore, we could not recover the data processing quickly, and the data processing was delayed. We have to consider how to handle the errors in the automatic data processing system in the future.

5. Ultra-rapid EOP Measurement

We implemented two experiments for ultra-rapid EOP measurement on November 29 and 30, 2011. For dUT1 measurement, we only need a long east-west baseline, but for EOP measurement, we need a long north-south baseline too. Therefore, we implemented experiments with the Tsukuba-Onsala and Tsukuba-Hobart baselines. The first experiment was the RD1106 session, and the second experiment was a special session “UREO01” optimized for EOP measurement.

The data processing and analysis system for the experiments is shown in Figure 10. For EOP measurement, we have to correlate two baselines. Thus, we prepared two data processing systems. Each system has four data conversion servers and eight correlation servers, and the management servers sent the job command to the conversion and the correlation servers. The data is also put into data storage based on the Lustre File System.

We failed in rapid data transfer from Hobart, so we could not obtain EOP results during the observing session. The Hobart data was transferred soon after the end of the session and processed that day.

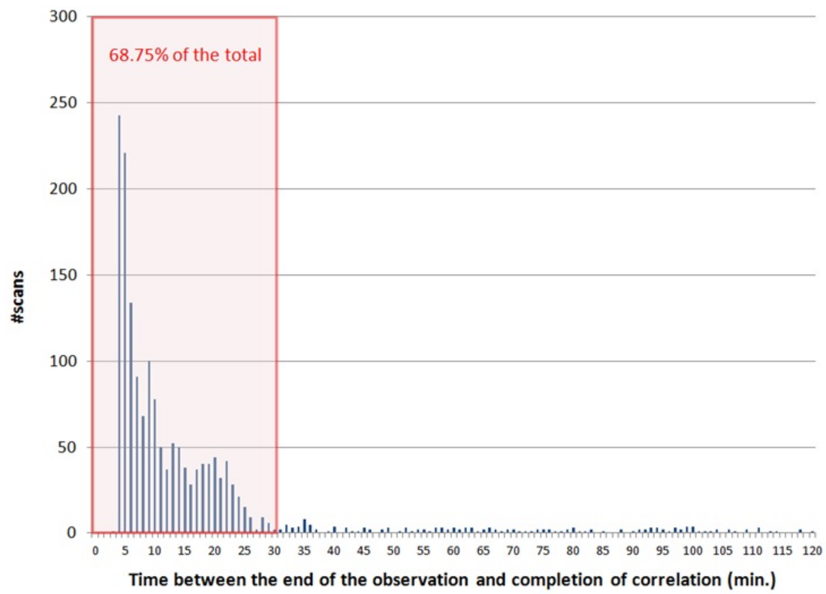

Figure 9. Data processing time for ultra-rapid dUT1 measurement during CONT11.

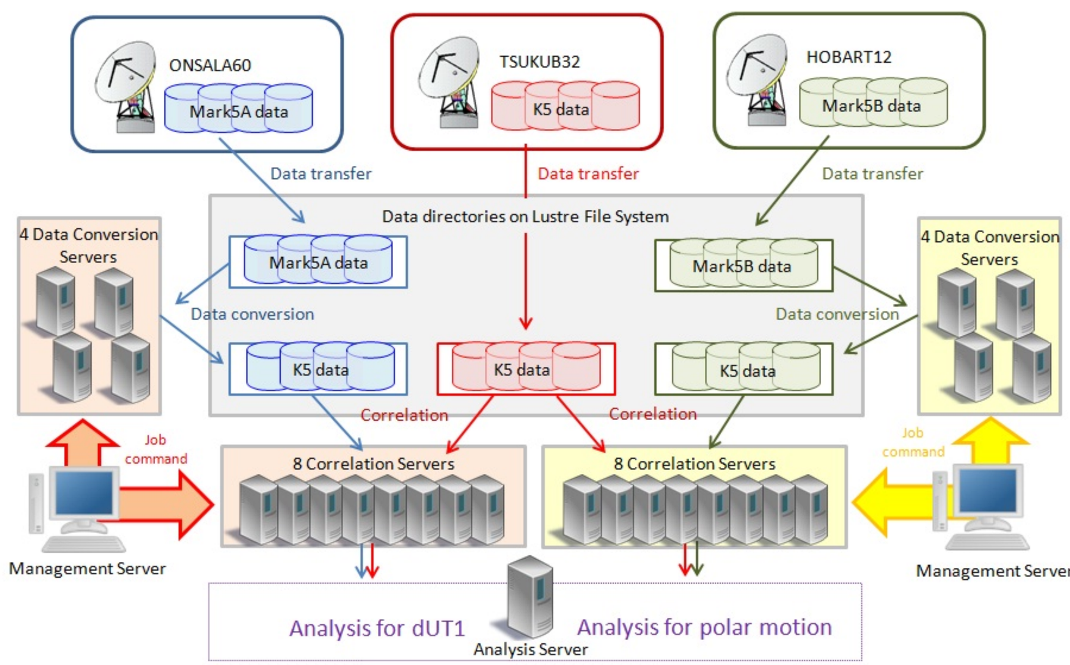

Figure 10. Data processing system for ultra-rapid EOP measurement.

EOP results were obtained within 24 hours after the end of the UREO01 session. The estimated dUT1 values are shown in Figure 11. The observed values are about 600 microseconds different from the predicted values. The estimated values of polar motion are shown in Figures 12 and 13, which show that there is a little difference between the estimated values from the experiment and the predicted values. If we could succeed in the data transfer from Hobart, we might be able to obtain the EOP results during the observations.

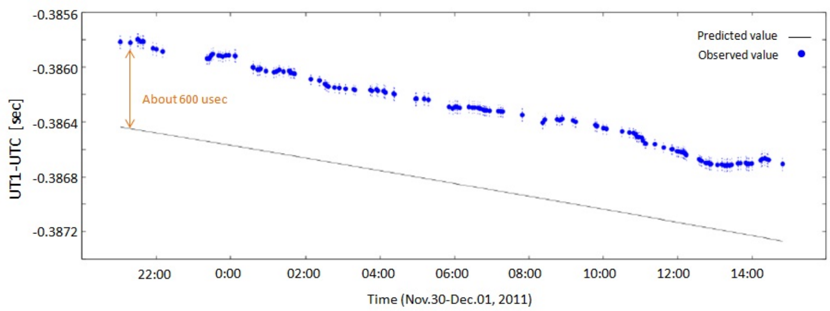

Figure 11. dUT1 values estimated from the ultra-rapid EOP measurement.

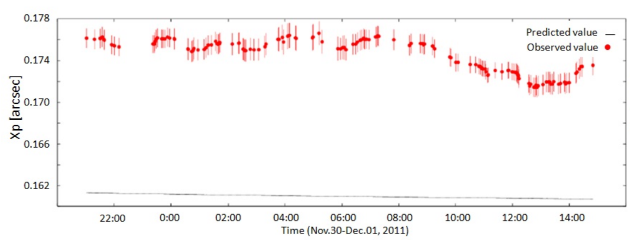

Figure 12. Estimated Xp values from UREO01.

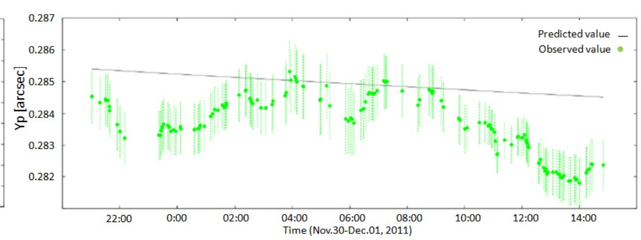

Figure 13. Estimated Yp values from UREO01.

6. Future Plan

On the basis of these results, we will continue to improve the data processing and analysis system in 2012. The first main plan is to perform analysis to determine the optimum sliding window for dUT1 analysis on each session. Within the IVS, there are many kinds of sessions such as R1, RD, or T2, and the strategy of each schedule is different, so we have to consider the optimum analysis method for each session. The second plan is to perform ultra-rapid dUT1 measurements on all IVS 24-hour sessions that include the Onsala and Tsukuba stations, and we plan to post the solutions to the IVS Data Center. The third plan is to implement the next ultra-rapid EOP experiment with the Onsala and Hobart stations. We hope that we succeed in obtaining EOP values during the observation of the next experiment.