B－10．2．2 Absolute Position Determination of the Tide Gauges by VLBI and GPS

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Abstract Since a rise of mean sea level brings disastrous results to not only human living but also the entire world ecological system, it is drawing a world-wide attention. In order to predict a possible sea rise and its effects on human activities, one should monitor mean sea level variations using a tide gauge. However, raw data from tide gauge is contaminated by fictitious variation of sea level coming from height change of the gauge associated with crustal vertical deformation. Careful correction for vertical crustal movement is important for precise monitoring of real mean sea level change. To achieve this, an effective method to monitor mean sea level is developed using combined geodetic technologies, i.e., Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS), and tide gauge. In this approach an ultra small site for VLBI is constructed and more effective analysis method for GPS is developed.

Key Words Global Warming, Sea Level Rise, Tide Gauge, Very Long Baseline Interferometry (VLBI), and Global Positioning System (GPS)

1. Introduction

In order to minimize the disastrous outcome of mean sea level change, it is essential to prepare counter measures for the prevention of such disasters. Decision makers require scientific scenario about what is going to happen in the future for their planning process. Such a scientific scenario should depend on a reliable physical model. It is thus important to construct a reliable earth model that covers atmosphere, hydrosphere and biosphere. However, there still exist different models and the discussion has not converged yet. It is thus very difficult to get a unique answer for a possible mean sea level change triggered by global warming effect. In this situation, we should first monitor the mean sea level change and feed this observed data back to the proposed models and refine the models. For this purpose, a number of projects to monitor the mean sea level are already initiated. 1),2),3),4),5),6),8),9),10)

The primary sensor for the mean sea level monitoring is tide gauge. The raw tide gauge data, however, are contaminated by vertical crustal deformation. It is thus important to remove this large noise from the raw tide gauge data. Space geodetic technology is used to achieve this correction. The basic idea is 1) first to monitor the change of vertical position of the tidal gauge by means of the space geodetic technologies and 2) then to correct the raw tidal gauge data for the vertical crustal movement. Two geodetic techniques are available for this purpose. The Very Long Baseline Interferometry (VLBI) is a technique which best fits to measurements of highly accurate (typically 1 cm) three-dimensional relative position vectors between radio telescopes separated by a long distance up to several thousands of kilometers. Though this is very accurate, the observation is very costly. The Global Positioning System (GPS), on the other hand, is alternative for shorter ranges because it is convenient to use and produces high accuracy for baselines shorter than 100 km. A combination of VLBI and GPS is a good candidate for the method to monitor the position change of the tidal gauge.

Although those methods are already well established technology in geodesy with high capability, they still need technical improvement in terms of maneuverability and economical efficiency. To be more specific, the transportability of the equipment such as VLBI antennas is the bottleneck of efficiency of VLBI. The difficulty of cycle slip recovery is major problem in GPS processing, which reduces efficiency of GPS observation to a great extent. As solutions for those problems, we developed a super small antenna for VLBI and introduced a highly tuned up GPS software to improve GPS measurement accuracy.

2. Development of Super Small VLBI System

We developed a super small antenna for VLBI observation to improve the transportability of the whole system. This is a joint project with the Communications Research Institute (CRL) of ministry of post and telecommunications. The diameter of the developed antenna is 2.4m. After a performance test in a laboratory, which proved satisfactory functions of the antenna, we carried out system performance test using 34 m antenna facility at Kashima of CRL on May 8, 1992.[7] The final performance test was carried out using 26 m antenna of the Geographical Survey Institute at Kashima in October 1992. Given in Table-1 are the estimated errors of 24 hour observation.

Table-1 Formal Errors of VLBI Performance Test Results with 2.4 m Antenna

X-Component	Y-Component	Z-Component
2.2 cm	1.9 cm	2.3 cm

The above estimated errors are larger than those of 5 m antenna by a factor of 1.5 which is quite reasonable when we take the size of antenna into consideration. In addition, in this test observation no ionospheric correction was applied because the 2.4 m antenna has only X band capability. An ionospheric correction method utilizing a dedicated GPS receiver is under development and the formal errors will be reduced when this correction method is available. Another comparison is possible for these test results. At Tsukuba site another VLBI result is available for accuracy assessment of newly developed 2.4m antenna. The comparison results are indicated in Table-2.

Table-2 Comparison of 2.4m and 5m Results

(Unit in Meters)

	Cartesian Coordinates for 2.4m Antenna Monument	Slant Range
2.4m	X = - 3957200.4468 ± 0.0232 Y = 3310183.0221 ± 0.0198 Z = 3737735.0472 ± 0.0244	66.907
5m + GPS	X = - 3957200.466 ± 0.02 Y = 3310183.0463 ± 0.02 Z = 3737735.0582 ± 0.02	66.898
EDM (DI3000)	Not Applicable	66.897
Difference	X = 0.019 Y = - 0.024 Z = - 0.011	0.009

Legend:
1. The reference coordinates system is ITRF 91.11),12)
2. The coordinates refers to the intersection of Az–El axes.
3. The slant range is calculated for the intersections of Az–El axes of 2.4m and 5m antennas.

In this table we compare two sets of coordinates for the same point, i.e., 2.4m antenna center (defined as the intersection of the Az–El axes). The first coordinates are derived from 2.4m VLBI observation; the second ones are derived from a combination of 5m VLBI observation and GPS local tie. Another comparison is given for slant range between the 2.4 m site and 5m site. The ranges given in the table are derived from 2.4m VLBI observation, combination of 5m VLBI and GPS observations and EDM survey. We can see that those agreements are quite satisfactory. These good agreements indicate that the newly developed 2.4m antenna has a sufficient capability for the VLBI observation.

Another improvement of the transportability of the VLBI system is brought by a construction of a mobile container of VLBI equipment. This container accommodates backend, power supply for the antenna, antenna control system, monitor lack, hydrogen maser, GPS time receiver and Cesium atomic clock. The container enables us to finish observation set-up of the system in a relatively short time. This is very important progress for the effective VLBI observation on a routine basis.

3. VLBI Observation at Mizusawa

As the first step of mean sea level change monitoring we carried out a VLBI observation at Mizusawa site in Iwate prefecture (north–eastern part of Japan) using the transportable VLBI system of the GSI.8) This observation was particular in a sense that we tried to observe low elevation radio sources as possible as we could. The purpose was to achieve the highest accuracy in vertical direction which is most important for sea level monitoring. The results of a total of 6 independent observations are listed in Table–3.

Table–3 Results of VLBI Observation at Mizusawa

(Unit in meters)

Session	X	Y	Z
VEGA I1	135480.325	-171566.215	277826.643
I2	.336	.226	.625
I3	.349	.239	.612
I4	.358	.245	.618
I5	.344	.225	.638
I6	.360	.252	.613

The repeatability of the observations is good indication that there was no seasonal variation. The accuracy of the vertical component is also good as a result of efforts to measure low elevation sources. The determined geocentric coordinates referring to IERS–91 are as follows; formal error for each component is about 1 cm:

$$X = -3862410.246 \text{ m}$$
$$Y = 3105014.157 \text{ m}$$
$$Z = 4001945.415 \text{ m}.$$

4. Improvement of GPS Data Processing Software

The refinement of the accuracy of the GPS positioning is also important because our approach for the sea level monitoring is to use combination of space geodetic technologies, i.e., VLBI and GPS. The bottleneck of the GPS data processing is cycle–slip removal. Since the occurrence of a cycle–slip is purely unpredictable, we need a sophisticated technique to detect and remove cycle–slips automatically in the data processing stage. A variety of numerical technologies to cope with this problem are developed.

One of the most successful software package for GPS data processing of the date is Bernese software developed by Bern University team. The most outstanding feature of this software is its powerful capability of removing cycle–slips. The advantage of the Bernese software is as follows:

1) Acceptance of RINEX format which allows us to use almost all receiver types,
2) Transparent source code, and
3) Wide distribution in the scientific community as a standard software for GPS data processing.

We introduced the Bernese software for our GPS data processing to achieve the highest accuracy.

5. Positioning of Two Tidal Gauges

Starting from VLBI positioning result at Mizusawa, we determined tree–dimensional positions of two tidal gauges using GPS technology. The observed tidal gauges are OGA tidal station and SOMA tidal station. The GPS observations were carried out from June 6 to June 11, 1991, receiving signals from satellites SV2, 6, 11, 13, 14, 15, and 19 for the baselines between those two stations and Mizusawa VLBI site. Both baseline lengths are about 150 km. After data processing we got reasonable result for each day observation. The formal error of each observation was about 2 cm which corresponds to 0.2 ppm.

Depending on VLBI result at Mizusawa and above mentioned GPS results between tidal gauges and VLBI site we computed the heights of the tidal gauges above reference ellipsoid as of June 1991. The results referring to IERS system are as follows:

1) Ellipsoidal height of OGA tidal station	39.632m
2) Ellipsoidal height of SOMA tidal station	44.348m .

We estimated the formal errors of those final values not worse than 5 cm. This error budged is derived from individual estimation for the errors of VLBI, GPS and spirit leveling each of which contributed to this determination of vertical position of tidal gauges. To shorten the necessary time span for sea level monitoring we should improve this accuracy.

6. Summary and Conclusions

We are in the process of developing a unified geodetic observation system for monitoring of possible sea level changes caused by the global warming due to climate change. We developed a super small VLBI system and introduced a powerful GPS data processing software. Using those technologies we determined the positions of the two tidal gauges. This is the very first step of our long term plan to monitor the possible sea level changes.

References:

1)Yoshiro NAKAHORI, S. MATSUZAKA, M. TOBITA, Y. TAKAHASHI, Y. SUGIMOTO, and A. KANEKO; Monitoring of Mean Sea Level Change Using an Small VLBI Station, Abstracts of the Papers Read at the 74 Meeting of the Geodetic Society of Japan, 1990.

2)Kosei OTOI, Y. NAKAHORI, S. MATSUZAKA, M. TOBITA, Y. TAKAHASHI, A. KANEKO and N. KURIHARA; Absolute Sea Level Monitoring by GSI and CRL, IERS Workshop, 1991.

3)Yukio TAKAHASHI, A. KANEKO, N. KURIHARA, Y. NAKAHORI, M. TOBITA and K. NITTA; Sea Level Monitoring System Using a Small Mobile VLBI Station, Journal of CRL Vol.38 No.3, 1991.

4) Yukio TAKAHASHI, A. KANEKO, N. NAKAHORI; A Transportable 2.4 Antenna for VLBI and Operating Software, Symposium on VLBI Network, 1992.

5)Yukio TAKAHASHI; Analytic Error Analysis of Domestic VLBI Experiments and Ionospheric Effects, Workshop on Coordinates, 1991.

6)Noriyuki KURIHARA, Y. TAKAHASHI, A. KANEKO, Y. NAKAHORI, T. KOMETANI and S. MATSUZAKA; A Project to Monitor Mean Sea Level Change Using a Small Transportable VLBI Station; Plan and System, The 3-rd Symposium on Small Sized Radio Telescope, National Radioastronomical Observatory Workshop, 1992.

7)Yukio TAKAHASHI, N. KURIHARA, A. KANEKO, Y. NAKAHORI, T. KOMETANI and S. MATSUZAKA; A 2.4 m Transportable VLBI Antenna for Domestic Use; Performance Test Results and Future Plans, The 3-rd Symposium on Small Sized Radio Telescope, National Radioastronomical Observatory Workshop, 1992.

8) Masao KARASAWA, T. KOMETANI, K. OTOI, K. YOSHIIKE, Y. NAKAHORI, J. AMAGAYA, Y. KOYAMA and KONDO; A VLBI Observation for the Baseline between Mizusawa and Kashima, Abstracts of the Papers Read at the 77-th Meeting of the Geodetic Society of Japan, 1992.

9) Makoto MURAKAMI; Surveying by GSI Using VLBI and GPS ; Proceedings of the International Workshop for Reference Frame Establishment and Technical Development in Space Geodesy, 1993, Tokyo.

10) Makoto MURAKAMI; Mean Sea Level Monitoring in Japan Using VLBI/GPS and Tide Gauge; Proceedings of the Eighth International Symposium on Recent Crustal Movements (CRCM'93) ,(in print), 1993, Kobe

11) Shigeru MATSUZAKA; Domestic VLBI Network by GSI; Proceedings of the International Workshop for Reference Frame Establishment and Technical Development in Space Geodesy, 1993, Tokyo.

12) Mikio TOBITA; Control of Precise Geodetic Network Using VLBI; Proceedings of the International Workshop for Reference Frame Establishment and Technical Development in Space Geodesy, 1993, Tokyo.