INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS
INTERNATIONAL ASSOCIATION OF GEODESY

Report of the Geodetic Works in Japan
During the Period
Between January 1999 and December 2002

NATIONAL REPORT TO THE XXIII GENERAL ASSEMBLY
SAPPORO, JAPAN
JUNE 30-JULY 11, 2003

Edited by the National Committee for Geodesy in Japan

THE NATIONAL COMMITTEE FOR GEODESY IN JAPAN
AND
THE GEODETIC SOCIETY OF JAPAN

This report is compiled by Kosuke Heki (National Astronomical Observatory),
Shuhei Okubo (Earthquake Research Institute, University of Tokyo)
and Taizoh Yoshino (Communications Research Laboratory).

The electronic file of this report is available at the following Web site.
http://wwwsoc.nii.ac.jp/geod-soc/iugg2003/

IUGG2003 National Report of Japan

Contents **page**

1. Introduction

During the period 1999-2002, several major international symposia related to geodesy were held in Japan, e.g. International workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE) at Tokyo in 1999, the 1999 Global Positioning System (GPS) International Workshop (GPS'99) at Tsukuba, the 2000 Earth Tide Symposium (ETS2000) at Mizusawa, and the 2002 International Very Long Baseline Interferometry (VLBI) Service General Meeting (IVS2002) at Tsukuba. They were attended by many researchers both from Japan and overseas, and papers presented there are summarized in special issues of journals [1, 2, 3, 4]. The National Council of Geodesy has sent official delegates to general meetings of International Association of Geodesy (IAG), held in Birmingham in 1999 and in Budapest in 2001. In addition to international activities, the Geodetic Society of Japan (GSJ) has two general meetings every year and a tutorial school for young geodesists every summer. GSJ awards an eminent young geodesist with the Tsuboi Prize once a year, and during 1999-2002 they were given to Drs. Yuki Kuroishi (Geographical Survey Inst., GSI), Masato Furuya (Earthquake Res. Inst.), MikioTobita (Geographical Survey Inst.) and Xu Peiliang (Disaster Prevention Inst., Kyoto University). The Group Tsuboi Prize started in 2001, and has been given to the BAYTAP-G development group (represented by Dr. Yoshiaki Tamura, National Astr. Obs., NAO), and the VLBI research and development group of the Communications Research Laboratory (CRL, represented by Dr. T. Kondo).

Several new facilities were established in this period; the number of receiving stations of the nationwide continuous GPS network GEONET, run by GSI, exceeded one thousand in 2002 and attained the original goal of nationwide dense deployment. An independent GPS network has also been run by Japan Coast Guard (JCG). The GEONET data became available to researchers on line at the GSI's web page (www.gsi.go.jp). The Keystone stations of CRL, space geodetic network composed of four stations in the Tokyo metropolitan area equipped with VLBI, SLR and GPS, ceased observations in 2001. It produced valuable data of crustal deformation since 1993 and provided ideal situations for inter-technique collocation studies. NAO built a new VLBI network VERA (VLBI Exploration of Radio Astrometry), composed of four domestic 20 m radio telescopes. This network is dedicated to radio astrometry using differential VLBI (ΔVLBI) technique. It will be also used as the ground stations to track the SELENE (Selenological and Engineering Explorer) lunar orbiter with ΔVLBI.

Apart from such government-lead activities, university researchers have been performing field observations of crustal deformation with extra-dense campaign type deployment of GPS stations. Areas studied in such activities include the Median Tectonic Line, the focal region of the 2000 Tottori earthquake, the area of the Izu and Tokai area where a sequence of the volcanic eruption, dyke intrusion and a silent earthquake has been continuing since 2000, and those around major active faults e.g. the Atotsugawa Fault, the Hanaore Fault, etc.. Continuous observations by the worldwide deployed superconducting gravimeters (SG) have been performed under international cooperation of the Global Geodynamics Project (GGP), in which Japanese participants maintain SG at Canberra (Australia), Svalvard (Norway), Syowa (Antarctica), Bandung (Indonesia), in addition to domestic points. Absolute gravimeters (AG) have been used to calibrate such SG, and have been deployed in fields to detect subtle gravity changes associated with earthquakes and volcanic eruptions.

Research and development studies of seafloor positioning using GPS/acoustic techniques have been actively performed by university groups and JCG. A new project has been launched in 2002 by a multi-agency group in order to realize a new-generation satellite gravity mission based on low-low satellite-to-satellite laser interferometry. Development of on-board instruments for the coming lunar exploration mission SELENE, such as laser altimeter, relay satellite to enable direct measurement of the lunar farside gravity fields by high-low satellite-to-satellite tracking, on-board radio transmitter for earth-based ΔVLBI tracking, has been done mainly by NAO toward the launch of SELENE in 2005 summer.

Events that occurred 1999-2002 in Japan contributed great deal to our knowledge on various crustal deformation phenomena. They include the 1996/2002 silent earthquakes at the Boso Peninsula, the 2000 summer sequence of the eruption of the Miyake Island, the intrusion of the submarine dyke connecting Miyake and the Kozu Island, followed by the Tokai silent earthquake that still continues now, the 2000 Tottori earthquake and its small afterslip, the 2001 Geiyo earthquake, and many others. Secular crustal movement studies in the Japanese Islands have revealed the existence of a zone of concentrated strain running from Niigata to Kobe. Secular vertical crustal movements have become accurate enough to be used for inversion studies of interplate coupling at trenches together with interseismic horizontal crustal movements. Seasonal components often found in GPS time series have been studied, and the large part was found to be driven by seasonally changing surface loads such as snow.

Bibliography

[1] Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE). Jan., 1999.

[2] Earth Planets and Space, GPS'99 Special Issue, 2000 November and December.

[3] Journal of Geodetic Society of Japan, ETS2000 Special Issue, 2001 March.

[4]International VLBI Service for Geodesy and Astrometry General Meeting Proceedings, NASA/CP-2002-210002.

2. Positioning

2-1.Single technique

Space geodetic techniques have been applied to determine the precise position of the stations. The activities are reviewed (Fukuzaki, 2001; Shiba, 2000; Takashima, 2000). To update the geodetic network in Japan, the method was investigated by Sugihara (1999) and Takahashi (1999). Aiba et al. (2002) used the GPS observations to monitor the Philippine Sea plate motion and Matsuzaka (1999) analysed the GPS observations to establish a reference datum in the Asia-Pacific region. An experimental real time positioning system using virtual reference station method.was created by Tsuzuku (2001).

Bibliography

Abe, K., O. Ohtaki, J. Fujisaku, Y. Kikuta, T. Kometani, M. Kusaka, H. Kawawa, and A. Hotta (1999): Drift of GPS-based control station caused by frost heave, Tech. Rep. Geogr. Surv. Inst.,A.1-No.210, 15-18.(in Japanese)

Aiba, M., and H. Hamazaki (2002): Displacement of the Okinotorishima Island from February 1999 to February 2002, J. of Geogr. Surv. Inst, Vol. 99. (in press) (in Japanese)

Fujisaku, J. (2000): Meteorological effects on GEONET, Tech. Rep. Geogr. Surv. Inst.,A.1-No.223, 9-10.(in Japanese)

Fukuzaki, Y., and GSI VLBI group (2001): Geodetic VLBI activities at GSI, Rev. Comm. Res. Lab.,. 47, 17-22. (in Japanese)

Matsuzaka, S. (1999):Analysis of APRGP98 GPS data set by GSI, Proceedings of the Second Workshop on Regional Geodetic Network, Ho Chi Minh City- Vietnam 1999, 38-45.

Shiba, K., S. Kurihara, K. Takashima, M. Ishihara, K. Nemoto, M. Iwata, M. Onogaki, K. Kobayashi (2000): The results of domestic VLBI experiments, Kokudochiriin Jihou Vol.93, 44-51. (in Japanese)

Sugihara, K., and T. Akiyama (1999): Study on updating heights of trig points for JGD2000. Geogr. Surv. Inst. Tech. Rep.A1-No.225, 33-36.(in Japanese)

Takahashi, Y. (1999): Geodetic coordinates 2000 - present status and problems of Tokyo Datum -, J. of Geogr. Surv. Inst., Vol. 91, 1-8. (in Japanese)

Takashima, K., S. Kurihara, M. Ishihara, K. Nemoto, M. Iwata, K. Shiba, M. Onogaki, and K. Kobayashi (2000): Status and results of GSI domestic VLBI networks, Bull. Geogr. Surv. Inst., 46, 1-9.

Tamura, T., F. Suga, M. Takahara, J. Fujisaku (2000): The effects of the waver of sun-baked

GPS-based control stations, Tech. Rep. Geogr. Surv. Inst., A.1-No.223, 13-14.(in Japanese)
Tamura, T., H. Sato (2001): Investigation about the effects of jamming on GPS- based control stations, Tech. Rep. Geogr. Surv. Inst., A.1-No.268, 97- 98
Tsuzuku, M., S. Nishi and S. Matsumura (2001): Real time positioning by virtual reference station, J. Geogr. Surv. Inst., 96, 39-44 (in Japanese)

2-2. Multiple techniques

In the IAG, Integrated Global Geodetic Observing System (IGGOS) is proposed recognizing the importance of multi-technique observations. Yoshino (1999a) discussed the benefit of collocation between the space geodetic techniques and the status was reported with the example of Keystone stations. Method of local tie was studied by Hasegawa et al. (2002) with the precision of 1.5mm at the Keystone stations and by Matsuzaka et al. (2000) with a sub-mm tie at Tsukuba and Aira VLBI stations. Nemoto et al. (1999) discussed a strategy for mm-level local tie survey between VLBI station and IGS station at Tsukuba. Loal tie measurement was performed at at four VLBI stations in Japan (Ishihara et al., 1999), Matsuzaka et al. (1999) reported the local tie survey between GPS and VLBI at Tsukuba. Coordinates of the Key Stone Project observation sites determined from VLBI, GPS, and SLR are compared by Koyama et al. (1999d, 1999e and 2000a) and.Otsubo et al. (1999c). Inconsistency is discussed. Ogi et al. (1999) compared the 1000 km baselines obtained from the regular VLBI experiments and daily GPS measurements. Watanabe et al. (1999) compared the GPS/GLONASS receiver precision, The baseline vectors agree within 25 mm.

Bibliography

Hasegawa, H., S. Xia, H. Tamura, J. Ooizumi, T. Yoshino, H. Kunimori, J. Amagai, F. Katsuo, Y. Koyama, and T. Kondo (2002): Local survey method of space geodetic observation systems at a collocation site, J. Geod. Soc. Japan, 48, 2, 85-100.
Ishihara, M., K. Nemoto, T. Kawahara, M. Iwata, K. Shiba, K. Takashima, K. Kobayashi, S. Matsuzaka, and S. Ogi (1999): The combination results of domestic VLBI network and GEONET, J. Geogr. Surv. Inst., Vol.92, 41-51. (in Japanese)
Koyama, Y., E. Kawai, M. Sekido, N. Kurihara, K. Sebata, and M. Furuya (1999d): Tie of the KSP VLBI network to the terrestrial reference system, J. Comm. Res. Lab., 46, 183-186.
Koyama, Y., R. Ichikawa, and T. Kondo (1999e): Comparison of coordinates and velocities of the Key Stone Project observation sites determined from VLBI, GPS, and SLR, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 50-55.

Koyama, Y., R. Ichikawa, T. Kondo, N. Kurihara, Y. Takahashi, T. Yoshino, K. Sebata, and M. Furuya (2000a): Comparison of site velocities measured by VLBI and GPS in the Key Stone Project network, Proceedings of the IAG Section 2 Symposium, Towards an Integrated Global Geodetic Observing System, IAG Symposia, 120, 158-160.

Matsuzaka, S., M. Ishihara, K. Nemoto, K. Kobayashi (1999): Local tie between VLBI and GPS at Geographical Survey Institute, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE) , (Jan., 1999, Koganei), 68-72.

Matsuzaka, S., Y. Hatanaka, K. Nemoto, Y. Fukuzaki, K. Kobayashi, K. Abe, and T. Akiyama (2000): VLBI-GPS collocation method at Geographical Survey Institute, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893, 96-100.

Nemoto, K. (1999): Study on a local tie survey between space geodetic techniques, Tech. Rep. Geogr. Surv. Inst. A1-No.225, 37-38. (in Japanese)

Ogi, S., M. Ishihara, Y. Fukuzaki, M. Iwata, K. Shiba, M. Yazawa, K. Takashima, and K. Nagata (1999): Comparison of the time variation with GSI VLBI domestic experiments and daily GPS measurements, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 101-105.

Otsubo, T., and Y. Koyama (1999c): Global station coordinates derived from SLR and VLBI observations, J. Comm. Res. Lab., 46, 1, 165-170.

Watanabe, M., M. Kagawa, H. Kato, and S. Miyaguchi (1999): Evaluation of GPS/GLONASS receiver precision, Tech. Rep. Geogr. Surv. Inst. A1-No.225, 29-32. (in Japanese)

Yoshino, T. (1999a): Role of the collocated stations, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 21-25.

3. Development in technology

3-1. VLBI

The Key Stone Project was performed until the end of 2001 running space geodetic network consisting of four sites around the Tokyo metropolitan area with VLBI, SLR and GPS facilities. To achieve the daily or sub-daily monitoring of the site positions, both observation system and data analysis system were fully automated (Koyama et al. 1999a and 1999b). Koyama et al. (1999c) used the automated data analysis system to estimate earth orientation parameters from real-time VLBI observation data with a delay less than one day independently. Koyama et al. (2001a) investigated the flux density variations of compact radio sources observed by Key Stone Project VLBI network.

Giga-bit VLBI system has been developed by CRL to improve sensitivity of the VLBI observations. The first successful geodetic VLBI experiment was reported by Koyama et al. (2000b). After the developments of the prototype Giga-bit VLBI system, the hardware specification of the VLBI Standard Interface (VSI) was established and the new Giga-bit VLBI system based on the VSI was developed. Koyama et al. (2001ｂ) reported the developments of the VSI based Giga-bit VLBI system and the IP-VLBI system which was developed to realize real-time VLBI observations over the high speed TCP/IP network. Koyama et al. (2003) then reported the results of experiments using the VSI based Giga-bit VLBI system and the IP-VLBI system.

Using the 32m antenna at Tsukuba VLBI station of Geographical Survey Institute, Fukuzaki et al. (2001) received pulsar signals to apply for high precision positioning and Kobayashi et al. (2000) studied the relationship between temperature and vertical deformation of the 32m antenna by field surveys.

Tamura et al. (2002) summarized a newly developed VERA (VLBI Exploration of Radio Astrometry) system and its application to the geodetic observation.

Bibliography

Fukuzaki. Y., and K. Takashima (2001): Feasibility study on a new high precision positioning system with radio pulsar, Tech. Rep. Geogr. Surv. Inst. A1-No.268, 23-26. (in Japanese)

Furuya, M., K. Sebata, Y. Koyama, and T. Kondo (1999): Routine observation results of the KSP VLBI network, J. Comm. Res. Lab., 46(1), 159-164.

Kobayashi, K., Y. Fukuzaki, T. Akiyama, K. Shiba, M. Yazawa, K. Takashima, K. Onogaki, S. Kurihara, and K. Miyagawa (2000): Study on temperature deformation of Tsukuba VLBI antenna, Tech. Rep. Geogr. Surv. Inst. A1-No. 245, 21-24. (in Japanese)

Koyama, Y., T. Iwata, and H. Takaba (1999a): Observation and system management software, J. Comm. Res. Lab., 46, 33-38.

Koyama, Y., K. Heki, Y. Takahashi, and M. Furuya (1999b): Data analysis software, J. Comm. Res. Lab., 46, 77-81.

Koyama, Y., R. Ichikawa, T. Otsubo, J. Amagai, K. Sebata, T. Kondo, and N. Kurihara (1999c): Recent achievements in Very Long Baseline Interferometry, J. Comm. Res. Lab., 46, 253-258.

Koyama, Y., T. Kondo, J. Nakajima, M. Sekido, R. Ichikawa, E. Kawai, H. Okubo, H. Osaki, H. Takaba, M. Yoshida, and K. Wakamatsu (2000b): Geodetic VLBI observations using the Giga-bit VLBI system, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893, 99-102.

Koyama, Y., T. Kondo, and N. Kurihara (2001a): Microwave flux density variations of compact radio sources monitored by real-time Very Long Baseline Interferometry, Radio Science, 36, 223-235.

Koyama, Y., T. Kondo, J. Nakajima, M. Sekido, and M. Kimura (2001b): Internet VLBI system and 1Gbps VLBI system based on the VSI, Proceedings of the 15th Working Meeting on European VLBI for Geodesy and Astrometry, 91-98.

Koyama, Y. (2002): Expected contributions of the K4 and its next-generation systems, International VLBI Service for Geodesy and Astrometry General Meeting Proceedings, NASA/CP-2002-210002, 55-99.

Koyama, Y. (2003): VLBI observation systems based on the VLBI Standard Interface Hardware (VSI-H) specifications, Proceedings of the IVS Symposium in Korea, New Technologies in VLBI, in press.

Tamura, Y., and VERA Group, (2002): Geodetic observation system in VERA, International VLBI Service for Geodesy and Astrometry General Meeting Proceedings, NASA/CP-2002-210002, 167-170.

Yazawa, M. , S. Kurihara, and K. Takashima (2000): Study on remote control operations of VLBI stations in Japan, Tech. Rep. Geogr. Surv. Inst. A1-No.245, 19-20. (in Japanese)

3-2. SLR

For satellite laser ranging system of the Keystone project, analysis software was developed for regional short-arc analysis and global analysis (Otsubo et al., 1999b). Katsuo et al. (1998, 1999) proposed a technique to determine the telescope reference point and system delay (Multi-target calibration) in the KSP-SLR system.

Otsubo et al. (1999a, 1999d) made it clear that the station-dependent satellite signature effect should be taken into account for the AJISAI satellite through an orbit analysis of laser ranging data.

Otsubo et al. (2001) extended this approach to the flat reflector array of Russian GLONASS satellites and found a systematic range offset of a few cm in multiphoton detection systems.

Otsubo et al. (2000) devised a method to estimate the spin motion of AJISAI. It utilized a small cyclic signal in the full-rate laser range residuals. This study was succeeded to Otsubo et al. (2002) where a unique reflector array for the H2A-LRE satellite was designed for monitoring the optical degradation of retroreflectors.

Kunbo-oka (2000) developed a new model of the non-gravitational forces on a satellite such as atmospheric drag, solar radiation pressure and albedo from the Earth. By combining this new non-gravitational force model with GEODYN-II orbit analysis software, in a simulation, the orbit determination accuracy of ADEOS-II is improved.

Range biases in the SLR data obtained at Shimosato Hydrographic Observatory is treated as time variable and estimated in the analysis of global SLR data by Fukura et al. (1999) and Sengoku, (1999). The estimated biases of three satellites Ajisai, Lageos 1 and 2 for 1995-1997 were about 3- 5 cm. Those of Lageos 1 and 2 are slightly greater than that of Ajisai, which means that range bias is dependent on the intensity of return signal.

Bibliography

Fukura, H., and M. Fujita (1999): Continuous estimation of range biases included in SLR data of Simosato Hydrographic Observatory, Tech. Bull. Hydrogr., 17, 51-54. (in Japanese)

Katsuo, F., T. Otsubo, J. Amagai, and H. Nojiri (1998): A new calibration technique for the telescope reference point and the system delay, 11th International Workshop on Laser Ranging, Deggendorf, 516-520.

Katsuo, F., T. Otsubo, J. Amagai, and H. Nojiri (1999): A dual checking system for determining the telescope reference point, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 216-220.

Kunbo-oka, T. (2000): Simulation of ADEOS-II Orbit Determination, Rep. Hydrogr. Res., 36, 25-36. (in Japanese)

Otsubo, T., J. Amagai, and H. Kunimori (1999a): The Center-of-mass correction of the geodetic satellite Ajisai for single-photon laser ranging, IEEE Trans. Geosci. Remote Sensing, 37, 4, 2011-2018.

Otsubo, T. , and F. Katsuo (1999b): Analysis software, J. Comm. Res. Lab., 46, 1, 129-134.

Otsubo, T., J. Amagai, and H. Kunimori (1999d): Center-of-mass correction of the satellite AJISAI, J. Comm. Res. Lab., 46, 1, 213-218.

Otsubo, T., J. Amagai, H. Kunimori, and M. Elphick (2000): Spin motion of the AJISAI satellite derived from spectral analysis of laser ranging data, IEEE Trans. Geosci. Remote Sensing, 38, 3, 1417-1424.

Otsubo, T., G. M. Appleby, and P. Gibbs (2001): GLONASS laser ranging accuracy with satellite signature effect, Surveys in Geophysics, 22, 6, 509-516.

Otsubo, T., H. Kunimori, K. Yoshihara, and H. Hashimoto (2002): Laser reflector arrangement on H2A-LRE satellite for monitoring spin rate and optical degradation, Applied Optics, 41, 27, 5672-5677.

Sengoku, A., M. Fujita, H. Fukura, and M. Sasaki (1999): Range bias problem associated with SLR data at Simosato, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 163-167.

3-3.GPS

Kinematic and Real Time Kinematic GPS are studied. Fujita et al. (1999) evaluated the accuracy of long baseline kinematic GPS (carrier phase base) positioning of survey vessel in the sea area by comparing the results of short baseline (about 10 km) and long baseline (about 100 km) reference stations. The difference for vertical component is less than 10 cm. Isshiki et al. (2000b) proposed KVD (Kinematics for precise Variance Detection) Method by relative GPS measurements. Kato et al. (2000; 2001) developed a new system to detect a tsunami before it reaches the coast employing the RTK-GPS technique. The system consists of dual-buoys: the Support-buoy, and the Sensor-buoy. The system has been anchored at about 2km away from the coast. Sea surface height is monitored. Uchida (2001) discussed the utilization of the precise vertical positioning of survey vessels with (real time) kinematic GPS (carria phase base) positioning technique for hydrographic survey. Precise height determination with sub-decimeter accuracy in the sea area will be useful for the sea bottom survey. A new positioning method (PVD: Point precise Variance Detection) by a single point GPS receiver is proposed by Isshiki et al. (2000a) aiming at the wave measurements by an ocean buoy and earthquake measurements with a simple and low-cost measuring system. It is demonstrated by Takanashi, Y. (2001) that the coast line is able to be surveyed with 1 meter accuracy by the public Differential GPS service. Nakamura, K. (1999) developed the software which runs on the Microsoft Windows95/98 to display a crustal deformation using GEONET data of GSI. Li et al. (2000) applied autoregressive moving average method for the GPS time series modeling. Hatanaka et al. (2001a; 2001b) investigated the phase characteristics of GEONET stations. Phase maps for each antenna-monument types for GEONET stations are obtained by a calibration experiment. The new phase maps are effective to reduce systematic error of the solutions. Tabei et al. (2002) extracted spatially correlated common-mode errors in the GPS coordinates time series of the Japanese nationwide continuous GPS array by using spatial filtering technique. The high resolution ionospheric modeling technique is developed by Rocken et al. (2000) for correction of GPS data.

The performance of the method is demonstrated with a 25-site network of Geographical Survey Institute. Ionospheric TEC measurement by GPS is evaluated by Sekido et al. (2001; 2003).

Bibliography

Fujita, M., A. Asada, and S. Toyama (1999): Experiment on long range kinematic GPS in the Sagami area, Tech. Bull. Hydrogr., 17, 44-50. (in Japanese)

Hatanaka, Y., M. Sawada, A. Horita, and M. Kusaka (2001a): Calibration of antenna-radome and monument-multipath effect of GEONET---part 1: measurement of phase characteristics, Earth Planets and Space, 53, 13-21.

Hatanaka, Y., M. Sawada, A. Horita, M. Kusaka, J. Johnson, and C. Rocken (2001b): Calibration of antenna-radome and monument-multipath effect of GEONET---part 2: evaluation of the phase map by GEONET data, Earth Planets and Space, 53, 23-30.

Hotta, A., K. Abe, Y. Kikuta (1999): Adjustment of positioning errors of GPS- based control stations using tilt data, Tech. Rep. Geogr. Surv. Inst.,A. 1-No.210, 19-20.(in Japanese)

Isshiki, H., A. Tsuchiya, T. Kato, Y. Terada, H. Kakimoto, M. Kinoshita, M. Kanzaki , and T. Tanno (2000a): Precise variance detection by a single GPS receiver - PVD (Point precise Variance Detection) Method -, J. Geod. Soc. Japan, 46 (4), 239-251.

Isshiki, H., A. Tsuchiya, T. Kato, Y. Terada, H. Kakimoto, M. Kinoshita, M. Kanzaki, and T. Tanno (2000b): Precise variance detection by simplified kinematic GPS measurements - KVD (Kinematics for precise Variance Detection) Method -, J. Geod. Soc. Japan, 46 (4), 253-267.

Kato, T., Y. Terada, M. Kinoshita, H. Kakimoto, H. Isshiki, M. Matsuishi, A. Yokoyama, and T. Tanno (2000): Real time observation of tsunami by RTK-GPS, Earth Planets and Space, 52(10), 841-845.

Kato, T., Y. Terada, M. Kinoshita, H. Kakimoto, H. Isshiki, T. Moriguchi, M. Kanzaki, M. Takada, and J. Johnson (2001): A development of tsunami observation system using RTK-GPS - continuous experiment at Ofunato city coast -, Tech. Rep. IEICE., 2001-04, 45-52.

Li, J., K. Miyashita, T. Kato, and S. Miyazaki (2000): GPS time series modeling by autoregressive moving average method: Application to the crustal deformation in central Japan, Earth Planets and Space, 52(3), 155-162.

Nakamura, K. (1999): The software for displaying GPS data (SEIS-GPS), Geoinformatics, 10, 257-266. (in Japanese)

Rocken, C., J. M. Johnson, J. J. Braun, H. Kawawa, Y. Hatanaka, and T. Imakiire (2000): Improving GPS surveying with modeled ionospheric corrections, Geophys. Res. Lett., 27, 3821-3824.

Sekido, M., T. Kondo, E. Kawai, and M. Imae (2001): Evaluation of GPS-based Ionospheric TEC Measurements, Technical Report of the Institute of Electronics, Information and Communication

Engineers, SANE2000-142, 61-68.
Sekido, M., T. Kondo, E. Kawai, and M. Imae (2003): Evaluation of GPS-based ionospheric TEC map by comparing with VLBI data, Radio Science, in press
Tabei, T. and W. L. Amin (2002): Common-mode errors in the GPS coordinates time series - Application of spatial filtering technique -, J. Geod. Soc. Japan, 48, 229-241.
Takanashi, Y. (2001): The accuracy of coastline survey by using differential GPS, Tech. Bull. Hydrogr., 19, 90-93. (in Japanese)
Uchida, A. (2001): Application of vertical GPS positioning on shipboard, Tech. Bull. Hydrogr., 19,94-99. (in Japanese)
Yabuki, T. (2000): The advance of hydrographic surveys using kinematic GPS for vertical control, Proceedings of Workshop on the Satellite Altimetry in the 21st Century, Nov. 25-26, 1999, Tokyo Japan, 11-16. (in Japanese)

3-4 Other techniques

Technical study of Interferometric SAR (Synthetic Aperture Radar) is made to get the results efficiently. Fujiwara et al. (1999) applied a correction method that the error due to the differential tropospheric delay between the two SAR scenes is removed by subtracting the DEM multiplied a coefficient. Tobita et al. (1999) proposed an image coregistration algorithm for SAR interferometry. Regarding this technique, Fujiwara et al. (1999) described an introductory guide for the geodetic researchers, and shows its principle, analysis processes and its error sources.

Satellite altimeter data is utilized. Using the Topex/Poseidon data in the Pacific ocean at the Kuroshio region, Yoritaka et al. (1999) reported the estimation of the dynamic heights and geostrophic currents with technical aspects. ERS-2 altimetry data is analyzed by Yamamoto et al. (2001) to obtain Kuroshio Extension paths. It is demonstrated that the sensitivity of ERS-2 altimetry data is sufficient for the estimation of Kuroshio Extension path. Japan Hydrographic Association (2002) created several datasets of water depths at mesh points by merging sea bottom topography derived from satellite altimetry data and echo sounding data compiled for many years. The dataset of 1'x1'.mesh covers the north-western pacific ocean, the widest area.

Takemoto et al. (1999) developed a 3-D real time measurement system of crustal strains by Electronic Speckle Pattern Interferometry. An EPSI recording system designed for monitoring crustal deformation was installed in the tunnel of Kamigamo Geophysical Observatory, Kyoto, Japan, in June 1997.

Bibliography

Fujiwara, S., and M. Tobita (1999): SAR interferometry techniques for precise surface change detection, J. Geod. Soc. Japan, 45, 283-295. (in Japanese)

Fujiwara, S., M. Tobita, Mak. Murakami, H. Nakagawa, and P. A. Rosen (1999): Baseline determination and correction of atmospheric delay induced by topography of SAR interferometry for precise surface change detection, J. Geod. Soc. Japan, 45, 315-325. (in Japanese)

Japan Hydrographic Association (2002): Recovery of sea bottom topography by using satellite altimetry data (3rd report), JHA Research and Study Report No.106, 82p. (in Japanese)

Takemoto, S., J. Kondo, and A. Mukai (1999): Development of a 3-D real time measurement system of crustal strains by means of electronic speckle pattern interferometry, Annuals Disas. Prev. Res. Inst. Kyoto Univ., 42, B-1, 151-157 .(in Japanese with English Abstract).

Tobita, M., S. Fujiwara, Mak. Murakami, H. Nakagawa, and P. A. Rosen (1999): Accurate offset estimation between two SLC images for SAR interferometry, J. Geod. Soc. Japan, 45, 297-314. (in Japanese)

Yamamoto, A., M. Sasaki, M. Ogawa, Y. Yamamoto, N. Fukuda, and T. Maeda (2001): Variation of the Kuroshio extension path in 1997 derived from ERS-2 altimeter data, Rep. Japan Coast Guard Academy, 46, 27-42. (in Japanese)

Yoritaka, H., H. Kudo, T. Yanuma, and Y. Oshima (1999): Estimation of ocean current using TOPEX/POSEIDON altimeter data, Tech. Bull. Hydrogr., 17, 31-36. (in Japanese).

4. General Theory and Methodology

Many papers have been published on the change of Japanese geodetic system to a new geocentric one by researchers in Geographical Survey Institute as seen in the list below (e.g. Murakami and Ogi, 1999). They also distribute a program to perform conversion between the old and the new systems from their website (Tobita, 2002). Xu Peiliang, Kyoto University, has been active in variety of theoretical problems in geodesy, and was awarded with the 10th Tsuboi Prize by the Geodetic Society of Japan for one of his theoretical works related to random tensor.

Bibliography

Gerasimenko, N., V. Shestakov, and T. Kato (2000): On optimal geodetic network design for fault-mechanics studies, Earth Planets and Space, 52(11), 985-987.

Hoshino, Y., H. Maruyama, and H. Tsuji (2002): Collaboration between Japan and Kenya for establishment of Kenya Institute of Surveying and Mapping, Bull. Geogr. Surv. Inst.,48, 1-16.

Imakiire, T., Mas. Murakami (2002): Establishment of the new geodetic reference frame of Japan(JGD2000), General Meeting Proceedings of IVS2002, 304-308.

Morii, W. (2001): A new method of spectral analysis based on the technique of the AM Receiver, J. Geod. Soc. Japan, 47, 294-299.

Murakami, Mas., and S. Ogi (1999): Realization of the Japanese Geodetic Datum 2000 (JGD2000), Bull. Geogr. Surv. Inst., 45, 1-10.

Murakami, Mas. (2000): Geodetic Coordinates 2000 - worldwide trend: the move to geocentric system -, J. Geogr. Surv. Inst., 91, 16-23. (in Japanese)

Naito, H., and S. Yoshikawa (1999): A program to assist crustal deformation analysis, Zisin, 52, 101-103. (in Japanese)

Notazawa, Y. (1999): Geodetic Coordinates 2000 - The outline of the Geodetic Coordinates 2000 -, J. Geogr. Surv. Inst., 91, 9-15. (in Japanese)

Tobita, M. (2002): Coordinate transformation software “TKY2JGD” from Tokyo Datum to a geocentric reference system, Japanese Geodetic Datum 2000, J. Geogr. Surv. Inst., 97, 31-52. (in Japanese)

Xu, P.L. (1999): Despeckling SAR-type multiplicative noise, International J. Remote Sensing, 20, 2577-2596.

Xu, P.L. (1999): Spectral theory for constrained second-rank random tensors, Geophys. J. Int., 138, 1-24.

Xu, P.L. (1999): Biases and accuracy of, and an alternative to nonlinear filtering, J. Geod., 73, 35-46.

Xu, P.L., E. Cannon, and G. Lachapelle (1999): Stabilizing ill-conditioned linear complementarity problems, J. Geod., 73, 204-213.

Xu, P.L. (1999): Testing physical properties of geopotential fields, Boll. Geod. Sc. Affini, 58, 135-150.

Xu, P.L., S. Shimada, Y. Fujii, and T. Tanaka (2000): Invariant geodynamical information in geometric geodetic measurements, Geophys. J. Int., 142, 586-602.

Xu, P.L., S.Shimada, Y. Fujii, and T. Tanaka (2000): The geodynamical value of historical geodetic measurements: a theoretical analysis, Earth Planets and Space, 52, 993-997.

Xu, P.L., and S. Shimada (2000): Least squares estimation in multiplicative noise models, Communications in Statistics, B29, 83-96.

Xu, P.L.(2001): Random simulation and GPS decorrelation, Journal of Geodesy, 75, 408-423.

Xu, P.L. (2002): Isotropic probabilistic models for directions, planes and referentials, Proc. Royal Soc. London, A458, 2017-2038.

Xu, P.L. (2002): A hybrid global optimization method: the one-dimensional case, J. Computational and Applied Mathematics, 147, 301-314.

Xu, P.L. (2002): New challenges in connection with precise GPS positioning, Proceedings of IAG, 125, 359-364.

5. Determination of the Gravity Field

5.1. International and domestic gravimetric connections

The Geographical Survey Institute (GSI) carried out part of the second-round, and is carrying out the third-round, national gravity connection survey with LaCoste & Romberg (LCR) model-G gravimeters in association with absolute gravity measurements. From April 1998 to March 2001 the second-round relative gravity measurements were made at 10 Fundamental Gravity Stations (FGSs), 31 first-order gravity stations, and 131 first-order benchmarks. Starting in April 2001, the third-round survey is underway from the southwest end to the northeast of the Japanese Islands: relative gravity measurements have been performed at three FGSs, 24 first-order gravity stations and 15 benchmarks up to March 2002.

Korea Institute of Geology, Mining and Materials (KIGAM) and the Geological Survey of Japan (GSJ), National Institute of Advanced Industrial Science and Technology established a gravity calibration route ``Korean Gravity Calibration Route -Bohyeonsan Mountain" near Taegu City in 2000. With the result of this gravity calibration route, Japan-Korea gravity compilation was performed and Bouguer anomaly map was produced (Geological Survey of Japan and Korea Institute of Geology, Mining and Materials, 2001).

5.2. Absolute gravimetry

In 1999, the absolute gravimeter FG5 #210 was introduced into Department of Geophysics, Kyoto University. Since then, Department of Geophysics, Kyoto University has repeatedly carried out absolute gravity measurements at the Fundamental Gravity Station (Kyoto C) in Kyoto University, at superconducting gravimeter stations in Matsushiro and Esashi, and at Aso Volcanological Laboratory. Absolute gravity measurements have been also carried out repeatedly at Cape Muroto of Shikoku District, in order to detect secular gravity changes at a subducting plate margin (Higashi et al., 2001a).

The GSI carried out absolute gravity measurements at 13 FGSs with one of the three FG5 absolute gravimeters (Micro-g Solutions Inc.: #104, #201 and #203). Five of these stations were newly occupied: Obihiro, Mt. Iwate, Mt. Fuji, Nobeoka, and Ishigaki Island FGSs. The rest were the existing FGSs: Kushiro, Hirosaki, Tsukuba, Omaezaki, Kochi, Aira, Fukuoka, and Naha FGSs. Though standard deviation of a single drop for the measurements varies from 9 to 44 μ gals, final gravity values were determined at a precision better than 2 μ gals. Under an agreement at the 26th Japan-Korea Conference for Cooperation in Geodesy and Cartography held at the National Geography Institute of Korea (NGI) in Suwon, Korea in June 1999, the GSI carried out absolute gravity measurement with FG5 #203 at NGI in December 1999. The standard deviation of a single drop was 12 μ gals and the final gravity value was determined at a precision better than 2 μ gals.

The National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology participated in the sixth International Comparison of Absolute Gravimeters (ICAG-2001) with the absolute gravimeter FG5 #231, which was held in BIPM (Bureau International des Poids et Mesures), Sévres, France, July 2001.

The GSJ purchased a portable absolute gravimeter, FG5-L #003, in 2001 in order to evaluate whether an absolute gravimeter is capable of geothermal reservoir monitoring.

As a result, it was found to be difficult to achieve a sufficient accuracy in geothermal areas (Sugihara, 2001), though FG5-L has an advantage of portability.

Moreover, in 2002 the absolute gravimeter FG5-L #003 was upgraded to FG5 #231, therefore the GSJ examined if it is accurate enough for geothermal reservoir monitoring. The GSJ participated in Domestic Comparison of Absolute Gravimeters with FG5 #231.

5.3. Gravimetry in Antarctica

The GSI conducted the fourth absolute gravity measurement with FG5 #203 from December 29, 2000 to January 25, 2001 at Syowa Station (International Absolute Gravity Basestation Network, IAGBN No. 0417) as an activity of the 42nd Japanese Antarctica Research Expedition (JARE) (Kimura et al., 2001; Kimura, 2002). Nearly continuous observation was carried out for one month. Standard deviation of a single drop was 17 μ gals and final gravity value was determined at a precision better than 2 μ gals. The value agrees within 2 μ gals with the adopted one obtained from the third measurement in 1996.

Terada et al. (2001) produced a new gravity anomaly image around Antarctica from 10 Hz sampled satellite altimetry data. They applied a combination of binarization, clustering and thinning techniques to the data and succeeded to extract detailed sea floor information.

Shibuya et al. (1999) estimated geoid height at the Scientific Committee on Antarctic Research (SCAR) GPS reference point on WGS84 reference frame with 20-30 cm accuracy, employing the Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS) beacon marker's position, results of geodetic tie between the marker's position and GPS point, and elevation of the GPS point above sea level.

Sato et al. (2001b) analyzed effect of sea surface height (SSH) variations on three superconducting gravimeter observation sites: Mizusawa (Japan), Canberra (Australia), and Syowa Station (Antarctica). Annual gravity variations estimated from the effects of solid tide, ocean tide, polar motion and SSH variation agree with the observations within 0.2 μ gals in amplitude and 20°in phase.

Higashi et al. (2001b, c) carried out gravity survey along the traverse routes from Syowa Station to Dome Fuji Station, East Antarctica. They determined the gravity values within an accuracy of 1 mgal. The calculated Bouguer gravity anomalies show a large negative anomaly trending inland toward Dome Fuji, in the most southern observation area, at about –200 mgals. They suggest that the depth of the Moho discontinuity around Dome Fuji Station, which is located about 1,000 km from coast, is about 45 km.

5-4. Tidal Gravity Changes and Loading Effects

Traditional Green's functions for load deformation have been used for estimating the effect of oceanic loading upon modern geodetic observations, such as superconducting gravimetry, GPS, VLBI and SLR. To improve accuracy of the load Green functions, Okubo and Tsuji (2001) introduced the effects of the earth's anelasticity while considering its frequency dependence (Absorption Band Model). It turns out that phase lags of Green's functions are of order 2 degree or less but they are strongly dependent on Q structure. Physical dispersion disturbs the real parts of Green's function by 2 % or less.

Earthquake Research Institute (ERI), University of Tokyo and Disaster Prevention Research Institute (DPRI), Kyoto University detected 5-10 μ gals diurnal/semidiurnal gravity signals of ocean tide origin by an FG5 absolute gravimeter at two stations in Sakurajima Volcano located 300 m and 2,500 m away from the shore (Yamamoto et al., 2001c, d).

They computed the gravity originating both from the global ocean tides and from the local ones in Kagoshima Bay, considering the fine-scale sea-land distribution around the stations. The observed FG5 records and the theoretical ocean tides agreed well with each other in both amplitude and phase, indicating that the oceanic loading effects can be predicted to an accuracy better than 2 μ gals within several hundred meters of the shore in Sakurajima. The apparently puzzling errors that have so far arisen on nearshore relative gravity measurements were resolved by the correction of the effects.

5-5. Non-tidal gravity changes

5.5.1 Gravity Changes Associated with Crustal Deformation and Seismic and Volcanic Activity

Laboratory of Geothermics, Kyushu University carried out gravity monitoring at the central part of the Kuju Volcano, central Kyushu, Japan which began to erupt in October 1995 (Ehara et al., 2000a, b; Nishijima et al., 2001a). Gravity values around the new craters and the pre-existing fumaroles decreased rapidly during two months after the eruption, but the decrement slowed down thereafter. It was shown that the hydrological state beneath the Kuju Volcano is reaching a new equilibrium state gradually after the eruption, based on the subsurface water mass balance deduced from the gravity change and an estimation of volcanic steam discharge rate.

The ninth precise gravity measurement was conducted in and around the Sakurajima Volcano in April 1997. Successive gravity increase observed around the center of the volcano since 1975 seems to slow down after the last 1992 measurement. The results may reflect the lowering activity of summit eruptions since 199 crustal movement observations to construct an elastic dislocation model with two tensile faults and a left lateral fault. Then, they use the gravity changes to constrain the density of the material which filled the tensile faults. They find that the density is likely to be small, and that the gravity changes of the first component are reproduced well by the

7674105

Laboratory of Geothermics, Kyushu University carried out repeated gravity measurements at three geothermal fields in Kyushu (H (H (Hush (H (H (Hush (H

Earthquake, Hokuriku and Hokusin-etsu regions in the northern part of Chubu District, the Sado Island in Niigata Prefecture, coast of Enshunada and the Nohbi Plain in Tokai District. By performing total revision on all gravity data collected from over 40 other institutes and organizations, Nagoya University and Hokkaido University compiled a gravity database, which covers southwestern Japan very densely with high precision gravity data for over 144,000 points. Among the data contained in the database, they published 90,298 net gravity data in a tabulated as well as digital form in 2001. Shichi and Yamamoto (2001a) published 49,004 net gravity data measured by Nagoya University during the periods from 1955 through 1957 and from 1978 through 2001. On the other hand, Gravity Research Group in Southwest Japan (GRGSWJ) published 41,294 net gravity data measured by the organizations other than Nagoya University (Gravity Research Group in Southwest Japan, 2001a). All those published data were also provided in a computer-readable form (CD-ROM) together with other information (Shichi and Yamamoto, 2001b). By compiling all the available gravity data, GRGSWJ constructed several kinds of large-sized precise gravity maps in Southwest Japan (Gravity Research Group in Southwest Japan, 2001b-f).

Owing to increased portability, stability and accuracy of modern gravimeters such as LCR and Scintrex CG-3M, microgravity survey has been used in various scientific and engineering fields. The expected structure scale detectable by microgravity anomaly is to be of the order of 1 m; accordingly, the typical spacing between gravity stations will be about 1 m. Examples of such microgravity survey are found in detecting very shallow artificial objects as buried remains, abandoned mine shafts, buried slags in reclaimed land, as well as natural density anomalies in very shallow sedimentary layers down to several tens meters. Karube (1997) successfully applied microgravity survey to non-destructive investigations for preserving archaeological sites in construction projects. He emphasized importance of the non-destructive nature of microgravity survey, together with other geophysical methods such as resistivity, magnetic and ground penetrating radar (GPR).

5.6.2 Hokkaido Area

The GSJ conducted gravity surveys around the western and northern parts of Hokkaido area and newly obtained 1,500 gravity data during the period from 1992 to 1997. These data were also published with CD-ROM (Geological Survey of Japan, 2000a). Further, Morijiri et al. (2000a) published gravity data of the eastern part of Hokkaido.

Yamamoto and Ishikawa (2002) performed gravity surveys around the southern part of the Oshima Peninsula, Hokkaido, Japan, in order to reveal a fine subsurface structure beneath the Peninsula.

These gravity stations number more than 600 and are used to construct a new Bouguer anomaly map. Fortunately, an experiment of explosion seismic observations was conducted in 1990 along an E-W profile, extending over a distance of about 70 km, in the southernmost part of the Oshima Peninsula using quarry blasts in the center of the profile. They forwarded crustal models iteratively in the same profile across the Oshima Peninsula, using the result by analyses of explosion seismic observations and geologic information, until their gravity attractions would make a best fit to the observed Bouguer anomalies. They further proposed a crustal model which well explains the observed gravity along this profile. The obtained crustal model implies that the light Quaternary sediments in the western margin of the Hakodate Plain extend to a depth of about 1.5 km assuming a density contrast of 0.7 g/cm^3.

Yamamoto et al. (2001a) carried out gravity surveys around the southern part of the Hidaka Mountains (Hidaka Collision Zone), Hokkaido, Japan, to improve station coverage of gravity measurements and to detect the inclined structures of the Hidaka Main Thrusts (HMT) beneath the Hidaka Mountains. The number of newly established gravity stations amounts to more than 500, including 54 stations measured on the national route inside the tunnels. A new Bouguer anomaly map of the Hidaka Mountains was produced on the basis of these data and pre-existed data (Yamamoto et al., 2001a; Yamamoto, 2002c). An enlarged migrated depth section obtained from vibroseismic studies shows two listric-shaped reflectors, corresponding to HMT and the Hidaka Western Thrust (HWT), and a duplex structure between them. Arita et al. (1998) and Yamamoto et al. (2001a) inverted gravity data together with the results from seismic data and obtained a best fit model as a preliminary crustal structure across the southern part of the Hidaka Mountains. Synthetic gravity showed a good agreement with the observed one along the three profiles across the Hidaka Mountains. Consequently, they obtained the crustal model which well explains the observed gravity around HMT. Moreover, Yamamoto (2001) argued about the relationship between seismicity and Bouguer anomaly over the northern Hokkaido, where significant changes in geological and gravimetric features are observed across the northward extension of the Hidaka Collision Zone. He showed that low Bouguer regions well correlated with those of active seismicity (Yamamoto, 2001; Yamamoto, 2002b).

For the purpose of investigating the subsurface structure beneath the Horoman Peridotite Region (HPR), located in the southernmost part of the Hidaka Collision Zone, Yamamoto et al. (2001b) conducted gravity surveys around HPR and established more than 400 stations including 75 new data around HPR. A new Bouguer anomaly map revealed an excellent correlation between tectonic boundaries or known faults and Bouguer anomaly distributions, and also suggested that high gravity anomalies in the Horoman and Nikanbetsu Peridotite Complexes and their surroundings are intimately related to their surface geology. In addition, surficial density distributions were theoretically inverted by the ABIC (Akaike's Bayesian Information Criterion) method using newly obtained gravity data and the results suggested that the Horoman and Nikanbetsu Peridotite

Complexes have a significant density contrast of more than 1.0 g/㎤. They also obtained the crustal model which well explains the observed gravity along this profile. The obtained crustal model implies that the Horoman and Nikanbetsu Peridotite Complexes are directly linked together at depths of more than 1 km.

Geological Survey of Hokkaido (GSH) carried out gravity survey at 277 stations around the Hakodate-Heiya-Seien active fault zone (Tajika et al., 1999), the Hakodate Plain, southern Hokkaido. Tajika et al. (1999) estimated a two-dimensional subsurface structure along a profile across the fault. Density boundary was assumed along the boundary fault, which forms topographic boundary between the Kamiiso Mountain and the Hakodate Plain. They found that the Kamiiso Mountain thrusts up over the plain.

GSH carried out gravity survey at 103 stations with the fast static GPS positioning along four profiles across the Ishikari-Teichi-Toen active fault zone, the Ishikari Plain, central Hokkaido (Oka et al., 2001). In order to delineate the subsurface structure associated with the reverse faulting in Tobetsu active fault zone, central Hokkaido, GSH (Ohtsu et al., 2002) also carried out extensive gravity surveys. They made regional gravity measurements at 66 stations over the 13 km × 16 km area as well as a dense measurement along a profile across the Tobetsu Fault. GSH (Hokkaido Government, 2002) conducted more gravity surveys in the Tokachi-Heiya active fault zone, the Tokachi Plain, eastern Hokkaido. They carried out regional gravity measurements over the area of 6.5 km × 8 km and newly established 115 stations. Dense measurements were also done along the four profiles across the fault zone.

Shimane University made 134 gravity measurements around the Mashu Caldera in eastern Hokkaido. These data are not published yet.

5.6.3 Honshu Area

The GSJ conducted gravity surveys at Mt. Fuji from 1999 to 2002 at about 200 stations, and found two narrow high anomaly belts concerning dike structure. The GSJ carried out gravity surveys in the Fukui Plain from 2000 to 2002 for investigation of underground structure and active faults, so that total number of gravity measurement points amounted to 540. Electric Power Development Co., Ltd. carried out a sea bottom gravity survey in the Tsugaru Strait in 1998 for investigation of active faults, and obtained about 100 gravity data. They produced a detailed gravity map with compiling land, shipborne and sea bottom gravity data.

In order to evaluate capability of one dimensional micro-gravity investigations, Iwano et al. (2001) carried out two test surveys across the Katagihara Fault in the southwest of the Kyoto Basin and the Fumotomura Fault at the foothills of Suzuka Range, the faults in which seismic reflection survey had already been carried out. They conducted precise gravity measurements and leveling surveys at about a 50 meter interval, and applied terrain corrections using the 50 meter Digital Elevation Model (DEM) provided by the GSI and partially using a 10 meter DEM compiled by themselves. Consequently, they obtained Bouguer anomalies with 0.1 mgals level precisions for almost all the survey points. Because one dimensional gravity survey is quite easy to conduct with very low cost, they recommend that gravity surveys should be carried out whenever seismic reflection survey is conducted.

Kyoto City Office (1999) carried out gravity data analysis for the purpose of investigating subsurface structure in the Kyoto Basin by compiling existing 1,319 gravity data. Kyoto City Office (2001) also carried out gravity surveys in the basin and newly established 525 gravity points in a 20 km by 10 km area.

The National Research Institute for Earth Science and Disaster Prevention (NIED) conducted gravity survey in the area of the Atera Fault zone, Gifu Prefecture in the central part of Japan (Ikeda et al., 2001). Gravity structure was compared with the resistivity structure and the physical properties determined from the borehole logging data and core samples from six boreholes drilled around the Atera Fault. Gravity measurements have been conducted at 242 points and an existing data set of 250 points in the area of 12 km× 12 km was compiled for the analyses. A two-layer model is assumed in this study. Arrangement of the active faults agrees well with the linear low-gravity basement. The linear arrangement of the gravity low shows ``S'' shaped geometry. These fabrics are similar to the strain field in the shear zone. The gravity high between the ``S'' reflects the boundary of the segments in the fault system. This inhomogeneity of the gravity basement along the fault suggests the existence of a mechanical barrier in the fault system.

Three dimensional structural analysis based on 2,264 gravity data revealed that the buried graben under the Shinjiko-Nakaumi Lowland is more than -2,000 m in depth (Komuro et al., 2000b). This graben is segmented into the western and eastern parts by a central transfer zone. The graben seems to have been subsided asymmetrically because of a tilted floor rimmed by a steep one margin and a gentle opposite margin. The calculated basement depth is controlled by the data of three wells. The best fit value of the Bouguer density is 2.4 g/cm^3. A density contrast between the basement and graben fills is estimated as 0.4 g/cm^3, because they consist of Paleogene granite and Miocene sedimentary rocks, respectively.

The Pliocene Teragi Group, located astride the eastern edge of Tottori Prefecture and the northwestern edge of Hyogo Prefecture, about 25 km southeast of Tottori City, consists of volcanic rocks, pyroclastic flows and clastic sedimentary rocks. The main part of this group fills a volcanic collapse basin. Komuro et al. (2002) named this volcanic collapse structure the ``Teragi cauldron.'' They constructed a detailed map of Bouguer gravity anomaly on the basis of gravity data from 612 observation points and suggested that the low gravity anomaly over the Teragi Group is not a funnel-shaped, but a pan-shaped gravity depression. The outline of the Teragi cauldron is distorted hexagon which coincides roughly with the margins of the gravity depression. Accordingly, the low gravity anomaly represents the subsurface structure of the Teragi cauldron. Further, they showed that the mass deficiency estimated from Gauss' theorem is about 3.0×10^{13} kg. The relation between this value and the cauldron diameter is comparable with those of the Quaternary calderas elsewhere in Japan.

Besides the above measurements, Shimane University made gravity measurements around Hikimi area in western Shimane Prefecture (120 points), around the epicenter of the 2000 Tottori-ken Seibu Earthquake (176 points), and around the epicenter of the 1995 Hyogo-ken Nanbu Earthquake (373 points), respectively. These data are not published yet.

Geophysical surveys, such as gravity, artificial earthquake and microseisms, are carried out in the Ohmi Basin, east of Lake Biwa, to study its basement structure. It becomes possible to find trough-like structure corresponding to the route of Kobiwako (Old Lake Biwa) going north in Cenozoic Pliocene-Pleistocene and a partial structure of old caldera formed between the last part of Mesozoic and the beginning of Cenozoic era under the area (Nishimura et al., 2001).

ERI carried out gravity surveying along a profile of the reflection seismological prospecting in the northern part of the Itoigawa-Shizuoka Tectonic Line (ISTL) (Okubo et al., 2000). Combined use of gravity and seismic data enables them to construct a 2-D subsurface density model. They also present a 3-D model which is consistent with the previous works on gravity and reflection/refraction prospecting. Both 2-D and 3-D models show a reverse fault structure dipping toward the east. They do not find any thrusting structure dipping toward the west as implied from uplifting of the Hida range.

Satomura (1998) showed Bouguer gravity anomaly maps of four tectonic lakes (Lake Biwa, Lake Yogo and Tokusa Basin in Japan, and Dead Sea) and explained that gravity measurements are useful to investigate the subsurface structure beneath tectonic lakes.

Hagita et al. (2000) revealed subsurface structure of the Yoro Fault in the west of the Nohbi Plain, central Japan. They estimated the depth of the Yoro Fault to be about 2,000 m and the gradient of the fault plane to be over 60°.

Tono Research Institute of Earthquake Science (TRIES) carried out gravity surveys in order to delineate basement structures of active faults in Tono area, the southeastern part of Gifu Prefecture, and accumulated 1,300 stations since the commencement of gravity measurements in 1997. All of the data are included in the ``Gravity Database of Southwest Japan'' (Gravity Research Group in Southwest Japan, 2001a; Shichi and Yamamoto, 2001b). TRIES calculated the strong ground motion in Tono area based on basement structure inferred from gravity anomaly (Tono Research Institute of Earthquake Science, 1999). TRIES compiled the results of investigation of the Byobu-san Fault and described a few steep gravity gradients originated from the reverse faulting (Tono Research Institute of Earthquake Science, 2000). Tanaka et al. (2001a) revealed the precise basement structure in the overstep part of the Enasan Fault by use of microgravity method and tried to discuss the history of stress field. TRIES compiled the results of investigation of the Atera Fault and compared the precise gravity anomalies with geological maps and depth sections derived by seismic reflection method (Tono Research Institute of Earthquake Science, 2002). Moreover, Tanaka et al. (2002) gave a preliminary interpretation of the fracture zone along the Atera Fault.

The Regional Construction Bureau of the Lower Kiso-River of the Ministry of Land, Infrastructure and Transport (LKRMLIT) carried out microgravity survey entrusting to OYO Corporation (OYO) to detect an ancient deversoir of the Satsuma-Araizeki in the lower part of the Nagara-River, Gifu Prefecture (Regional Construction Bureau of the Lower Kiso-River of the Ministry of Land, Infrastructure and Transport, 1997). LKRMLIT established 250 stations in total over t methods. Results of borehole investigations showed that density of the sand layer of the peninsula is 1.9 g/cm^3. They also found a remarkable high gravity anomaly in the northern part of the peninsula, as well as a belt-like low anomaly zone around the Nakaumi are, the central part of the peninsula. Further, assuming a density contrast of 0.5 g/cm^3, they constructed a two-layer subsurface density model along a N-S profile, passing through the peninsula, across the low anomaly zone. Results indicated that the very shallow upper (sand) layer at the south end of the profile gradually deepens northward and reaches its maximum depth (900 m) around the Sakai Channel near the north end of the profile, where the upper layer shallows abruptly northward across the channel.

The 1943 Tottori Earthquake (M7.2) occurred in a shallow location on land, and its focal region was near the Tottori Plain. The damage was concentrated in the Tottori Plain where the soft ground is extensively distributed. For the purpose of investigating 2-D density structure beneath the focal area, gravity measurements were carried out around four regions, (1) at 197 points at 200-300 m intervals in central Tottori City, (2) at 192 points at 50-200 m intervals in the Yoshioka hot spring area, (3) at 43 points in the mountainous area surrounding the plain, and (4) at 296 points around the Yoshioka-Shikano Fault area and its peripheral mountains. These data were added to 417 gravity stations at 500 m interval (Nishida et al., 2001) for 2-D crustal modeling. They estimated average density of the basement layer to be 2.4 g/cm^3. In order to extract the features of short-wavelength components of Bouguer anomaly, they removed the gravitational effects due to subsurface materials deeper than 1 km. The filtered anomaly is characterized by a high and low anomaly pair near the coast and inland, respectively. They also inverted gravity data to obtain a density structure model across N-S and E-W profiles around the plain. The N-S profile ischaracterized by a sharp inlandward increase of thickness of the light sediments and its gradual decrease toward the center of the plain. Shallow sediments at the west end of the E-W profile keep constant thickness toward the center of the plain, and gradually increase their thickness eastward and take the maximum value around the east end of the profile.

5.6.4 Shikoku and Kyushu Area

In order to delineate basic feature of gravity anomalies inthe Kyushu area, the GSJ conducted gravity surveys at about 2,500 stations during the period from 1999 to 2001. For the purpose of improving station coverage of gravity data in a part of Chugoku and Shikoku district, the GSJ further obtained about 700 gravity data until March 2002.

For searching hot spring and geothermal resources in detail, the GSJ conducted gravity surveys at 310 gravity stations in Tashiro town, Kagoshima Prefecture, and at 220 gravity stations in Fukiage town, Kagoshima Prefecture.

Laboratory of Geothermics, Kyushu University carried out gravity surveys around two active fault zones (the Minou and Kego Faults) in north Kyushu to clarify the detailed fault structures and established new gravity stations that amounts to 1,256 from 1996 to 2001 (Kawaguchi et al., 1999; Nishijim surficial density of the Guntur Volcano was assumed to be 2.5 g/cm^3. Gravity anomaly increases near the central part of the surveyed area. The Guntur Volcano is enclosed by relatively low gravity anomaly area as if it looks like island in the crater lake.

As a part of the project of ``International Joint Research on Seismic Microzonation of Metro Manila'' between Kanto Gakuin University and the Philippine Institute of Volcanology and Seismology (PHIVOLCS) of the Philippines, Nagoya University and Aichi Institute of Technology conducted a dense gravity survey in the area of Metro Manila during the period from 1999 through 2001. In the surveyed area that includes the entire zone of the Metro Manila, about 28 km by 27 km (from 14° 30′ N through 14° 45′ N and from 120° 57′ E through 121° 12′ E), they obtained more than 850 precise gravity data. The average spacing between neighbouring stations was about 1 to 2 km. To perform terrain corrections precisely, a set of topographic mesh data with the KS-110 format by the GSI was created from 1/2,500 topographic maps provided by Japan International Cooperation Agency (JICA). By using precise gravity data thus produced, Yamazaki et al. (2001) revealed subsurface structure of the concerned area, with special reference to the Marikina Fault System. Apart from this Metro Manila area, Nagoya University made gravity measurements at 170 stations in and around the area of the Taal Volcano and the southern part of the Marikina Fault System, adjacent to the south of Metro Manila from 1999 to 2000.

The GSJ and PHIVOLCS conducted a gravity survey using differential GPS in order to verify whether Laguna de Bay is an assemblage of many calderas or it was a graben in 1999 and 2000 in and around Laguna de Bay, a lake located in the south of Manila metropolitan (Komazawa et al., 2000). The total number of measurement points amounted to 360, and 25 stations are taken at the cottage on the lake.

The GSJ conducted a gravity survey in the geothermal area, the central Flores Island, eastern Indonesia, in 1999 to 2001. The total number of measurement points amounted to about 800, and about 170 stations were taken at very short intervals, about 200 m, in the Mataloko geothermal area. The location and altitude were determined by differential GPS and the accuracy was within 1 m or better.

The GSJ conducted a gravity survey at the Vulcano Volcano and the Lipari Volcano, the Eolia Islands, southern Italy, in 2000 and 2001. The total number of measurement points amounted to about 510, and short station intervals were taken at about 200 m - 1 km. The surface density of the Vulcano Volcano was estimated to be about 1.8 g/cm^3, which is very small as compared with that of other volcanoes. DPRI and the GSJ conducted a gravity survey in the Lijiang Basin, which is located in the Yunnan province of China, in 1998 and 1999. A seismic refraction survey was performed at the same time. The total number of measurement points amounted to about 400, and about 70 stations were taken at the seismic refraction observation point. Topographically, the Lijiang Basin has a typical basin structure, but underground structure, i.e., thickness of sedimentary layer or the location of active fault which caused the 1996 Lijiang Earthquake, is less certain. To investigate the underground structure, a gravity survey was carried out in August 1998 together with a seismic refraction survey.

DPRI and the GSJ conducted a gravity survey in the Adapazari Basin, western Turkey, in 2000 and 2001 to study the cause of severe damage to Adapazari central city during the 1999 Kocaeli Earthquake. The total number of measurement points amounted to about 645. A 3-D bedrock-model was obtained from gravity analysis, and a possible cause of strong input-motions in the area was discussed.

The Research Group of Andes Science (Hokkaido University and University of Tokyo) collected all the data of gravity measurements carried out over the last 40 years by Instituto Geofisico del Peru (IGP). Because of the long time since data collection, some of the information needed for data reduction were lost over the years. Accordingly, there was a need for independently determined gravity stations to which the measurements done by IGP may be compared. In order to provide reference gravity values, they utilized Japanese survey data collected between 1980 and 1984, and conducted more surveys in various parts of Peru in the period between 1995 and 1998. These gravity stations number more than 800, and provide three or more reference points for each of the IGP survey routes. Using these references, the Research Group calculated the absolute gravity values for the IGP dataset and established more than 9,000 gravity stations over the Peruvian Andes (Fukao et al., 1999). Consequently, they produced a Bouguer anomaly map of whole Peru on the basis of these gravity data and pointed out the main features of the Bouguer anomaly map together with the reliability of the reduced data and all the procedures involved in the data reduction.

5.8. Marine Gravimetry

An ocean bottom gravimeter with acoustic release mechanism was developed for use with a submersible or stand-alone seafloor measurement under a joint research work between ERI and OceanResearch Institute (ORI), both in University of Tokyo (Fujimoto et al., 1998). Free gimbal suspensions with an oil damper mechanism keep a sensor package of Scintrex CG-3M/SB roughly vertical, and the effect of the remaining tilt is numerically corrected. Results of a sea trial on shallow seafloor for one day show that resolution of the gravimeter is about 10 μ gals. Gravity values measured during the transits from Tokyo to the seafloor agreed with those measured by LCR model-G gravimeter (G #124) within a few tens of μ gals. The drift rate was 0.34 mgals/day (Fujimoto et al., 1998).

An underwater gravimeter for use with a submersible or a large autonomous underwater vehicle (AUV) is under development (Fujimoto et al., 2000). It is designed that a platform controlled by a vertical gyroscope keeps a gravity sensor of Scintrex CG-3M/SB vertical. The system assumes fairly stable motion of an AUV or submersible, but it is rather difficult to attain such a condition during an actual experiment due to sea conditions and water currents.

The GSJ has conducted marine gravity surveys since 1974 as a part of the geological mapping program of continental margin around the Japanese Islands. The survey vessel ``Hakurei-maru (No. 2)" has been used since 2000 after the retirement of the 26-years-old ``Hakurei-maru (No. 1)." The cruises during the period from 1998 through 2001 are listed in Table 1. The gravity measurements were conducted using the same straight-line sea gravimeter, LCR SL-2, in all the cruises. Free-air and Bouguer anomaly maps were published as appendices of ``Marine Geology Map Series" at a scale of 1:200,000 (Geological Survey of Japan, 1999, 2000b, 2001).

Table 1.Cruises for marine gravimetry by the GSJ during the period from 1998 to 2001

CruiseID	Period	Survey Area
GH98	Jun. - Aug. 1998	Off Rumoi and Teshio (west of Hokkaido)
GH99	Jun. - Aug. 1999	West of Hokkaido
GH00	Aug. - Sep. 2000	Okhotsk Sea northeast of Hokkaido
GH01	Aug. - Sep. 2001	Okhotsk Sea northeast of Hokkaido

The JHD carried out marine gravity surveys using three survey vessels ``Shoyo" (3,128 gross tons), ``Takuyo" (2,600 gross tons) and ``Meiyo" (550 gross tons) during the period from 1998 to 2002. These vessels are equipped with the sea gravimeter Bodenseewerk KSS-31 or KSS-30. The cruises from April 1998 through March 2002 are listed in Tables 2, 3 and 4 (Hydrographic Department, 1999b, 2000b, 2001, 2002b).

Table 2.Cruises of “Shoyo" for sea gravity surveys conducted by the JHD during the period from April 1998 to March 2002

Cruise	Period	Survey Area
Sep.	1998	Around Myozin Syo
Oct.	1998	Japan Trench (Offing of Fukusima)
Feb. - Mar.	1999	Northern sea area off Minami-Tori Shima
Apr. - May	1999	Southern sea area off Ishigaki Shima
Jun.	1999	Around Myojin Sho
Jun. - Aug.	1999	Fukutoku Okanoba
Oct. - Nov.	1999	Japan Trench (Offing of Fukusima)
Jan.	2000	Southern sea area off Minami-Tori Shima
May - Jun.	2000	Southeastern sea area off Kyushu
Jun. - Jul.	2000	Western area off Miyake Jima
Oct. - Nov.	2000	Eastern part of the Southeastern sea area off Minami-Tori Shima
Feb.	2001	Western area off Miyake Jima
Feb. - Mar.	2001	Offing of the Southeastern sea area off Minami-Tori Shima
Jun. - Jul.	2001	Western part of Daito Ridge
Aug.	2001	Minami-Hiyoshi Kaizan
Sep.	2001	Western sea area off Mariana Trench
Oct. - Nov.	2001	Japan Trench (Offing of Fukusima)
Nov. - Dec.	2001	Eastern sea area off Mariana Trench

Table 3. Cruises of ``Takuyo" for sea gravity surveys conducted by the JHD during the period from April 1998 to March 2002

Cruise	Period	Survey Area
Jun.	1998	Minami-Tori Shima
Oct. - Nov.	1998	Eastern sea area off Minami-Tori Shima
Feb. - Mar.	1999	Southeastern sea area off Minami-Tori Shima
Jun.	1999	Northeastern sea area off Minami-Tori Shima
Oct.	1999	Northwestern sea area off Minami-Tori Shima
Nov. - Dec.	1999	Southwestern sea area off Minami-Tori Shima
Nov. - Dec.	1999	Easternmost part of Ogasawara Plateau
Jan. - Feb.	2000	Offing of the Southern sea area off Minami-Tori Shima
Apr. - May	2000	Southern sea area off Shatsky Rise
Jun.	2000	Offing of the Eastern sea area off Minami-Tori Shima
Jan. - Feb.	2001	Eastern part of the Offing of the Southern sea area off Minami-Tori Shima
Apr. - May	2001	Ogasawara Plateau
Apr. - May	2001	Southern sea area off Minami-Io Shima
May - Jun.	2001	Eastern part of Daito Ridge
Jan.	2002	Western part of the Offing of the Southern sea area off Minami-Tori Shima

Table 4. Cruises of ``Meiyo" for sea gravity surveys conducted by the JHD during the period from April 1998 to March 2002

Cruise	Period	Survey Area
Jul.	1998	Kii Suido
Jul.	1998	Western sea area off Danjo Basin
Nov.	1998	South eastern part of Izu Peninsula
Feb. - Mar.	2000	Bungo Suido
Jul. - Aug.	2000	Western area off Miyake Jima
Aug. - Sep.	2000	Offing of Simane
Oct.	2000	Western area off Miyake Jima
Aug.	2001	Offing of Simane

Satomura et al. (1999) and Segawa et al. (1999) carried out sea-surface gravity measurements as well as interferometry GPS measurements with three antennas on the Pacific Ocean, south off central Japan. Root Mean Square (RMS) of the gravity value based on interferometry GPS positioning was about 0.85 mgals at cross points, and it was much more precise than that based on single positioning, while precisions of three kinds of gravity values based on a single antenna position, center of the three antennas and gravity sensor position, were approximately equivalent.

5.9. Data Handling and Gravity/Geoid Maps

The GSJ published eight detailed complete Bouguer anomaly maps at a 1:200,000 scale, called ``Gravity Map Series." The eight maps cover the following eight areas: Obihiro District, Asahikawa District, Nemuro District, Kitami District, Nayoro District, Tenpoku District, Oita District and Fukuoka District, respectively. They were produced from about 80 thousands of data as part of the gravity mapping program of the JapaneseIslands (Hiroshima et al., 1999; Makino et al., 1999; Morijiri et al., 2000b; Murata et al., 2000, 2001; Hiroshima et al., 2001; Komazawa et al., 2001; Morijiri et al., 2002). The GSJ published nation-wide detailed complete Bouguer anomaly maps of 1:1,000,000 scale (Komazawa et al., 1999) and a CD-ROM, Japan Gravity CD-ROM (Geological Survey of Japan, 2000a). The 136,698 gravity data measured by three organizations, the GSJ, New Energy & Industrial Technology Development Organization, Japan (NEDO) and Metal Mining Agency of Japan (MMAJ), are also recorded on the CD-ROM.

Leni et al. (1998) and Leni and Fukuda (1999) derived an Indonesian marine gravity map using the GEOSAT (GEOdetic SATellite) Geodetic Mission (GM). Leni and Fukuda (2001) proposed a simulation technique to estimate influence of variation of SSH on accuracy of the satellite derived gravity map. This simulation is based on a distribution of SSH variability derived from Topex/Poseidon (T/P) data. They concluded that influence of the SSH variation on the gravity map around Indonesian waters was within the range of 0.8-93 mgals.

Terada et al. (2001) produced a new gravity anomaly map around Antarctica to derive detailed sea floor information from 10 Hz sampled GEOSAT GM data. They applied a combination of binarization, clustering and thinning techniques to the obtained gravity image, and revealed several lineaments located off the Gunnerus Ridge in the South Indian Ocean. In the middle of the lineaments they found a fossil ridge; the existence of which suggests that the direction of spreading changed during the early stage of sea floor spreading between Antarctica and India.

In March 2000, the GSI produced gravity anomaly anaglyphic maps of Japan in collaboration with Nagoya University, the GSJ, and Hokkaido University (Geographical Survey Institute, 2001). The gravity data were compiled by Nagoya University (about 108,000 sites), the GSI (about 14,000 sites), and the GSJ (about 228,000 grid points in the northern part of Japan). Complete Bouguer anomalies were computed with the following parameters: vertical gravity gradient of 0.3086 mgals/m (1 mgal = 3×10^{-5} m/sec^2) for free-air corrections, and nominal density of 2.67×10^3 kg/m^3 for the topographic masses in both Bouguer and terrain corrections. A digital elevation model on a grid of 7.5 arc-seconds in latitude by 11.25 arc-seconds in longitude, prepared by the GSI, was used for the terrain correction computation. The GSJ gridded the Bouguer anomalies on a 7.5 by 11.25 arc-second lattice. The geographical distribution of Bouguer anomalies in Japan was visualized in three anaglyphic stereograms, namely (a) Northern (b) Central (c) Western Japan. The following parameters were used:

Scale: 1:1,000,000,

Elevation angle: 2°,

Vertical intensification: 10 times,

Angle of incident ray of light: N55° W for (a), N45° W for (b),and N30° W for (c).

In April 2002, the GSI also published a map of the geoid model for Japan, called GSIGEO2000, at a scale of 1:6,000,000 by Mercator projection (Geographical Survey Institute, 2002). The geoid model and its development will be described in Chapter 11.

With regard to the gravity field modeling for Japan, Kuroishi (2001a) studied on the improvement of marine gravity data around Japan and the resulting gravity field model was used for the development of an improved gravimetric geoid model, JGEOID98 (ditto). Comparing the gravity field model with an altimetry-derived global marine gravity model, KMS98, Kuroishi (2000c) found the existence of systematic errors of the order of 10 mgals, southwest-off and northeast-off Hokkaido, in the gravity field model from marine data and tried to correct the errors by applying a cosine-tapered low-pass filter to the gravity differences between the two gravity field models. The correction significantly reduces the errors at long wavelengths, but worsens the resulting geoid model at short wavelengths in Suruga, Sagami, and Toyama Bays, which indicates the existence of errors of a few tens of mgals in KMS98. Kuroishi and Denker (2001) handled marine and altimetric gravity data to yield an improved gravity field model for Japan. Evaluations in terms of accuracy of the recovered geoid models show that a network adjustment of crossover errors in marine gravity data with a linear trend model in time on a per cruise basis is superior to that with a bias model on a per track (linear section in cruise measurements) basis, and that the de-trending (plane fitting of the gravity field model to the reference global geopotential model) effectively reduces the errors at long wavelengths.

The GSI published their point gravity data set obtained from the national first-order and second-order gravity surveys, in October 2000 on the web site of the GSI (http://vldb.gsi.go.jp/sokuchi/gravity/main.html). The data set contains gravity values in the Japan Gravity Standardization Net 1975 (JGSN75) for 112 first-order gravity stations from the first-order gravity survey, and for 13,475 points from the second-order gravity survey.

5.10.Gravity Data Analysis

Kuroishi (1998) evaluated errors of surface gravity at national benchmarks estimated from a Bouguer anomaly grid and their effects on determination of Helmert heights at the benchmarks. The results show that the Helmert heights can be estimated at a maximum error of 10 mm from the Bouguer anomaly grid. The method was employed to introduce Helmert (orthometric) heights as the national height system for the benchmarks in Japan, which was put in force on April 1, 2002.

Iwano and Fukuda (2000) studied accuracy of gravity terrain correction using the 50 m DEM published by the GSI. They prepared a 10 m DEM from 1/2,500 city planning maps and compared two Bouguer gravity anomalies obtained by using the 50 m DEM and the 10 m DEM, respectively. The result shows that about 0.2 mgals or a better terrain correction can be obtained by using the 50 m DEM in topographically flat area, although more detailed DEMs are required in mountain areas or to achieve an accuracy better than 0.1 mgals.

We require terrain corrections to evaluate complete Bouguer anomalies particularly for gravity measurements made in a rugged topography, where the magnitude of terrain corrections can be comparable to Bouguer anomalies. Yamamoto (2002a) gave a comprehensive description of a method to compute spherical terrain corrections for a gravity survey using the 50 m DEM provided by the GSI. Surface topography nearest to a gravity station is strictly approximated by truncated cones or cylindrically-truncated rectangular prisms for first nine square compartments of the 50 m DEM, while in the distant area from a gravity station topography is approximated by a standard right rectangular prism. Spherical terrain corrections are computed as a function of the radius (R) within which terrain effects are systematically estimated in order to clarify quantitatively to what spatial extent the terrain corrections should be made. The radial distance $R_{0.5}$ km at which the terrain correction takes a value 0.5 mgals smaller than that at $R_{0.5}$ + 10 km is a good index to investigate the spatial extent. The numerical results suggest that most of the gravity stations more than 3,000 m high take a value of 80～ 90 km for $R_{0.5}$ except for Mt. Fuji which takes $R_{0.5}$=120 km. Finally, Yamamoto (2002a) showed that the overall accuracy to compute spherical terrain corrections, using the 50 m DEM, for gravity stations in mountainous regions with rugged topography is remarkably good, on the order of 1～2 mgals, which may be better than that estimated by using the 250 m DEM.

Quantitative analysis of gravity anomalies relies heavily on the accuracy of Bouguer reduction density about which we need a priori information. An error of 0.1 g/cm^3 in the reduction density, corresponding to an error of nearly 0.42 mgals in Bouguer anomaly for every 100 m, is not a very large error in itself but an error of 0.1 g/cm^3 in the density may have a large effect on the interpretations of Bouguer anomalies. Yamamoto (1999) summarized and reviewed several methods, developed independently during the last sixty years, which furnish an optimum reduction density from surface gravity measurements. He also gave a theoretical overview of these methods, where mathematical expressions and their significance are extensively discussed.

Since 2001, NIED has been promoting a national project for earthquake disaster mitigation named he National Strong-Motion Mapping Project which will be lasted for four years. As one of the main parts of this project, NIED attempted to construct 3-D underground structures for strong ground motion prediction, covering nationwide 20 areas of main plains or basins that include urban areas where serious damages might be caused by potential great earthquakes (Fujiwara et al., 2001). In the course of constructing these structure models, existing gravity database such as one by the GSJ (Geological Survey of Japan, 2000a), which is given in a form of grids, is employed to complete the lack of existing seismic data such as refraction and reflection surveys, etc.

In the period from April 2001 to March 2002, NIED, under the assist by OYO Corporation (OYO) and Ohsaki Research Institute, Inc., constructed two 3-D structure models with the aid of gravity data provided by the GSJ (Geological Survey of Japan, 2000a). One of them is for the area along ISTL, where a 3-D and non-stratified multi-layer model with reverse faults was constructed on the basis of gravity data. Because of the complicated geology in this area, imaging of the model is based on interpolation of the results of 2-D gravity analyses. The other is for land and offshore area of Miyagi Prefecture, northeast Japan. For this area, a 3-D and stratified multi-layer model was constructed by utilizing the correlation between gravity and seismic data. For the purpose of earthquake disaster mitigation, these results were applied to strong ground motion prediction. Results of subsequent analyses will be published later.

The 1995 Hyogo-ken Nanbu Earthquake induced serious strong ground motions corresponding to seven of JMA (Japan Meteorological Agency) Seismic Intensity Scale in a restricted strip-like zone, called ``the Shinsai no obi (Strip of earthquake disaster)." After the earthquake, researchers pointed out that outbreak of the zone was induced as a result of the local site effect of geological structure around edge zone of the Osaka Bay sedimentary basin on seismic wave propagation. Also many researchers pointed out the importance of taking account the deep underground structure, i.e., the geological structure of basement rock down to several km from the ground surface and upper layers in the sedimentary basin into prediction of seismic ground motions, and the necessity of two or three dimensional response analysis on the seismic ground motions.

After the 1995 Hyogo-ken Nanbu Earthquake, the Japan Society of Engineering Geology (JSEG) and the Japan Geotechnical Consultant Association (JGCA) formed the Committee on Geotechnical Mapping of Underground Structures in Urban Areas for Earthquake Disaster Mitigation, and carried out practical researches cooperatively on dynamic properties of ground motion, earthquake disaster of artificial structures, etc. In the course of these researches, the JSEG and the JGCA investigated the deep underground structure in the Nohbi Plain based on the analyses of existing gravity data provided by Nagoya University, and inductively discussed the methodology to construct deep underground structures (Baba et al., 1999). The JSEG and the JGCA (Baba et al., 2001) carried out 2-D response analysis on the seismic ground motions based on the 3-D multi-layer underground model in the Nohbi Plain area as derived from gravity data analysis. Baba et al. (2000) also summarized the strategic methodology of constructing 3-D multi-layer geological structure of sedimentary basin for strong ground motion prediction that is based on the analyses of gravity anomaly distribution.

5.11.Theoretical Studies on Geoid and Gravity Field

In respect to the geoid modeling for Japan, Kuroishi (1999) studied effects of the bias fitting of a marine gravity field model to the reference global-geopotential-model-induced gravity field, and of the removal of the Stokes kernel approximation error associated with use of the single-band 2-D FFT method of spherical Stokes integration in a remove-restore manner. The fitting of -4.9 mgals yielded a reduction of tilt from 2.2 to 1.9 ppm, and of RMS errors from 23.6 cm down to 18.7 cm in short wavelength (after a tilted plane removal) over the Japanese Islands, in the resulting gravimetric geoid model with respect to the geoid undulations data from the national net of GPS at benchmarks. The kernel approximation results in geoid errors in a range of -25 cm to 15 cm with a 2-3 cm RMS.

Kuroishi (2001a) developed an improved gravimetric geoid model for Japan, JGEOID98 on a 3 by 3 arc-minute grid by the 1-D FFT method with Earth Gravity Model 96 (EGM96) as a foundation. The coverage expansion of marine data and their reprocessing with tighter criterion in the crossover adjustment improve the geoid model over the pre-existing model, JGEOID93: 29 % in short wavelength and tilt reduction from 2.1 to 1.4 ppm. Kuroishi (2001b) further developed the latest gravimetric geoid model for Japan, JGEOID2000 on a 1 by 1.5 arc-minute grid, with an intensive nclusion of dense land gravity data (as a result of the inclusion, total number of land gravity points eaches 244,569). The 1-D FFT method of spherical Stokes integration in a remove-restore manner as used with EGM96 as a foundation. De-trending of a marine gravity field model with respect to the EGM96 gravity field effectively reduces the errors of the gravity field/geoid models in long wavelength. Compared with the nationwide net of GPS at benchmarks, JGEOID2000 shows substantial improvements over previous gravimetric geoid models: a standard deviation about the mean differences is 21.4 cm, tilt is 0.40 ppm, and a post-fit RMS (after a tilted plane removal) is 14.3 cm.

Under a joint study between the GSI and Kyoto University,Kuroishi et al. (2002) developed a hybrid geoid model for Japan, GSIGEO2000, from JGEOID2000 and the geoid undulation data of the nationwide net of GPS at benchmarks. (Strictly, the model is a conversion surface from

GPS-derived ellipsoidal heights to orthometric heights, or a geocentric position model of the Japanese Vertical Datum, the Mean Sea Level of Tokyo Bay.) Least squares collocation method was applied to correct/fit JGEOID2000 to the geoid undulation data. The GPS/leveling data were re-analyzed, in advance, in terms of leveling-derived orthometric heights and GPS-derived ellipsoidal heights with tighter constraints to the permanent GPS array of Japan, GEONET (the GPS Earth Observation Network of the GSI) in ITRF94 (International Terrestrial Reference Frame 1994, epoch 1997.0) frame. The changes range from -14 to +22 cm with a 6.1-cm SD about the mean of 3.5 cm in ellipsoidal heights, from -41 to +30 cm with an 11.4-cm SD about the mean of -1.5 cm in orthometric heights, and from -30 to +58 cm with a 12.5-cm SD about the mean of 5.0 cm in geoid undulation. The model is, therefore, adapted to the newly adopted Japanese geodetic reference system, the Japanese Geodetic Datum 2000. Kuroishi et al. (2002) estimated the precision of GSIGEO2000 at 4 cm throughout the region. The GSI adopted it as the official model to be effective on April 1, 2002 and published a national geoid map (Geographical Survey Institute, 2002).

Kuroishi (2000a) evaluated the geocentric positions of the Japanese vertical datum with respect to the EGM96 geoid and found that the mean differences, in areas of about 1.5 by 1.5 arc-degree extent, between the datum and EGM96 geoid show geographically gradual variations of the peak to peak amplitude of about 50 cm. The errors are attributed to the errors of EGM96 at medium wavelengths over the Japanese Islands.

Kuroishi (2000b) discussed relation between the Helmert/Stokes' and Molodenskii's approaches. Under spherical assumption in the radial derivatives of the disturbing potential and consideration of Molodenskii series up to the first order term, Kuroishi (ditto) showed that the geoid height can be given by adding the indirect effect of the topographic masses condensed on the geoid surface with respect to the co-geoid height to, and by subtracting the indirect effect with respect to the height anomaly at the (normal) ellipsoid from, the height anomaly at the ellipsoid multiplied by the ratio of normal gravity at the telluroid to that at the ellipsoid.

Sun and Okubo (1998) presented a numerical formulation for computing elastic deformations caused by a dislocation on a finite plane in a spherically symmetric earth, based on their previous theoretical work. The formulation enables them to compute the displacement, potential and gravity changes due to an earthquake modeled as spatially distributed dislocations. As an application of the finite-fault dislocation theory, they made a case study of the theoretical and observed gravity changes. The computed results are in excellent agreement with the observed gravity changes during the earthquake. The gravity changes in the near field can reach some 100 μgals, which can be easily detected by any modern gravimeter. In the far field they are still significantly large: $|\delta g| > 10\,\mu$gals within the epicentral distance $\theta < 6^\circ$; $|\delta g| > 1\,\mu$gal within $\theta < 16^\circ$; $|\delta g| > 0.1\,\mu$gals within $\theta < 40^\circ$; and $|\delta g| > 0.01\,\mu$gals globally. They also calculated the geoid height changes caused by the 1964 Alaska Earthquake and by the same earthquake with revised parameters and an assumed barrier. They found that the earthquake should have caused geoid height changes as large as 1.5 cm.

For precise geoid determination, terrain correction is necessary and important. Sun and Sjöberg (2001) studied convergence and optimal truncation of binomial expansions used in isostatic compensations and terrain corrections. A binomial expansion is a powerful tool in geodetic research. It is often used in terrain correction and isostatic compensation. In this research, they investigated behavior, convergence and truncation of the binomial expansion. Through some theoretical and numerical results, they discussed relations of topographic height, spherical harmonic degree and binomial series term. According to the relation, they determined truncation number for reaching an accuracy of 1 %, which indicates how many terms (or power numbers of topography) should be used in practical calculations.

Sun (2001, 2002) further proposed a general formula for gravimetric terrain corrections using powers of topographic height. The application of Stokes' formula to create geoid undulations requires no masses outside the geoid. However, due to existence of the topography, terrain corrections must be applied in order to satisfy the theoretical requirement, and refine the geoid determination. A common way to deal with the topography is to expand the inverse of a spatial distance into spherical harmonics, which contain factors as functions of the mean radius of the earth and the topographic height. Then, the factors are expanded into a binomial series, since they can dramatically simplify formula derivations and numerical computations. In this research, he investigated terrain corrections while considering the topographic potential. By introducing auxiliary equations, he derived and presented a general formula for calculating the topographic potential, which is a function of the binomial term and is expressed in terms of powers of topographic height. This formula can be directly used for calculating the terrain effects in geoid determination and isostatic compensation, by truncating the series according to an accuracy requirement. It can also be used to estimate the effects of each individual power of the topographic height on terrain corrections.

Nozaki (1999) examined the gravitational behavior of a thin spherical cap of axial symmetry, which is one of the most fundamental elements of gravity correction. The derived formulae and their characteristics entirely revealed the gravitational behavior at points along the symmetry axis of a given spherical cap with a small thickness.

Nozaki (2001) presented a new formula of the generalized Bouguer anomaly using Prey reduction, which is reduced onto an arbitrary equi-potential surface. He introduced the following four variables: altitude of datum reduction level, geiod height, regional vertical gradient of gravity (VGG) anomaly, and truncation angle of the spherical-shell system of gravity correction. Compared with conventional schemes, the new formula has the advantage that a specific altitude can be determined in order to eliminate gravitational effects due to topographic undulation for any Bouguer density.

On the basis of this new formula of the generalized Bouguer anomaly, Nozaki and Iwamoto (2001) discussed the possibility of a new method to construct Bouguer anomaly distribution without gravitational effect due to topographic undulation. The method is intended to determine the Bouguer density and the regional VGG anomaly so as to satisfy the condition to eliminate the topographic gravitational effects. For this purpose, the authors introduced new concepts of ``the special datum level such that the value of the Bouguer anomaly becomes invariant for any Bouguer density" and ``the special datum levels such that the quantity of Bouguer and terrain corrections becomes zero for any Bouguer density." Based on the new concept of the generalized Bouguer anomalies with special datum levels, Nozaki and Iwamoto (2001) presented an approximate equation to be satisfied by Bouguer density and regional VGG anomaly. The authors also presented an explicit formula to estimate Bouguer density under the assumption that regional VGG anomaly is zero.

5.12. Space Gravimetry

5.12.1 Lunar and Planetary Gravimetry

To discuss the shapes of celestial bodies Yatabe (2000a) introduced the residual gravity field, which is defined as the acceleration field subtracted the self-gravitation. As an application of the formulation, he considered Mercury's shape and suggested that Mercury has an almost spherical shape. Next, Yatabe (2000b) discussed the lunar shape and the history using the Goddard Lunar Gravity Model 2 (GLGM-2) and the Goddard Lunar Topography Model 2B (GLTM-2B). There is a strong positive correlation between the residual gravity and the lunar geoid. From this correlation, he discussed the lunar rotational velocity and the distance from the Earth at that time of the lunar surface solidification. A correlation between the residual gravity and the topography has a regional difference. The correlation on the far side is strong. On the contrary, the correlation on the near side is weak. Yatabe (2000b) explained this difference as follows: When the magma ocean solidifies, the lunar topography must have an equilibrium shape fitting the residual gravity field at the time. After that, the mare formation erases the topography affected by the residual gravity on the near side. Moreover, from the correlation on the far side, it is inferred that the Moon is synchronously rotating when the lunar surface is covered by the magma ocean.

In the SELENE (SELenological and ENgineering Explorer) project which is Japanese lunar program to be launched in 2005 by the Institute of Space and Astronautical Science (ISAS) and National Space Development Agency of Japan (NASDA), RISE (Research In SElenodesy) group in National Astronomical Observatory, Mizusawa (NAOM), NASDA, Kyushu University and other institution proposed to measure angular distance between a radio transmitter on a relay satellite, that on the Moon and quasars by differential VLBI and determine amplitudes of the physical librations,

gravitational harmonic coefficients of the Moon and lunar ephemeris with an accuracy of one or two orders higher than before in cooperation with 4-way Doppler measurements and two-way Doppler and ranging measurements by using the lunar orbiter and the relay satellite
(Iwata et al., 1998, 1999; Kawano et al., 1998a, b, 2000a, b, 2001; Hanada, 1999; Hanada et al., 1999, 2000; Namiki et al., 1999).

RISE group developed a special recording system for the differential VLBI Observation (Hanada et al., 1998; Kono et al., 1998), developed a thermal insulating system for the radio source on the Moon (Tsuruta et al., 1998, 1999, 2000a, b), developed sub-satellites for Doppler and VLBI observations (Iwata et al., 2000a, b, 2001, 2002), developed data reduction system and observation system (Ishikawa et al., 2001; Tsuruta et al., 2001 Hanada et al., 2002) and made a preliminary VLBI observations of Lunar Prospector (Kono et al, 2000a, b, 2002) in order to proceed the RISE project.

RISE group also examined possible effects of spin, antenna pattern and inclination of the sub-satellites upon Doppler measurements in order to improve Lunar Gravity models (Kono et al., 2000c, 2001; Ping et al., 2000a, b, 2001a, b; Kikuchi et al., 2001).

As theoretical problems, Ooe and Matsumoto (2001) estimated effects of lunar tides on lunar orbiters, Hanada (1998) showed that gravity observations in SELENE can put a constraint upon the density of the lunar core, and Matsumoto et al. (2002) showed that planned satellites configuration will improve lunar gravity field in wide range of wavelength as well as far-side selenoid by numerical simulation.

Kawano et al. (1999a, b) proposed a new method named inverse VLBI method which is able to detect not only rotation and deformation of the Moon but also those of other planets with almost the same accuracy as that of VLBI applications on the Earth, and Hanada et al. (2001) investigated if there are interesting phenomena related to the rotation or the deformation on the planets and estimated how accurately we can measure such phenomena by the inverse VLBI method.

Lunar gravity field has been measured only in the line-of-sight directions using the two-way Doppler method. Heki et al. (1999) showed that combination with differential very-long-baseline-interferometry enables measurements of the components perpendicular to the line-of-sight direction. Because the orbital motion and the spin of the Moon are synchronous, we can measure its gravity field only at its nearside. Matsumoto et al. (1999) showed that the four-way Doppler measurement of a lunar orbiter via a relay satellite makes it possible to measure the farside gravity field directly. Such observations are planned in the SELENE project.Namiki et al. (1999) summarized the general description of the three geodetic missions in the SELENE project, i.e., VRAD (VLBI RADio Transmitter) / RSAT (Relay SATellite) for lunar gravimetry and LALT (Laser ALTimetry) for lunar topography measurements.

5.12.2 Satellite Gravity Missions

Characteristics of the ocean response to the atmospheric surface pressure variations are essentially unknown, even though it is important for many studies such as precise gravimetry, satellite altimetry, crustal deformation, the Earth rotation and so on. Foldvary and Fukuda (2001a) proposed several ocean response models, i.e., IB (Inverted Barometer), NIB (Non-Inverted Barometer), and intermediate ones, and calculated their effects on gravity variations. They showed that resulting degree power differences of the gravity fields variations are distinguishable by expected GRACE (Gravity Research and Climate Experiment) mission data.

Foldvary and Fukuda (2001b) tried to model geoid heights changes caused by the hydrosphere and the atmosphere, and composed them to simulate the measurable signals by GRACE. Then, they decomposed the signals by considering, (1) different ocean responses to atmospheric pressure changes, and (2) different time-frequencies of the variations of the hydrospheric contributors. These tests prove that an appropriate assumption for the ocean response is important to minimize decomposition errors.

Recent progress of precise gravity measurements using superconducting gravimeters (SG) and/or absolute gravimeters (AG) enables us to study the very weak signals (less than a few μ gals in amplitude) of long-term gravity changes due to polar motion effects, post-glacial rebounds, crustal movements, sea level changes, and other various phenomena. Fukuda and Foldvary (2001) proposed a practical method and discuss some problems related to corrections for the gravity effects of fluid envelope of the Earth, using coming satellite gravity mission data. Further, they concluded that the coefficients obtained by the satellite gravity mission data could be used for the correction of the gravity changes due to the global mass redistribution.

5.13.Superconducting Gravimetry

Routine observations of gravity changes have been performed in Kyoto (Japan) and in Bandung (Indonesia) by employing SGs. Takemoto et al. (1998a) reported the first results of the precise gravity observation in Bandung where only one station exists near the equator. They revealed that the noise level in Bandung is relatively smaller than that in Kyoto.

Takemoto et al. (1998b) reported the precise observation of two SGs during the period from 1988 to 1997 in Kyoto. Sun et al. (2001) studied precise tidal gravity recorded with three SGs at stations Wuhan (China) and Kyoto (Japan). They clarified that the precision of the main tidal amplitudes is at the same level of 0.01 μ gals. They also found that the oceanic tide models developed by the analysis of measurements from T/P altimeters have the best fit to the SG measurements.

Mukai et al. (2001) clarified characteristics of phase lags of oceanic loading tides using two SGs data in Kyoto and Bandung. The observed phase has a deviation about 10 degrees from the predicted phase in major parts of tidal constituents, though phase lag due to viscosity in the Earth is expected to be 0.1 degree or less.

Ogasawara et al. (2001) carried out simultaneous observations with SG and absolute gravimeter FG5 to determine the calibration factor of the SG in Kyoto. The precision of calibration factor could not reach 0.1 % with less than one week data sets because of environmental noise such as urban noise, meteorological disturbances and regional earthquakes. They showed that at least one month observations would be necessary to achieve the accuracy of 0.1 % from simultaneous observations of SG and AG. They also showed that the gravity values obtained at Kyoto C are apparently decreasing at a rate about 3 μ gals/year. It is not sure the cause of gravity decreasing at present time.

Imanishi and Segawa (1998) summarized the six years observations of gravity at the Kakioka station with a superconducting gravimeter TT70 #11. Parameters of the free core nutation were estimated based on the tidal analysis results, but they were strongly dependent on the corrections of minor oceanic tides. The residual gravity data showed correlation with polar motion and local rainfall. The gravimeter was moved to a new station Matsushiro in 1995.

Imanishi (2000) reported the status of the superconducting gravimeter observation at the Matsushiro station. He found that instrumental drift of the gravimeter is well modeled by a very slowly decaying exponential function of time, with the current rate of about 20 μ gals per year. There was a strong correlation between the local rainfall and the gravity changes. Unlike most other gravity stations, gravity decreases after rainfall at Matsushiro. Since the gravimeter is located inside a tunnel, Newtonian attraction from the mass of water above the gravimeter horizon may be responsible for this correlation. Finally, a gravimetric factor of 1.22 ± 0.03 was obtained for the polar motion effect from the analysis of the residual series.

Imanishi (1999) and Imanishi (2001) reported development of a high-rate and high-resolution data acquisition system and its application to superconducting gravimetry. This system is based on a real-time computer operating system called RT-Linux. Combining a real-time clock module synchronized to an external GPS clock and the GPIB (General Purpose Interface Bus) interface board, th n tComa sites: from the north, Ny-Alesund (78.9° N) in Arctic, Esashi (39.1° N), Matsushiro (36.5° N) and Kyoto (35.0° N) in Japan, Bandung (6.8° S) in Indonesia, Canberra (35.3° S) in Australia, and Syowa Station (69.0° S) in Antarctica. An advantageous point of this network is its longitudinal distribution of the observation sites on the earth. This is an important point to study many gravity signals such as those due to the Earth's free oscillations, earth tides and the effect of the polar motion, which essentially imply a latitude dependency in their amplitude and phase.

Many studies were carried out using the SG data over the period from 20 seconds to 1.4 years or longer. For the seismic normal mode, Nawa et al. (1998) had an important discovery from analysis of the SG data at Syowa Station, i.e., an incessant excitation of the Earth's free oscillations, recently called ``Earth's background free oscillations." Since then, many researchers confirmed the existence of this oscillation not only from analyzing SG data, but also from analyzing the data observed by long-period seismometer networks. Nawa et al. (2000) analyzed SG data obtained from several sites of the GGP network to examine the spatial characteristics in seasonal variations of the background free oscillations.

The data obtained from SG networks can be used for a comparison with those obtained from satellite gravity missions. Related to this, Fukuda et al. (1999a) studied the effect of SSH variations on the gravity measurements from the space. One hand, Fukuda (1998) and Sato et al. (2001b) studied its effect on the gravity measurements made on the ground. From the analysis of the SG data of Esashi, Canberra and Syowa, Sato et al. (2001a) showed that the observed annual signals are well recovered from the sum of four effects of the solid and ocean tides, the polar motion and the SSH variations, and their results suggest importance of the SSH variations to explain the observed gravity changes. There is a possibility that the SG at Bandung detects an ocean oscillation related to ENSO like motion in the Pacific Ocean. Steric changes in SSH variations should be corrected when one estimates their effect on gravity measurement, however, this is not easy to do correctly, because of the complex ocean motions that are two mixed effects of the baroclinic and barotropic modes. Related to this, it is also important to know the frequency characteristics in the ocean response to sea surface pressure changes (Foldvary and Fukuda, 2001a). In order to study these problems, a Japanese group started a project in 2001 to compare the SG data with the T/P satellite altimeter and ocean bottom pressure gauges set at the three cross over points of T/P in off Sanriku of the north-west Pacific Ocean.

To make precise ocean tide correction to the recent high precision gravity and displacement measurements, Matsumoto et al. (2001) developed a new computer code called ``GOTIC2". In this code, the ocean tide models developed by Matsumoto et al. (2000) and Takanezawa et al. (2001) are used for the short-period and for the long-period, respectively. GOTIC2 can also treat other tidal components such as the tilts, strains and deflections of vertical. Many studies related to the calibration of SGs and instrumentation and the environmental effects on gravity observations have been carried out (for example, Sun et al., 2000; Imanishi, 2001; Mukai et al., 2001; Ogasawara et al., 2001; Sato et al., 2001a, b).

During the period of 1998-2001, GGP-Japan group coordinated a meeting called GGP Workshop at the frequency of once or twice a year to discuss the topics mentioned above and related. Papers presented at the meetings were published in the volumes 8 to 10 of ``Proceedings of Workshop on SG" and in ``Proceedings of Workshop on Geodesy in Antarctica expected from the New Satellite Gravity Missions and the Ground Base Observations", printed in March 2001 by National Institute of Polar Researches. Many papers related to the SG observation were presented at the 14th International Symposium on Earth Tide held in Mizusawa in 2000, and they were published in Vol. 47 No.1 of Journal of the Geodetic Society of Japan.

5.14.Air-Borne Gravimetry

1998 was the year when the first comprehensive experiment for air gravimetry started in Japan, though some similar attempts had been made since 1980's. The School of Marine Science and Technology, Tokai University, manufactured a new air gravimeter for helicopter use with the aid of a special support from NEDO. The project of helicopter-borne gravimetry is the result of co-operation of three GO (Governmental Organization) and NGO (Non-Governmental Organization) organizations, i.e., the GSJ, Aero Asahi Corporation and Tokai University (Segawa et al., 2000a). A new air gravimeter for helicopter use employs a servo accelerometer for gravity sensor and an optical fiber gyro for level. In the first stage of experimental measurements they met with numbers of problems as to mechanical vibration of helicopter and stabilization of flight. They mostly used the Bell 412 model helicopter and made measurements at altitude of about 610 m with a speed of 90 knots. After several technical improvements including the correction for horizontal acceleration they could attain to an accuracy of approximately 1 mgal by the test made in 2000, so that they proceeded to practical measurement in the following stages (Segawa et al., 2000b, 2001a, b).

The objectives in practical air gravimetry are to investigate detailed gravity anomaly structures in land-to-sea bordered areas as well as sea floor surrounded by volcanic islands. In tectonically active zones such as the Japanese Islands, land-to-sea bordered areas are usually cut by conspicuous active faults which cause significant earthquakes. Altho

In the following are listed the areas where gravity were measured by helicopter gravity measuring system in the period from 1998 to 2002.

(1) Saitama, Ibaraki and Offshore Kashimanada
(2) The Suruga Bay
(3) Tokai Coastal Zone from Omaezaki Pt. to Atsumi Pt.

Bibliography

Arita, K., T. Ikawa, T. Ito, Y. Nishida, A. Yamamoto, H. Satoh, M. Saito, G. Kimura, T. Watanabe, T. Ikawa and T. Kuroda (1998): Crustal Structure and Tectonics of the Hidaka Collision Zone, Hokkaido (Japan), Revealed by Vibroseis Seismic Reflection, Magnetotelluric and Gravity Surveys, Tectonophysics, 290, 197-210.

Asaka City Office (1998): Geophysical Exploration of the Hiiragizuka-Kofun, an Ancient Mound, Saitama Prefecture, Special Issue, November 1998. (in Japanese)

Baba, K., H. Matsuzawa, K. Yasue and K. Nozaki (1999): Tasks and Prospects on Constructing Underground Models for Earthquake Disaster Mitigation in Urban Areas, Special Issue, Symposium on Mapping Underground Structures in Urban Areas for Earthquake Disaster Mitigation - Earthquake Disaster Mitigation and Deep Underground Structure - (Chapter 5, 85-115), January 1999, Edition by the Committee on Mapping Underground Structures in Urban Areas for Earthquake Disaster Mitigation (Japan Society of Engineering Geology, JSEG and Japan Geotechnical Consultant Association, JGCA), Publication by JGCA, 150p.

Baba, K., H. Matsuzawa, K. Nozaki, K. Hayashi and K. Yasue (2000): Approximate Estimation of Three Dimensional Multi-Layers Geological Structure of Sedimentary Basin for Seismic Disaster Prevention Based on Analysis of Gravity Anomaly – Its Application to the Nohbi Plain Area -, OYO Technical Report 2000, No. 20, 1-41. (in Japanese with English abstract)

Baba, K., H. Matsuzawa, K. Yasue, K. Nozaki and S. Higashi (2001): 2-D Response Analysis on the Seismic Ground Motions Based on the 3-D Multi-Layer Underground Model in the Nohbi Plain Area Derived from Gravity Data Analysis, Special Issue (Final Report), Symposium on the Improvement of Underground Structure Models in Urban Areas for Earthquake Disaster Mitigation (Chapter 3, 49-67), March 2001, Edition and Publication by the Committee on Mapping Underground Structures in Urban Areas for Earthquake Disaster Mitigation (Japan Society of Engineering Geology, JSEG and Japan Geotechnical Consultant Association, JGCA), 127p.

Chiba City Office (2001): Geophysical Exploration of the Daikakujiyama-Kofun, an Ancient Mound in Chiba City, Chiba, Special Issue, February 2001. (in Japanese)

Committee of Education of Yasu-Cho Town Office, Shiga Prefecture (2001): Geophysical Exploration of the Otsukayama-Kofun, an Ancient Mound, Shiga Prefecture, Special Issue, December 2001. (in Japanese)

Crossley, D., J. Hinderer, G. Casula, O. Francice, H. -T. Hsu, Y. Imanishi, G. Jenzch, J. Kaariainen, J. Merriam, B. Meurers, J. Neumeyer, B. Richter, K. Shibuya, T. Sato and T. van Dam (1999): Network of Superconducting Gravimeters Benefits a Number of Disciplines, EOS, Transaction American Geophysical Union, 80, 11, 125-126.

Ehara, S., Y. Fujimitsu, J. Nishijima, T. Motoyama, N. Shimosako and Y. Nakano (1998): Reservoir Monitoring by Repeat Gravity Measurements at Some Geothermal Fields in Kyushu, Japan, Geothermal Resources Council Transactions, 22, 153-158.

Ehara, S., Y. Fujimitsu, J. Nishijima, T. Motoyama, N. Shimosako, Y. Nakano and K. Yoneshige (1999): Macroscopic Monitoring of Underground Fluid Flow by Repeat Gravity Measurements, Proc. Workshop on Rock Hydraulics, 41-46. (in Japanese)

Ehara, S., Y. Fujimitsu, J. Nishijima, A. Ono and Y. Nakanao (2000a): Heat and Mass Transfer Processes After 1995 Phreatic Eruption of Kuju Volcano, Central Kyushu, Japan, Proc. World Geothermal Congress 2000, 3683-3687.

Ehara, S., Y. Fujimitsu, J. Nishijim

Fukao, Y., M. Kono, A. Yamamoto, M. Saito, K. Nawa and C. Perales (1999): Gravity Measurements and Data Reduction for Bouguer Anomaly Map of Peru, Bull. Earthq. Res. Inst., Univ. Tokyo, 74, 161-266.

Fukuda, Y. (1998): Application of Precise Altimetry to the Study of the Earth's Gravity Field in the Western Pacific Region and the Dynamics of the Earth, AVISO News Letter, 6, 48.

Fukuda, Y., T. Sato and Y. Aoyama (1999a): The Effects of Sea-Surface Height Variations on the Long-Period Gravity Changes - Results of EOF Analysis -, Proc. Symp. on Studies of Ocean and Solid Earth Dynamics Using Satellite Altimetry Data, November 12-13, 1998, 125-133.

Fukuda, Y., T. Sato, Y. Tamura and Y. Aoyama (1999b): The Effects of Sea-Surface Height Variations on the Long-Period Gravity Changes, Bollettino di Geofisica Teorica ed Applicata, 40, 511-517.

Fukuda, Y. and L. Foldvary (2001): Environmental Corrections for the Precise Gravity Observations by Means of Satellite Gravity Data, J. Geod. Soc. Japan, 47, 679-685. (in Japanese)

Furuya, M., Y. Ohki, S. Okubo, T. Maekawa, H. Ohshima and H. Shimizu (2001a): Urgent Gravity Measurements for the Eruption of Usu Volcano in 2000 - Construction of Absolute Gravity Network and the Co-Eruptive and Post-Eruptive Gravity Changes, Bull. Earthq. Res. Inst., Univ. Tokyo, 76, 2, 237-246. (in Japanese with English abstract)

Furuya, M., S. Okubo, Y. Tanaka, W. Sun, H. Watanabe, J. Oikawa and T. Maekawa (2001b): Caldera Formation Process during the Miyakejima 2000 Volcanic Activity Detected by Spatio-Temporal Gravity Changes, J. Geography, 110, 2, 217-225. (in Japanese with English abstract)

Furuya, M., S. Okubo, W. Sun, Y. Tanaka, J. Oikawa, H. Watanabe, and T. Maekawa (2002): Spatio-Temporal Gravity Changes at Miyakejima Volcano, Japan: Caldera Collapse, Explosive Eruptions and Magma Movement, J. Geophys. Res., in press.

Geographical Survey Institute (2001): Gravity Anomaly Relief Map of Japan, Technical Report of the Geographical Survey Institute, B1-No. 28, Geogr. Surv. Inst., March 2001.

Geographical Survey Institute (2002): Japanese Geoid Model, GSIGEO2000, Technical Report of the Geographical Survey Institute, B1-No. 36, Geogr. Surv. Inst., April 2002.

Geological Survey of Japan (1999): Geological Map of Suruga Bay, 1:200,000, Marine Geological Map Ser., 52.

Geological Survey of Japan (2000a): Gravity CD-ROM of Japan, Digital Geoscience Map P-2, Geological Survey of Japan.

Geological Survey of Japan (2000b): Geological Map of Offshore of Gentatsu-Se, 1:200,000, Marine Geological Map Ser., 50.

Geological Survey of Japan (2001): Geological Map of off Shioya Saki, 1:200,000, Marine Geological Map Ser., 55.

Geological Survey of Japan and Korea Institute of Geology, Mining and Materials (2001): Gravity

Anomaly Map (Bouguer Anomaly Map), Geoscientific Maps of Southern Part of Korea, Western Part of Japan and Their Adjoining Seas, No. 3.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001a): List of Gravity Data Measured by the Organizations other than Nagoya University, Bull. Nagoya University Museum, Special Rept., No. 9, Part-II, 1-279.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001b): Gravity Anomaly Map of Southwest Japan (1) by Gravity Research Group in Southwest Japan (A0-Size, 1:700,000 Scale Map), Bull. Nagoya University Museum, Special Rept., No. 9, Appended Map.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001c): Gravity Anomaly Map of Southwest Japan (2) by Gravity Research Group in Southwest Japan (A0-Size, 1:700,000 Scale Map), Bull. Nagoya University Museum, Special Rept., No. 9, Appended Map.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001d): Gravity Anomaly Map in and around the Focal Area of 1995 Southern Hyogo Prefecture Earthquake by Gravity Research Group in Southwest Japan (B2-Size, 1:250,000 Scale Map), Bull. Nagoya University Museum, Special Rept., No. 9, Appended Map.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001e): Gravity Anomaly Relief Map of Southwest Japan (1) by Gravity Research Group in Southwest Japan (A1-Size, 1:2,700,000 Scale Map), Bull. Nagoya University Museum, Special Rept., No. 9, Appended Map.

Gravity Research Group in Southwest Japan (Representatives: Shichi, R. and A. Yamamoto) (2001f): Gravity Anomaly Relief Map of Southwest Japan (2) by Gravity Research Group in Southwest Japan (A1-Size, 1:2,700,000 Scale Map), Bull. Nagoya University Museum, Special Rept., No. 9, Appended Map.

Hagita, N., M. Adachi and R. Shichi (2000): Subsurface Structure of the Yoro Fault and Its Environs in Central Japan as Inferred from Gravity Anomaly, Bull. Nagoya University Museum, No. 16, 43-89. (in Japanese)

Hanada, H. (1998): Constraint on Density of Lunar Core by Observation of Gravity Potential, J. Jap. Soc. Planet. Sci., 7, 229-232. (in Japanese)

Hanada, H., N. Kawano, S. Tsuruta, H. Araki and Y. Kono (1998): Examination of Receiving System for Differential VLBI of Radio Sources on and around the Moon, Proc. Dev. On Board Instruments, 11, 23-29. (in Japanese)

Hanada, H. (1999): Science in RISE Related to VERA, Proc. VERA Symp. 1999, 167-172. (in Japanese)

Hanada, H., T. Iwata, N. Kawano, K. Heki, S. Tsuruta, T. Ishikawa, H. Araki, K. Matsumoto, Y.

Kono, Y. Kaneko, M. Ogawa, Y. Iijima, Y. Koyama, M. Hosokawa, T. Miyazaki, N. Namiki, A. Sengoku, Y. Fukuzaki, T. Ikeda, F. Fuke and RISE Group (1999): Observation System of Radio Sources on the Moon by VLBI in SELENE Project, Proc. Int. Workshop on Geodetic Measurements by the Collocation of Space Techniques on Earth (GEMSTONE) (January 25-28, 1999, Koganei), 126-130.

Hanada, H., K. Heki, N. Kawano, M. Ooe, T. Tsubokawa, S. Tsuruta, T. Ishikawa, H. Araki, K. Matsumoto, T. Takanezawa, Y. Kono, H. Karoji, T. Iwata, Y. Kaneko and T. Yokoyama (2000): Advanced Observations of Lunar Physical Librations and Gravitational Fields in Japanese Lunar Missions in the Near Future, ASP Conference Series, 208, 623-630.

Hanada, H., N. Kawano, M. Hosokawa and M. Imae (2001): Possibility of Observations of Rotational Fluctuations and Tidal Deformations of Planets by the Inverse VLBI Method, J. Geod. Soc. Japan, 47, 521-527.

Hanada, H., T. Iwata, Y. Kono, K. Matsumoto, S. Tsuruta, T. Ishikawa, K. Asari, J. Ping, K. Heki and N. Kawano (2002): VRAD Mission; Precise Observation of Sub-Satellites in SELENE with International VLBI Network, 2nd IVS General Meeting, 2002, 2.

Heki, K., K. Matsumoto and R. Floberghagen (1999): Three-Dimensional Tracking of a Lunar Satellite with Differential Very-Long-Baseline-Interferometry, Adv. Space Res., 23, 1821-1824.

Higashi, T., Y. Fukuda and S. Takemoto (2001a): Detection of Plate Motions by Absolute Gravimeters, IAG 2001 Scientific Assembly, Budapest, Hungary, 2001, Proc., 154BD, (CD-ROM).

Higashi, T., M. Kanao and H. Motoyama (2001b): Gravity and GPS Observations in the Inland, Antarctica, IAG Symposia, 123, Gravity, Geoid and Geodynamics 2000, 387-390.

Higashi, T., M. Kanao, H. Motoyama and T. Yamanouchi (2001c): Gravity Observations along the Traverse Routes from Syowa Station to Dome Fuji Station, East Antarctica, Polar Geoscience, 14, 226-234.

Hiroshima, T., R. Morijiri, M. Komazawa, M. Makino and Y. Murata (1999): Gravity Map of Obihiro District (Bouguer Anomalies), Gravity Map Ser., 11, Geological Survey of Japan.

Hiroshima, T., R. Morijiri, M. Komazawa, M. Makino, Y. Murata and K. Nawa (2001): Gravity Map of Oita District (Bouguer Anomalies), Gravity Map Ser., 17, Geological Survey of Japan.

Hokkaido Government (2002): A Report on the Survey for the Tokachi-Heiya Fault Zone and Tobetsu Fault, Hokkaido, Japan, Special Issue, March 2002, 192p. (in Japanese)

Hunt,T., M. Sugihara, T. Sato, and T. Takemura (2002): Measurements and use of the vertical gravity gradient in correcting repeat microgravity measurements for the effects of ground subsidence in geothermal systems, Geothermics, 31, 525-543.

Hydrographic Department (1999a): Gravity Measurements on Land, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 33.

(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (1999b): Gravity Survey at Sea in 1998, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 33.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (2000a): Gravity Measurements on Land, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 34.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (2000b): Gravity Survey at Sea in 1999, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 34.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (2001): Gravity Survey at Sea in 2000, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 35.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (2002a): Gravity Measurements on Land, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 36.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic Department (2002b): Gravity Survey at Sea in 2001, Data Rep. of Hydrogr. Obs., Series of Astronomy and Geodesy, 36.
(http://www1.kaiho.mlit.go.jp/jhd-E.html)
Hydrographic and Oceanographic Department (2002b): Gravity Survey at Sea in 2001, Data Rep. of Hydrogr. Obs., Ser. Astronomy and Geodesy, 36.
Ikeda, R., K. Omura, T. Matsuda, Y. Mizuochi, D. Uehara, A. Chiba, A. Kikuchi and S. Yamamoto (2001): Central Japan's Atera Active Fault's Wide-Fractured Zone: An Examination of the Structure and in-situ Crustal Stress, EOS, Transaction American Geophysical Union, 82, 47, F1229.
Imanishi, Y. and J. Segawa (1998): Earth Tides and Residuals Observed by a Superconducting Gravimeter at Kakioka, Japan, in Proc. 13th Int. Symp. on Earth Tides, Ducarme, B. and P. Paquet (Eds.), 575-582.
Imanishi, Y. (1999): Development of a High-Rate Data Acquisition System Based on a Real-Time Operating System, J. Geod. Soc. Japan, 45, 43-54.
Imanishi, Y. (2000): Present Status of SG T011 at Matsushiro, Japan, Proc. Workshop: High Precision Gravity Measurements with Application to Geodynamics and Second GGP Workshop, Cahiers du Centre Européen de Géo-dynami-que et de Séismologie, Ducarme, B. and J. Barthelemy (Eds.), 17, 97-102.
Imanishi, Y. (2001): Development of a High-Rate and High-Resolution Data Acquisition System Based on a Real-Time Operating System, J. Geod. Soc. Japan, 47, 52-57.

Ishikawa, T., H. Hanada, K. Heki, K. Matsumoto, Y. Kono, H. Araki, M. Ogawa and T. Iwata (2001): Summary of Data Reduction in RISE Project, Proc. 21st Symp. on Technologies in Astronomy, 31-36. (in Japanese)

Iwano, S. and Y. Fukuda (2000): On the Accuracy of Terrain Correction Using a Fine Scale Digital Elevation Model, J. Geod. Soc. Japan, 46, 149-152. (in Japanese)

Iwano, S., Y. Fukuda and T. Ishiyama (2001): An Estimation of Fault Related Structures by Means of One-Dimensional Gravity Surveys - Case Studies at the Katagihara Fault and the Fumotomura Fault -, J. Geography, 110, 44-57. (in Japanese)

Iwata, T., N. Namiki, N. Kawano, H. Hanada and RSAT/VRAD Group (1998): Observation of Lunar Gravity Field by Ranging and Differential VLBI of Sub-Satellite in SELENE, Proc. VLBI Symp. 1988, 112-116. (in Japanese)

Iwata, T., M. Ogawa, K. Yonekura, T. Babauchi, N. Nonaka, N. Namiki, H. Hanada, N. Kawano, K. Heki, Y. Kozai, T. Takano, M. Hosokawa and RSAT/VRAD Mission Group (1999): A Conceptual Study of the Mission Instruments for Selenodesy Using SELENE Relay Satellite, Proc. Int. Workshop on Geodetic Measurements by the Collocation of Space Techniques on Earth (GEMSTONE) (January 25-28, 1999, Koganei), 122-125.

Iwata, T., Y. Nagae, M. Takahashi, N. Namiki and H. Hanada (2000a): System Design of SELENE Relay Satellite for Selenodesy Mission, Proc. 22nd Int. Symp. Space Technology and Science, 1582-1587, 2000.

Iwata, T., N. Namiki, C. Aoshima, H. Hanada, N. Kawano and Y. Kono (2000b): Development of Selenodetic Observation System Using a Sub-Satellite in SELENE, Proc. VLBI Symp. 1999, 71-74. (in Japanese)

Iwata, T., M. Takahashi, N. Namiki, H. Hanada, N. Kawano, K. Heki, K. Matsumoto and T. Takano (2001): Mission Instruments for Lunar Gravity Measurements Using SELENE Sub-Satellites, J. Geod. Soc. Japan, 47, 558-563.

Iwata, T., T. Sasaki, Y. Kono, H. Hanada, N. Kawano and N. Namiki (2002): Results of the Critical Design for the Selenodetic Mission Using Differential VLBI Methods by SELENE, 2nd IVS General Meeting, (in press).

Karube, F. (1997): Geophysical Exploration for Preserving Archaeological Site in Construction Projects, Butsuri-Tansa (Geophysical Exploration), 50, 6, 555-577. (in Japanese)

Kawaguchi, M., J. Nishijima, Y. Fujimitsu, T. Mogi and S. Ehara (1999): Gravity Anomalies and Low Temperature Hydrothermal Systems around the Minou Fault in Central Kyushu, Southwest Japan, Geothermal Research Report of Kyushu University, 9, 72-78. (in Japanese)

Kawano, N., H. Hanada, S. Tsuruta, T. Iwata and RISE Group (1998a): VLBI Radio Source on the Moon Towards SELENE-II, Proc. VLBI Symp. 1998, 117-119. (in Japanese)

Kawano, N., M. Ooe, T. Tsubokawa, H. Hanada, K. Heki, S. Tsuruta, H. Araki, T. Ishikawa and K.

Matsumoto (1998b): RISE Project, Proc. Cosmic Radio Astronomy and VLBI Conference, 138-142. (in Japanese)

Kawano, N., M. Hosokawa, H. Hanada and M. Imae (1999a): Feasibility Study of Planetodesy by Use of Inverse VLBI Method, Proc. 7th Symp. On Scientific Satellites and Space Observations, 59-62. (in Japanese)

Kawano, N., M. Hosokawa, H. Hanada and M. Imae (1999b): Feasibility Study of Planetodesy by Use of Inverse VLBI Method, J. Geod. Soc. Japan, 45, 181-204.

Kawano, N., H. Hanada, T. Iwata and Y. Koyama (2000a): Differential VLBI Observations among a Lunar Orbiter, the Moon and a QSO, Proc. 1st IVS General Meeting, 160-163.

Kawano, N., M. Ooe, K. Heki, T. Tsubokawa, H. Hanada and RISE Group (2000b): RISE Project, Proc. Cosmic Radio Astronomy Conference 1999, 28-31. (in Japanese)

Kawano, N., H. Hanada, T. Iwata and T. Tsubokawa (2001): Japanese Lunar Explorer ``SELENE" and Geodetic Observations of the Moon, Astronomy and Geodesy in New Millennium, 157-160.

Kikuchi, F., Y. Kono, N. Kawano, H. Hanada and T. Ono (2001): Effect of Attitude of Spin Stabilized Satellites on Gravity Observations, Proc. 23rd Symp. on Solar System Science, 67-70. (in Japanese)

Kimura, I., K. Doi and S. Iwano (2001): Absolute Gravity Measurement at Syowa Station, Antarctica, Program and Abstracts of 96th Meeting of the Geodetic Society of Japan, 157-158. (in Japanese)

Kimura, I. (2002): Gravity Measurements with the Portable Absolute Gravimeter FG5 at Antarctica (II), J. Geogr. Surv. Inst., 97, 17-23. (in Japanese)

Komazawa, M., T. Hiroshima, T. Ishihara, Y. Murata, T. Yamazaki, M. Joshima, M. Makino, R. Morijiri, R. Shichi, K. Kishimoto and E. Kikawa (1999): Gravity Map of Japan (Bouguer Anomalies), 1:1,000,000 Scale Map Ser., Geological Survey of Japan.

Komazawa, M., M. Arpa, M. D. Panol and J. Pantig (2000): Gravity Survey of Laguna de Bay Using Differential GPS, Research on Volcanic Hazard Assessment in Asia, Report of International Research and Development Cooperation ITIT Project, 39-41.

Komazawa, M., Y. Murata, M. Makino, T. Hiroshima, R. Morijiri and T. Yamazaki (2001): Gravity Map of Tenpoku District (Bouguer Anomalies), Gravity Map Ser., 16, Geological Survey of Japan.

Komazawa,M., and M. Mishina (2002): Caldera structure inferred from gravity anomalies west of Nagamachi-Rifu Fault, Mortheast Japan, Earth Planets and Space, 54, 1049-1053.

Komuro, H., R. Shichi and Y. Shitama (2000a): Gravity Anomaly in the Unzen Volcanic Area, Kyushu, Japan, Geosci. Rep. Shimane Univ., 19, 97-100. (in Japanese with English abstract)

Komuro, H., S. Yamauchi and R. Shichi (2000b): Basement Relief Estimated from Bouguer Gravity Anomaly in and around the Shinji-Nakaumi Graben, Abstract, the 107 Annual Meeting of the Geological Society of Japan, p. 42. (in Japanese)

Komuro, H., K. Furuyama, R. Shichi, N. Hagi and A. Yamamoto (2002): Gravity Anomaly on the Teragi Cauldron, Bull. Volcanol. Soc. Japan, 47, 9-15. (in Japanese with English abstract)

Kono, Y., N. Kawano and H. Hanada (1998): Development of Receiving System for Differential VLBI in RISE Project, Proc. Cosmic Radio Astronomy and VLBI Conference, 138-142. (in Japanese)

Kono, Y., H. Hanada, K. Iwadate, H. Araki, N. Kawano, Y. Koyama and Y. Fukuzaki (2000a): Differential VLBI Observations of the Lunar Prospector, Proc. 1st IVS General Meeting, 346-349.

Kono, Y., H. Hanada, H. Araki, K. Iwadate, N. Kawano, Y. Koyama and Y. Fukuzaki (2000b): Differential VLBI Observation of Lunar Prospector, Proc. User's Meeting of Mizusawa 10 m Telescope, 66-68. (in Japanese)

Kono, Y., T. Iwata, H. Hanada and N. Kawano (2000c): Removal of Effect of Spin on Doppler Frequency by Using Symmetrical Antennas, Proc. Japan Society for Aeronautical and Space Science, 1-4. (in Japanese)

Kono, Y., J. Ping, T. Kato, T. Ichikawa and N. Kawano (2001): Analysis of Short Period Variation of Doppler Frequency Caused by the Spin of Mars Spacecraft, NOZOMI, Trans. Inst. Electr. Inform. Comm. Engin., J84-B, 1071-1078. (in Japanese)

Kono, Y., H. Hanada, N. Kawano, K. Iwadate, Y. Koyama and Y. Fukuzaki (2002): Precise Positioning of Spacecrafts by Multi-Frequency VLBI, 2nd IVS General Meeting, (in press).

Kudou, T., Y. Nakano, J. Nishijima and S. Ehara (199

Relationships to Marine Gravity Data, J. Geodesy, 74, 745-755, Springer.
Kuroishi, Y. (2001b): A New Geoid Model for Japan, JGEOID2000, In M. G. Sideris (Ed.) International Association of Geodesy Symposia, 123, Gravity, Geoid and Geodynamics 2000, Springer, 329-333.
Kuroishi, Y. and H. Denker (2001): Development of Improved Gravity Field Models around Japan, In M. G. Sideris (Ed.) International Association of Geodesy Symposia, 123, Gravity, Geoid and Geodynamics 2000, Springer, 317-322.
Kuroishi, Y., H. Ando and Y. Fukuda (2002): A New Hybrid Geoid Model for Japan, GSIGEO2000, J. Geodesy, accepted for publication.
Kyoto City Office (1999): A Report on the Survey for the Underground Structure in Kyoto Basin in 1998, Kyoto City, Special Issue, March, 32p. (in Japanese)
Kyoto City Office (2001): A Report on the Survey for the Underground Structure in Kyoto Basin in 2000, Kyoto City, Special Issue, March, (in press). (in Japanese)
Leni, S. H., Y. Fukuda and S. Takemoto (1998): Gravity Mapping around Indonesia Islands Using Satellite Altimeter Data, Proc. Symp. on Japan-Indonesia IDNDR Project Volcanology, Tectonics, Flood and Sediment Hazards 1998, Bandung, Indonesia, 231-236.
Leni, S. H. and Y. Fukuda (1999): Gravity Mapping around Indonesian Islands, Proc. Symp. on Studies of Ocean and Solid Earth Dynamics Using Satellite Altimetry Data, November 12-13, 1998, 149-158.
Leni, S. H. and Y. Fukuda (2001): On the Influence of Sea Surface Height Variability on Satellite Altimeter Derived Gravity, Marine Geodesy, 24, 73-84.
Machida, M., I. Kimura, T. Kosuge, H. Ando, T. Toyota, Y. Tanaka and S. Okubo (2000): Gravity Observations around Iwate Volcano since August 1998, J. Geogr. Surv. Inst., 93, 19-27. (in Japanese)
Makino, M., T. Hiroshima, R. Morijiri, M. Komazawa and Y. Murata (1999): Gravity Map of Asahikawa District(Bouguer Anomalies), Gravity Map Ser., 12, Geological Survey of Japan.
Matsumoto, K., K. Heki and D. D. Rowlands (1999): Impact of Far-Side Satellite Tracking on Gravity Estimation in the SELENE Project, Adv. Space Res., 23, 1809-1812.
Matsumoto, K., T. Takanezawa and M. Ooe (2000): Ocean Tide Models Developed by Assimilating TOPEX/POSEIDON Altimeter Data into Hydrodynamical Model: A Global Model and Regional Model around Japan, J. Oceanography, 56, 567-581.
Matsumoto, K., T. Sato, T. Takanezawa and M. Ooe (2001): A Program for Computation of Oceanic Loading Effects, J. Geod. Soc. Japan, 47, 1, 243-254.
Matsumoto, K., K. Heki and H. Hanada (2002): Global Lunar Gravity Field Recovery from SELENE, 2nd IVS General Meeting, 2002, 2.
Miyamachi, H., K. Higashiura, F. Hirano and A. Yamamoto (2000): High Dense Gravity

Measurement in Sakurajima Volcano, Southern Kyushu, Japan, Rep. Fac. Sci., Kagoshima Univ., 33, 101-116. (in Japanese with English abstract)

Morijiri,M., Y. Murata, M. Makino, T. Hiroshima, and M. Komazawa (2000): Gravity map of Nemuro District (Bouguer anomalies), Gravity Map Ser.,14, Geological Survey of Japan.

Morijiri,M., T. Hiroshima, M. Komazawa, M. Makino, Y. Murata, K. Nawa, J. Nisjijima, and T. Mogi (2002): Gravity map of Fukuoka District (Bouguer anomalies), Gravity Map Ser.,18, Geological Survey of Japan.

Morijiri, R., T. Hiroshima, Y. Murata, M. Makino and M. Komazawa (2000a): Bouguer Gravity Anomalies in the Eastern Part of Hokkaido, Northeast Japan, Bull. Geol. Surv. Japan, 51, 537-558. (in Japanese)

Morijiri, R., Y. Murata, M. Makino, T. Hiroshima and M. Komazawa (2000b): Gravity Map of Nemuro District (Bouguer Anomalies), Gravity Map Ser., 14, Geological Survey of Japan.

Morijiri, R., T. Hiroshima, M. Komazawa, M. Makino, Y. Murata, K. Nawa, J. Nishijima and T. Mogi (2002): Gravity Map of Fukuoka District (Bouguer Anomalies), Gravity Map Ser., 18, Geological Survey of Japan.

Mukai, A., S. Takemoto, T. Higashi and Y. Fukuda (2001): Oceanic Tidal Loadings Estimated from Gravity Observations in Kyoto and Bandung, J. Geod. Soc. Japan, 47, 261-266.

Murata, Y., M. Makino, K. Nishimura, R. Morijiri, T. Hiroshima, T. Ishihara and M. Komazawa (2000): Gravity Map of Kitami District (Bouguer Anomalies), Gravity Map Ser., 13, Geological Survey of Japan.

Murata,Y., M. Makino, K. Nishimura, M. Morijiri, T. Hiroshima, T. Ishihara, and M. Komazawa (2001): Gravity map of Nayoro District (Bouguer anomalies), Gravity Map Ser.,15, Geological Survey of Japan.

Murata, Y., M. Makino, K. Nishimura, R. Morijiri, T. Hiroshima, T. Ishihara and M. Komazawa (2001): Gravity Map of Nayoro District (Bouguer Anomalies), Gravity Map Ser., 15, Geological Survey of Japan.

Nagasaki Prefectural Investigation Bureau of Haruno-Tsuji Remains (1999): Microgravity Survey for the Harunotuzi Remains in the Iki Island, Nagasaki, Special Issue, February 1999. (in Japanese)

Nakamura, K., K. Ito, H. Wada, T. Asada, T. Tanaka, S. Bambang, K. Wedyanto and J. Kahar (1998): Gravity Survey Crossing the Lembang Fault and the Cimandiri Fault, Proc. Symp. on Japan-Indonesia IDNDR Project Volcanology, Tectonics, Flood and Sediment Hazards, 1998, Bandung, Indonesia, 215-222.

Nakamura, K., K. S. Ony, M. Gamal, Y. P. Tedy, I. S. Widhie, A. K. Mipi and Z. A. Hasanuddin (2000): Gravity Survey around Guntur Volcano, Abstract of IAVCEI General Assembly 2000, 61.

Nakamura, K., K. Ito, T. Asada, S. Matsuo, T. Y. Pusudiano, D. Darmawan, A. K. Mipi and Z. A.

Hasanuddin (2001): Gravity Surveys around the Bandung Basin and the Guntur Volcano, Jawa Barat, Indonesia, Annuals, Disas. Prev. Res. Inst., Kyoto Univ., 44, 207-216. (in Japanese)

Namiki, N., H. Hanada, T. Tsubokawa, N. Kawano, M. Ooe, K. Heki, T. Iwata, M. Ogawa, T. Takano and RSAT/VRAD/LALT Mission Groups (1999): Selenodetic Experiments of SELENE: Relay Subsatellite, Differential VLBI and Laser Altimeter, Adv. Space Res., 23, 1817-1820.

Nawa, K., N. Suda, Y. Fukao, T. Sato and K. Shibuya (1998): Incessant Excitation of the Earth's Free Oscillations, Earth Planets Space, 50, 3-8.

Nawa, K., N. Suda, Y. Fukao, T. Sato, Y. Tamura, K. Shibuya, H. McQueen, H. Virtanen and J. Kaariainen (2000): Incessant Excitation of the Earth's Free Oscillations: Global Comparison of Superconducting Gravimeter Records, Phys. Earth Planet. Int., 120, 289-297.

Nishida, R., W. Munetou, H. Nakamura, T. Ueda, H. Nishiyama and T. Noguchi (2001): Subsurface Structure Analysis by Gravity Survey, Reports of the 53rd Japan Society of Civil Engineers Chugoku Branch Conference, T-48, 95. (in Japanese)

Nishijima, J., F. Saito, T. Kato, Y. Fujimitsu and S. Ehara (1998): Monitoring of Ground Water Level by Repea

Nishijima, J., N. Sakamura, Y. Fujimitsu, S. Ehara, E. Kouno and S. Kusaba (2001c): GPS and Microgravity Monitoring at Hatchobaru Geothermal Field, Central Kyushu, Japan, Proc. 23rd New Zealand Geothermal Workshop 2001, 75-78.

Nishimura, K., M. Komazawa, M. Takabayashi and T. Tsutsui (2001): Basement Structure of Ohmi Basin, East of Lake Biwa, as Deduced from Geophysical Explosion, Research Report of the Lake Biwa Museum, 15, 106-116. (in Japanese)

Nozaki, K. (1999): A Note on the Basic Characteristics of Spherical Gravity Corrections: Gravitational Behavior of a Thin Spherical Cap of Axial Symmetry, J. Geod. Soc. Japan, 45, 3, 215-226. (in Japanese with English abstract)

Nozaki, K. (2001): Generalized Bouguer Gravity Anomaly (1): Formulation of Spherical Bouguer Anomaly Reduced onto an Arbitrary Equi-Potential Surface, ASEG 15th Geophysical Conference and Exhibition, August 2001, Brisbane, Extended Abstracts (CD-ROM), 4p.

Nozaki, K. and K. Iwamoto (2001): Generalized Bouguer Gravity Anomaly (2): Possibility of Constructing Bouguer Gravity Anomaly Distribution with No Gravitational Effect Due to Topographic Undulation, ASEG 15th Geophysical Conference and Exhibition, August 2001, Brisbane, Extended Abstracts (CD-ROM), 4p.

Ogasawara, S., T. Higashi, Y. Fukuda and S. Takemoto (2001): Calibration of a Superconducting Gravimeter with an Absolute Gravimeter FG-5 in Kyoto, J. Geod. Soc. Japan, 47, 404-409.

Ohtsu, S., J. Tajika, W. Hirose, N. Okazaki and S. Ishimaru (2002): Explanatory Text of the Map of Active Faults in Hokkaido, No. 4 ``Tobetsu Fault and Southern Extension Parts'', Hokkaido, 109p. (in Japanese)

Oka, T., J. Tajika, S, Ohtsu, W. Hirose, N. Okazaki and S. Ishimaru (2001): Explanatory Text of the Map of Active Faults in Hokkaido, No. 3 ``Ishikari-Teichi-Toen Fault Zone'', Hokkaido, 157p. (in Japanese)

Okino, K. (1999): Comparison between satellite derived gravity/predicted bathymetry and shipboard data, Technical Bulletin on Hydrography, 17,65-69. (in Japanese)

Okubo, S., Y. Ikeda, T. Kumamoto, G. Seta, N. Matsuta, T. Chiba and Y. Arai (2000): 2-D and 3-D Subsurface Density Structure in the Northern Part of the Itoigawa-Shizuoka Tectonic Line Derived by Gravity Surveying, J. Geod. Soc. Japan, 46, 3, 177-186. (in Japanese with English abstract)

Okubo, S. and D. Tsuji (2001): Complex Green's Function for Diurnal/Semidiurnal Loading Problem, J. Geod. Soc. Japan, 47, 1, 225-230.

Okubo, S., Y. Kuroishi, M. Machida and Y. Hiraoka (2001): Repeated Absolute Gravity Measurement at Omaezaki, Chikyu Monthly, 33, 89-96. (in Japanese)

Ooe, M. and K. Matsumoto (2001): Estimation of Lunar Tidal Effects to the Orbits of the Lunar Orbiters in the SELENE Mission, J. Geod. Soc. Japan, 47, 629-636. (in Japanese)

Ping, J., Y. Kono, F. Weischede, H. Hanada, N. Kawano and Y. Koyama (2000a): Getting 3-Way

Doppler Data from Differential VLBI Observation for Lunar Prospector, Proc. User's Meeting of Mizusawa 10 m Telescope, 91-95. (in Japanese)

Ping, J., Y. Kono, F. Weischede, H. Hanada, N. Kawano and Y. Koyama (2000b): A Method of Getting Velocity Information from S/C VLBI Observation, J. Beijing Normal University (Natural Science), 36, 769-774.

Ping, J., F. Weischede, Y. Kono, H. Hanada and N. Kawano (2001a): High Frequency Components in LP Doppler Data, J. Planetary Geodesy, 36, 15-23.

Ping, J., Y. Kono, N. Kawano, H. Hanada, K. Matsumoto and RISE Group (2001b): SELENE Mission: Mathematical Model for SST Doppler Measurements, Program and Abstracts, 19, 354-364. (in Chinese)

Regional Construction Bureau of the Lower Kiso-River of the Ministry of Land, Infrastructure and Transport (1997): Subsurface Investigations for the Ancient Deversoir, the Satsuma-Araizeki, Gifu Prefecture, Special Issue, July 1997. (in Japanese)

Report on the Gravimetry in Japan during the Period from January 1999 to December 2002 (Geological Survey of Japan and National Metrology Institute of Japan, National institute of Advanced Industrial Science and Technology)

Saito, H., K. Tagomori, H. Nagano, I. Kumagae, S. Nagano and S. Ehara (1998): Reservoir Behavior Inferred from 2D Modeling Analysis of Gravity Changes in the Hatchobaru Geothermal Field, Journal of the Geothermal Research Society of Japan, 20, 185-199. (in Japanese)

Sato, T. (2002): The quadrennial national report of gravimetric works made in Japan during the period from April 1998 to March 2002, The National Committee for Geodesy of Japan and The Geodetic Society of Japan, section 12, Superconducting Gravimetery, 28-31.

Sato, T., H. McQueen, B. Murphy, K. Lambeck, Y. Hamano, K. Asari, Y. Tamura and M. Ooe (1998): On the Observations of Gravity Tides and Earth's Free Oscillations with Superconducting Gravimeter CT#031 at Mt. Stromlo, Australia, Proc. 13th Int. Symp. Earth Tides, Brussels, 583-589.

Sato, T., K. Asari, Y. Tamura, H. P. Plag, H. Digre, Y. Fukuda, J. Hinderer, K. Kaminuma and Y. Hamano (2001a): Continuous Gravity Observation at Ny-Alesund, Svalbard, Norway with a Superconducting Gravimeter CT#039, J. Geod. Soc. Japan, 47, 341-346.

Sato, T., Y. Fukuda, Y. Aoyama, H. McQueen, K. Shibuya, Y. Tamura, K. Asari and M. Ooe (2001b): On the Observed Annual Gravity Variation and the Effect of Sea Surface Height Variations, Phys. Earth Planet. Int., 123, 45-63.

Sato, T., Y. Tamura, K. Matsumoto, Y. Imanishi, and H. McQueen (2002): Parameters of the fluid core resonance estimated from superconductiong gravimeter data, Marees Terrestres Bulletin D'Informations, 136, 10751-10760.

Satomura, M. (1998): Gravity Anomalies of Tectonic Lakes, International Project on Paleolimnology and Late Cenozoic Climate, Newsletter, 11, 154-158.

Satomura, M., J. Segawa, J. Tanimoto, Y. Imanishi, C. Kuramoto and K. Koizumi (1999): Sea Surface Gravity Measurements with Interferometry GPS Positionings, Abstracts of IUGG 99, Birmingham, Week A, 430.

Segawa, J., M. Satomura, J. Tanimoto, Y. Imanishi, C. Kuramoto and K. Koizumi (1999): Sea Surface Gravity Measurements with Interferometry GPS positionings, Program and Abstracts of GPS 99, Tsukuba, 13-03.

Segawa, J., H. Hasegawa, T. Ishihara, S. Sakuma and M. Ishii (2000a): A Preliminary Study of the Development of a Helicopter-Mounted Gravity Measuring System, Bull. Inst. Oceanic Res. & Develop., Tokai Univ., 21, 1-10.

Segawa, J., S. Kusumoto, E. J. Joseph, H. Hasegawa, S. Sekizaki, K. Takada, E. Nakayama, H. Suzuki, T. Ishihara, M. Komazawa, K. Yamamoto and S. Sakuma (2000b): Airborne Gravity Measurement System by Use of a Helicopter, J. Geod. Soc. Japan, 46, 223-229. (in Japanese)

Segawa, J., E. J. Joseph, S. Kusumoto, T. Ishihara, M. Komazawa, H. Hasegawa, K. Takada, E. Nakayama, S. Sekizaki, H. Suzuki and S. Sakuma (2001a): Results of the Tests Conducted by a Newly Developed Helicopter Borne Gravimeter System, Bull. Geol. Surv. Japan, 52, 73-81.

Segawa, J., S. Kusumoto, T. Ishihara, E. J. Joseph, M. Komazawa, H. Hasegawa, S. Sekizaki, K. Takada, H. Suzuki, E. Nakayama and S. Sakuma (2001b): Results of Gravity Measurements (1999) Using a Helicopter-Mounted Gravimeter, Bull. Inst. Oceanic Res. Develop., 22, 1-14.

Segawa, J., E. J. Joseph, S. Kusumoto, T. Ishihara, M. Komazawa, H. Hasegawa, S. Sekizaki, K. Takada, E. Nakayama, M. Satomura and S. Sakuma (2002): Helicopter Gravimetry - Summary of the Developmental Study from 1998 to 2000 -, Bull. Inst. Oceanic Res. Develop., 23, 1-16. (in Japanese)

Shibuya, K., K. Doi and S. Aoki (1999): Precise Determination of Geoid Height and Free-Air Gravity Anomaly at Syowa Station, Earth Planets Space, 51, 159-168.

Shichi, R. and A. Yamamoto (2001a): List of Gravity Data Measured by Nagoya University, Bull. Nagoya University Museum, Special Rept., No. 9, Part-I, 1-256.

Shichi, R. and A. Yamamoto (Representatives of the Gravity Research Group in Southwest Japan) (2001b): Gravity Database of Southwest Japan (CD-ROM), Bull. Nagoya University Museum, Special Rept., No. 9.

Sugihara, M. (2001): Absolute Gravity Measurement for Geothermal Reservoir Monitoring, GRC Transactions, 25, 697-700.

Sun, H. -P., S. Takemoto, H. -T. Hsu, T. Higashi and A. Mukai (2000): Observation Results of the High Precision Tidal Gravity with Superconducting Gravimeters at Stations Wuhan and Kyoto, Acta Geodaetica et Cartographica Sinica, 29, 181-187.

Sun, H. -P., S. Takemoto, H. -T. Hsu, T. Higashi and A. Mukai (2001): Precise Tidal Gravity

Recorded with Superconducting Gravimeters at Stations Wuhan (China) and Kyoto (Japan), J. Geodesy, 74, 720-729.

Sun, W. and S. Okubo (1998): Surface Potential and Gravity Changes due to Internal Dislocations in a Spherical Earth - II. Application to a Finite Fault, Geophys. J. Int., 132, 1, 79-88.

Sun, W. (2001): General Formulas for Estimating Powers of Topographic Height to be Taken into Account for Terrain Corrections in Geoid Determination and Isostatic Compensation, Proc. IAG 2001 Scientific Assembly, September 2-7, 2001, Budapest, Hungary, (CD-ROM).

Sun, W. and L. Sjöberg (2001): Convergence and Optimal Truncation of Binomial Expansions Used in Isostatic Compensations and Terrain Corrections, J. Geodesy, 74, 627-636.

Sun, W. (2002): A Formula for Gravimetric Terrain Corrections Using Powers of Topographic Height, J. Geodesy, 76, 399-406.

Tajika, J., S. Ohtsu, N. Okazaki, T. Suzuki, K. Hirakawa and Y. Fusejima (1999): Explanatory Text of the Map of Active Faults in Hokkaido, No. 2 ``Hakodate-Heiya-Seien Fault Zone'', Hokkaido, 65p. (in Japanese)

Takanezawa, T., K. Matsumoto, M. Ooe and I. Naito (2001): Nonequilibrium Characteristics of the Long-Period Ocean Tides from Dynamics and Energetics, J. Geodesy, 74, 551-557.

Takemoto, S., S. Dwipa, Y. Fukuda, T. Higashi, A. Andan, R. Sukhyar, W. S. Tjetjep, T. Tanaka and L. S. Heliani (1998a): Precise Gravity Observation in Bandung Using a Superconducting Gravimeter, Proc. Symp. on Japan-Indonesia IDNDR Project Volcanology, Tectonics, Flood and Sediment Hazards 1998, Bandung, Indonesia, 223-230.

Takemoto, S., T. Higashi, A. Mukai, Y. Fukuda and T. Tanaka (1998b): Precise Observation of Gravity Changes with Superconducting Gravimeters in Kyoto (1988-1997), Annuals, Disas. Prev. Res. Inst., Kyoto Univ., 41, B-1, 77-85. (in Japanese with English abstract)

Tanaka, T., H. Aoki, K. Oshita, M. Ishikawa, K. Nozaki and M. Onishi (2001a): Basement Structure of the Overstep Part along the Enasan Fault, Tono Area, Central Japan, J. Seis. Soc. Japan (Zisin Ser. 2), 54, 319-330. (in Japanese)

Tanaka, T., H. Aoki, M. Okubo, K. Oshita and M. Onishi (2002): Exploration of Subsurface Structure Across the Atera Fault Zone, Technical Note of the National Research Institute for Earth Science and Disaster Prevention, (in press).

Tanaka, Y., S. Okubo, M. Machida, I. Kimura and T. Kosuge (2001b): First Detection of Absolute Gravity Change Caused by Earthquake, Geophys. Res. Lett., 28, 15, 2979-2981.

Terada, K., Y. Fukuda and Y. Nogi (2001): Detection of Sea Floor Structures off the Gunnerus Ridge, Polar Geoscience, 14, 235-243.

Tono Research Institute of Earthquake Science (1999): Security Investigation against Strong Ground Motion in Tono Area, Gifu, Japan, Report of Tono Research Institute of Earthquake Science, 1, 170p., Association for the Development of Earthquake Prediction. (in Japanese)

Tono Research Institute of Earthquake Science (2000): Report of Research Committee for the Investigation of the Byobu-Zan Fault, Report of Tono Research Institute of Earthquake Science, 5, 133p., A

845-880.

Yamamoto, A. (2002b): Seismicity and Gravity Anomaly in the Northern Hokkaido, Japan, Geol. Soc. Japan News, 5, 4, Cover Illustration with Japanese Explanations, p. 18.

Yamamoto, A. (2002c): Gravity Anomaly around the Hidaka Collision Zone, Hokkaido, Japan, Chikyu Monthly, (in press). (in Japanese)

Yamamoto, A. and H. Ishikawa (2002): Gravity Anomaly and Shallow Crustal Structure around the Southernmost Part of the Oshima Peninsula, Hokkaido, Japan, Geoph. Bull. Hokkaido Univ., 65, 247-290. (in Japanese with English abstract)

Yamamoto, K., T. Takayama, K. Ishihara, H. Oshima, T. Maekawa, S. Ueki, M. Sawada and J. Oikawa (1998): Trend of Gravity Change in and around Sakurajima Volcano, Annuals, Disas. Prev. Res. Inst., Kyoto Univ., 41, 153-160. (in Japanese)

Yamamoto, K., K. Ishihara, S. Okubo and A. Araya (2001c): Accurate Evaluation of Ocean Tide Loading Effects for Gravity in Nearshore Region: the FG5 Measurements at Sakurajima Volcano in Kagoshima Bay, Japan, Geophys. Res. Lett., 28, 9, 1807-1810.

Yamamoto, K., K. Ishihara, S. Okubo, A. Araya, M. Furuya, Y. Ohki and T. Takayama (2001d): Gravity Change Associated with the Volcanism of the Sakurajima as Revealed with Absolute Gravity Measurement, Chikyu Monthly, 23, 8, 578-582. (in Japanese)

Yamazaki, F., R. Shichi, K. Masaki, I. C. Narag, E. L. Banganan, W. G. Sevilla and J. B. Deocampo (2001): Subsurface Geologic Condition Evaluated by Gravity Survey in Metro Manila, Proc. International Workshop on the Integration of Data for Seismic Disaster Mitigation in Metro Manila, November 24-25, 2000, Philippine Institute of Volcanology and Seismology (PHIVOLCS), 9-12.

Yatabe, M. (2000a): Formulation of the Residual Gravity Field and Prediction of the Mercury's Shape, J. Geod. Soc. Japan, 46, 125-148.

Yatabe, M. (2000b): The Lunar Shape Examined by the Residual Gravity Field, J. Geod. Soc. Japan, 46, 203-222.

Yoneshige, K., J. Nishijima and S. Ehara (1999): Observation of Gravity Changes at Yamagawa Geothermal Field, Kagoshima Prefecture, Japan, Geothermal Research Report of Kyushu University, 9, 87-94. (in Japanese)

Yoshida, S., G. Seta, S. Okubo and S. Kobayashi (1999): Absolute Gravity Change Associated with the March 1997 Earthquake Swarm in the Izu Peninsula, Earth Planets Space, 51, 1, 3-12.

6. Crustal Deformation

This is the field where great amount of important works have been published 1999-2002, due partly to the completion of the nationwide continuous GPS network, GEONET, and to the occurrences of events such as inland earthquakes (e.g., the 2000 Western Tottori Earthquake, the 2001 Geiyo Earthquake), silent events at plate boundaries (e.g., the Tokai silent event 2000-present) and volcanic eruptions (e.g., 1999 Usu, Hokkaido, and 2000 Miyake-Jima). In this chapter, papers are classified into those related to secular (interseismic), transient (coseismic, postseismic, etc.) and periodic crustal movements. There have been a lot of works concerning a series of event that started with the eruption of the Miyake-Jima in 2000 summer, followed by the submarine dike intrusion northwest of Miyake-Jima, and the Tokai silent event starting 2000 autumn. Papers related to this event are listed separately in an independent section.

6.1. Secular Motions

International deployments of GPS receivers led by Japanese researchers have been done in Asian Far East, such as Sakhalin, Kamchatka (Takahashi et al., 1999) and in the Pacific area (Kato et al., 1999), etc.. Several papers discussed plate tectonic framework in Eurasia, determining the Euler vector of the Amurian Plate (e.g. Heki et al., 1999). This new framework influenced interpretations of interseismic crustal deformation in Japan (e.g. Hashimoto et al., 2000; Miyazaki and Heki, 2001). Velocity field by GEONET revealed the existence of a zone along which deformation concentrates, which was later named the Niigata-Kobe Deformation Zone by Sagiya et al. (2000). This zone is interpreted as the kinematic plate boundary between plates on which NEJ and SWJ reside. Collision of the two plates in central Japan also causes variation of convergence rates along the Nankai-Suruga Trough, which is important in discussing the recurrence of interplate events in the Tokai area (Heki and Miyazaki, 2001). Interseismic crustal deformation has been studied in NEJ (e.g. Nishimura et al., 2000; Miura et al., 2002) and in SWJ (e.g. Ozawa et al, 1999; Ito et al., 1999) to map coupling strength on the plate interface. Campaign-type dense network observations have been done around major active faults such as the Median Tectonic Line (Tabei et al., 2002). Studies over the last four years, however, are based mainly on horizontal crustal deformation. Detailed studies incorporating vertical velocities are expected to be performed in the next four years.

6.1.1 Plate Motions

Bibliography

Gerasimenko, M. D., and T. Kato (2000): Establishment of the three-dimensional kinematic reference frame by space geodetic measurements, Earth Planets and Space, 52, 959-963.

Harada, Y., S. Matsuzaka, S. Miyazaki, Y. Kikuta, H. DOi, Y. Iimura, T. Miyazaki, K. Murakami, H. Nakagawa, M. Kusaka, K. Maruyama, and M. Ishimoto (2000): The plate motion of the Pacific Plate and its intraplate deformation, Earth Monthly,23, 476-479. (in Japanese).

Heki, K., S. Miyazaki, H. Takahashi, M. Kasahara, F. Kimata, S. Miura, N. Vasilenco (1999): A. Ivashchenco and K. An, The Amurian Plate motion and current plate kinematics in eastern Asia, J. Geophys. Res., 104, 29147-29155.

Ishida, M., S. Maruyama, D. Suetsugu, S. Matsuzaka, and T. Eguchi (1999): Superplume Project: Towards a new view of whole Earth dynamics, Earth Planets and Space, 51(1), i-v,.

Kato, T., and Japanese University Consortium for GPS Research (JUNCO)(1999): WING - Present status and future development -, Earth Monthly, Suppl. 25, 132-135. (in Japanese)

Miyazaki, S., S. Matsuzaka, K. Heki, M. Kaidzu, Y. Kuroishi, Mak. Murakami, T. Imakiire, T. Tada, K. Nitta, H. Nakagawa, A. Itabashi, M. Karasawa, O. Ootaki, N. Ishikawa, M. Ishimoto, H. Takahashi, M. Kasahara, and K. An (2002): Tectonics in the Eastern Asia inferred from GPS observations, Bull. Geogr. Surv. Inst., 47, 1-12.

Takahashi, H., M. Kasahara, F. Kimata, S. Miura, K. Heki, T. Seno, T. Kato, N. Vasilenko, A. Ivashchenko, V. Bahtiarov, V. Levin, E. Gordeev, F. Korchagin, and M. Gerasimenko (1999): Velocity field of around the Sea of Okhotsk and Sea of Japan regions determined from a new continuous GPS network data, Geophys. Res. Lett., 26, 2544-2536

6.1.2.Interseismic Motions

Bibliography

El-Fiky, G.S., and T. Kato (1999): Continuous distribution of the horizontal strain in the Tohoku district, Japan, predicted by least-squares collocation, Geodynamics, 27, 213-236.

El-Fiky, G. S., and T. Kato (1999): Interplate coupling in the Tohoku district, Japan, deduced from geodetic data inversion, J. Geophys. Res., 104, B9, 20361-20377.

El-Fiky, G. S., T. Kato, and E. N. Oware (1999): Crustal deformation and interplate coupling in the Shikoku district, Japan, as seen from continuous GPS observation, Tectonophysics, 314, 387-399, 1999.

Fujihara, S., M. Hashimoto, and S. Takemoto (2001): Numerical analysis of back-arc spreading mechanism in the Okinawa Trough, J. Geod. Soc. Japan, 47, 659-678.

Fukuda, Y., M. Itahara, S. Kusumoto, T. Higashi, K. Takemura, H. Mawatari, Y. Yusa, T. Yamamoto, and T. Kato (2000): Crustal movements around the Beppu Bay area, East-Central Kyushu, Japan, observed by GPS 1996-1998, Earth Planets and Space, 52(11), 979-984.

Furuya, M., K. Sebata, J. Amagai, T. Yoshino, M. Sekido, Y. Koyama, and T. Kondo (1999): Strain Field inferred from Keystone VLBI Network, Proceedings of the International Workshop on Geodetic Measurements by the Collocation of Space Techniques on Earth (GEMSTONE), Communications Research Laboratory, Koganei, Tokyo, January 25-28, 1999, Communications Research Laboratory, 265-270

Hasegawa, A., A. Yamamoto, N. Umino, S. Miura, S. Horiuchi, D. Zhao, and H. Sato (2000): Seismic activity and deformation process of the overriding plate in the northeastern Japan subduction zone, Tectonophys., 319, 225-239.

Heki, K., and S. Miyazaki (2001): Plate convergence and long term crustal deformation in central Japan, Geophys. Res. Lett., 28, 2313-2316.

Hori, M., T. Kameda, and T. Kato (2000): Prediction of stress field in Japan using GPS network data, Earth Planets and Space, 52, 1101-1105.

Hori, M., T. Kameda, and T. Kato (2001): Prediction of stress field in Japan using GPS network data, Geophys. J. Int., 144, 597-608.

Hydrographic Department (1999): GPS observations for monitoring crustal movements 1997, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 12. (in Japanese)

Hydrographic Department (2002): GPS Observations for monitoring crustal movements 1998, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 13. (in Japanese)

Hydrographic and Oceanographic Department (2002): GPS observations for monitoring crustal movements 1999, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 14. (in Japanese)

Ito, T., S. Yoshioka, and S. Miyazaki (1999): Interplate coupling in southwest Japan deduced from inversion analysis of GPS data, Phys. Earth Planet. Inter., 115, 17-34.

Kato, T., and G. S. El-Fiky (2000): Strain rate distribution in Taiwan before the 1999 Chi-Chi, Taiwan earthquake derived from GPS observations, Bull. Earthq. Res. Inst., 75, 93-104.

Li, J., K. Miyashita, T. Kato, and S. Miyazaki (2000): GPS time series modeling by autoregressive moving average method: Application to the crustal deformation in central Japan, Earth Planets and Space, 52, 155-162.

Miura, S., T. Sato, K. Tachibana, Y. Satake, and A. Hasegawa (2002): Strain accumulation in and around Ou Backbone Range, northeastern Japan as observed by a dense GPS network, Earth Planets Space, 54, 1071-1076.

Miyazaki, S., and K. Heki, Crustal velocity field of southwest Japan: Subduction and arc-arc collision, J. Geophys. Res. 106, 4305-4326, 2001.

Nakagawa, Y., I. Kawasaki, and Y. Ishizuki (2001): A model of steady-state faulting at depths for GPS surface displacements and the stress field in the Hida Mountains in the Chubu District, Central Honshu, Japan, Bull. Earthq. Res. Inst., 75, 135-143. (in Japanese)

Nishimura, T., S. Miura, K. Tachibana, K. Hashimoto, T. Sato, S. Hori, E. Murakami, T. Kono, K. Nida, M. Mishina, T. Hirasawa, and S. Miyazaki (2000): Distribution of seismic coupling on the subducting plate boundary in northeastern Japan inferred from GPS observations, Tectonophys., 323, 217-238.

Ohtani, R., N. Koizumi, N. Matsumoto, and E. Tsukuda (2000): Preliminary results from permanent GPS array by the Geological Survey of Japan in conjunction with groundwater-level observations, Earth Planets and Space, 52, 663-668.

Ozawa, T., T. Tabei, and S. Miyazaki (1999): Interplate coupling along the Nankai Trough off southwest Japan derived from GPS measurements, Geophys. Res. Lett., 26, 927-930.

Reddy, C. D., G. El-Fiky, T. Kato, S. Shimada, and K. V. Kumar (2000): Crustal strain field in the Deccan trap region, western India, derived from GPS measurements, Earth Planets and Space, 52, 965-969.

Sagiya, T. (2000): Simulation for crustal activity forecast and assimilation of crustal movement data. Bull. Earthq. Res. Inst., 75, 145-158, (in Japanese with English abstract).

Sagiya, T., S. Miyazaki, and T. Tada (2000): Continuous GPS array and present-day crustal deformation of Japan, PAGEOPH, 157, 2303-2322.

Sagiya, T., T. Nishimura, Y. Iio, and T. Tada (2002): Crustal deformation around the northern and central Itoigawa-Shizuoka Tectonic Line, Earth Planets and Space, 54, 1059-1063.

Sagiya, T., Z. Wu, T. Terakawa, M. Igami, T. Homma, T. Ando (2002): Crustal deformation analysis with DFEM, J. Geogr. Surv. Inst., 97, 53-61. (in Japanese)

Sato, T., S. Miura, K. Tachibana, Y. Satake, and A. Hasegawa (2002): Crustal deformation around Ou backbone range, Northeastern Japan observed by a dense GPS network, Zisin, 55, 181-191 (in Japanese with English abstract).

Tabei, T. (1999): Lateral heterogeneity of subduction process at the Nankai trough inferred from GPS data, Proc. Int. Workshop on "Recurrence of great interplate earthquakes and its mechanism", Kochi, Japan, 6-12.

Tabei, T., M. Hashimoto, S. Miyazaki, K. Hirahara, F. Kimata, T. Matsushima, T. Tanaka, Y. Eguchi, T. Takaya, Y. Hoso, F. Ohya, and T. Kato (2002): Subsurface structure and faulting of the Median Tectonic Line, southwest Japan inferred from GPS velocity field, Earth Planets and Space, 54, 1065-1070.

Tanaka, M. (2002): Relationship between arc-scale tectonic deformation caused by subducting plate motion and the regional crustal deformation in South Kyushu, Japan. Proceedings of Meeting 13K-7, DPRI, Kyoto Univ., 113-126, March.(in Japanese with English abstract)

Yoshioka, S., and Y. Ito (2001): Lateral variations of effective elastic thickness of the subducting Philippine Sea plate along the Nankai trough, Earth Planets and Space, 53, 261-273.

Zhao, S., and S. Takemoto (2000): Deformation and stress change associated with plate Interaction at subduction zones: a kinematic modelling, Geophys. J. Int., 142, 300-318.

6.2. Transient Movements

Bibliography

Coseismic crustal movements have been detected by space geodetic techniques such as GPS and SAR interferometry, in Mt. Iwate in 1998 (Fujiwara et al., 2000), the 2000 Western Tottori Earthquake (Sagiya et al., 2002), the 2001 Geiyo Earthquake, and so on. Coseismic deformations with old ground survey data have been newly performed for several past earthquakes (e.g. Sagiya, 1999; Kobayashi et al., 2002). Slow fault slip after normal earthquakes, similar to the one following the 1994 Sanriku Earthquake (Nishimura et al., 2000), was studied using tide gauge data after the 1978 Miyagi-Oki Earthquake (Ueda et al., 2001). Based on such studies, Kawasaki et al., (2001) summarized space-time distribution of normal and slow events at the Japan Trench in the Sanriku region. A purely slow event (i.e. no preceding normal slip) was found beneath the Bungo Channel (Hirose et al., 1999), for which time-dependent inversion technique of fault slips has been applied by Ozawa et al. (2001).

Crustal movements associated with volcanic activities have been studied for the 1999 eruption of the Usu Volcano, Hokkaido (Tobita et al., 2001; Kimata et al., 2002), and for the 1998 seismo-volcanic crisis of the Mt. Iwate (Miura et al., 2000; Nishimura et al., 2001). The time-dependent inversion technique was first applied for a real case to study temporal evolution of the 1997 submarine dike intrusion event east of the Izu Peninsula by Aoki et al. (1999). The large eruption of the Miyake-jima in 2000 was followed by the intrusion of a dike running from Miyake-jima to Kozu-shima, which caused large amount of crustal deformation over an extensive area of the Kanto-Tokai region (e.g. Kaidzu et al., 2000; Nishimura et al., 2001). This event might have triggered a silent event down-dip the plate interface where the Tokai earthquake is anticipated to occur (Ozawa et al., 2002). Crustal deformation studies of this series of event are listed in the section 6.2.4.

6.2.1 Coseismic Movements

Bibliography

Fujiwara, S., T. Nishimura, M. Murakami, H. Nakagawa, and M. Tobita (2000): 2.5-D surface deformation of M6.1 earthquake near Mt. Iwate detected by SAR interferometry, Geophys. Res.

Lett., 27, 2049-2052.

Kato, N., and X. Lei (2001): Interaction of parallel strike-slip faults and a characteristic distance in the spatial distribution of active faults, Geophys. J. Int., 144, 157-164.

Kobayashi, A., A. Yoshida, and N. Manago (2002): Co- and post-seismic crustal deformation of the 1946 Nankai earthquake deduced from tide gauge records, J. Geod. Soc. Japan, 48, (in press). (in Japanese)

Komazawa,M., H. Morikawa, K. Nakamura, J. Akamatsu, K. Nishimura, S. Sawada, A. Erken, and A. Onalp (2002): Bedrock structure in Adapazari, Turkey - a possible cause of severe damage by the 1999 Kociaeli eartquake, Soil Dynamics and Earthquake Engineering, 22, 829-836.

Murakami, Mak., S. Ozawa, T. Nishimura, S. Miyazaki, T. Sagiya, and T. Tada (2000) : Application for seismological and volcanological researches by monitoring crustal deformation using GPS continuous observation, J. Geogr., 109, 971-982. (in Japanese)

Murakami, Mak., T. Tobita, H. Yarai, S. Ozawa, T. Nishimura, H. Nakagawa, and S. Fujiwara (2000): Application of SAR to detect crustal deformation for seismological and volcanological researches, J. Geogr., 109, 944-956. (in Japanese)

Sagiya, T., T. Nishimura, Y. Hatanaka, E. Fukuyama, W. L. Ellsworth (2002): Crustal movements associated with the 2000 Western Tottori Earthquake and its fault models, Zisin, 54, 523-534. (in Japanese with English abstract).

Sagiya, T., and W. Thatcher (1999): Coseismic slip resolution along a plate boundary megathrust: The Nankai Trough, southwest Japan, J. Geophys. Res., 104, 1111-1129.

Sagiya, T. (1999): Crustal movements associated with the 1948 Fukui Earthquake (M=7.1) and its fault model, Zisin, 52, 111-120. (in Japanese with English abstract).

Tanaka, M. (2000): Crustal deformation model associated with intraplate earthquakes induced from crustal deformation characteristics in Kyushu, Japan, J. Geod. Soc. Japan, 46,31-42. (in Japanese with English abstract)

Yoshioka, S. (2001): Coseismic slip distribution of the 1999 Chi-Chi, Taiwan, earthquake, deduced from inversion analysis of GPS data, Bull. Seism. Soc. Am., 91, 1182-1189.

6.2.2 Slow/silent Deformation

Bibliography

Hirose, H., K. Hirahara, F. Kimata, N. Fujii, and S. Miyazaki (1999): A slow thrust slip event following the two 1996 Hyuganada earthquakes beneath the Bungo Channel, southwest Japan, Geophy. Res. Lett.,26, 3237-3240.

Hirose, I., I. Kawasaki, Y. Okada, T. Sagiya, and Y. Tamura (2000): A silent earthquake of December

9, 1989, in the Tokyo Bay, as revealed by the continuous observation of crustal movements in the southern Kanto District, Central Japan, Zisin, 53, 95-99. (in Japanese).

Kato, N. (2001): Effect of frictional heating on preseismic sliding: a numerical simulation using a rate, state, and temperature dependent friction law, Geophys. J. Int., 147, 183-188.

Kato, N., and T. Hirasawa (1999): Nonuniform and unsteady sliding of a plate boundary in a great earthquake cycle: a numerical simulation using a laboratory-derived friction law, PAGEOPH, 155, 93-118.

Kato, N., and T. Hirasawa (2000): Effect of a large outer rise earthquake on seismic cycles of interplate earthquakes: a model study, J. Geophys. Res.,105, 653-662

Kawasaki, I., Y. Asai, and Y. Tamura (2001): Space-time distribution of interplate moment release including slow earthquakes and the seismo-geodetic coupling in the Sanriku-Oki region along the Japan Trench, Tectonophys., 330, 267-283.

Ozawa, S., Mak. Murakami, and T. Tada (2001): Time dependent inversion analysis of the slow earthquake of the Bungo Strait, J. Geogr., 110, 566-580.(in Japanese)

Ozawa, S., Mak. Murakami, T. Tada (2001): Time-dependent inversion study of the slow thrust event in the Nankai trough subduction zone, southwestern Japan, J. Geophys. Res .106 , 787.

Sagiya, T. (2002): Searching for silent earthquake with geodetic data, Bull. Geogr. Surv. Inst., 48, 25-38.

Ueda, H., M. Ohtake, and H. Sato (2001): Afterslip of the plate interface following the 1978 Miyagi-Oki, Japan, earthquake, as revealed from geodetic measurement data, Tectonophys., 338, 45-57.

Yoshioka, S., and H. Suzuki (1999): Effects of three-dimensional inhomogeneous viscoelastic structures on post-seismic surface deformations associated with the great 1946 Nankaido earthquake, PAGEOPH, 154, 307-328, 1999.

Zhao, S., and S. Takemoto (1999): Aseismic fault movement before the 1976 Tangshan earthquake detected by levelling: implications for pre-seismic stress localization?, Geophys. J. Int., 136, 68-82.

6.2.3 Volcanic activities

Bibliography

Kimata, F., H. Mori, and K. Yamamoto (2002): Real time monitor of grand deformation at Usu Volcano using RTKGPS Measurements (April 15-30,2000), J.Volcanol.Soc. Japan, 47, 167-170. (in Japanese with English abstract) Earth Planets and Space, 52, 975-978,2000.

Koyama, J., K. Yomogida, T. Moriya, M. Takada, M. Ichiyanagi, and M. Furuya (2002): Time constant of the 2000 eruption activity of Volcano Usu (in Japanese with abstract in English), Bull. Volcanol. Soc. Japan, 47, 587-594.

Matsushima, T., and A. Takagi (2000): GPS and EDM monitoring of Unzen Volcano ground deformation, Earth Planets and Space, 52, 1015-1018.

Miura, S., S. Ueki, T. Sato, K. Tachibana, and H. Hamaguchi (2000): Crustal deformation associated with the 1998 seismo-volcanic crisis of Iwate Volcano, Northeastern Japan, as observed by a dense GPS network, Earth Planets and Space, 52,1003-1008.

Nishimura, T., Mak. Murakami, M. Tobita, H. Nakagawa, T. Sagiya, T. Tada, F. Suga, J. Fujisaku, T. Tamura, and H. Sato (2000): Crustal movement caused by volcanic activity of Mt. Iwate and M6.1 earthquake at northern Iwate Prefecture and possibility of that volcanic activity triggered the earthquake. J. Geogr. Surv. Inst., 94, 21-30. (in Japanese)

Nishimura, T., S. Fujiwara, Mak. Murakami, M. Tobita, H. Nakagawa, T. Sagiya, and T. Tada (2001): The M6.1 earthquake triggered by volcanic inflation of Iwate volcano, northern Japan, observed by satellite radar interferometry, Geophys Res. Let., 28, 635-638.

Nishimura, T. (2002): Triggering earthquakes by volcanic sources at Ito and Mt. Iwate region, J. Geogr., 111, 166-174.

Otaki, S., F. Suga, T. Tamura, J. Fujisaku, H. Sato, T. Iizuka, M. Sawada, A. Yamagiwa, S. Nishi, T. Imakiire, K. Aoki, K. Sugita, A. Yamada, and T. Miyazaki (2001): Crustal deformation monitoring of Mt. Usu by GPS earth observation network system (GEONET), J. Geogr. Surv. Inst., 95, 29-36. (in Japanese)

Sato, T., K. Kazahaya, A. Suzuki, and N. Matsumoto (2002): Estimation of amplitude of crustal movement by measurement of intervals between poles, Bull. Volcanol. Soc. Japan, 47, 699-704.

Tanaka, M. (2000): Periodic anomalous vertical crustal movement in tectonic regions and its influences on volcanic activities -Sakurajima Volcano-. Rep. Fac. Sci., Kagoshima Univ., 33, 89-100.

Tobita, M., Mak. Murakami, H. Nakagawa, H. Yarai, S. Fujiwara, and P. A. Rosen (2001): 3-D surface deformation of the 2000 Usu eruption measured by matching of SAR images, Geophys. Res. Lett. Vol. 28 , No. 22 , 4291-4294.

Ueki, S., and S. Miura (2002): Volcanic and seismic activities observed around Iwate volcano in 1998, J. Geography, 111, 154-165. (in Japanese with English abstract).

Ueno, K., R. Minami, X. Wu, R. Furuta, C. Nomoto, T. Eto, and M. Tanaka (2002): Crustal deformation in and around Sakurajima volcano (1997-2000). Proceedings of Meeting 13K-7, DPRI, Kyoto Univ., 105-112, March.(in Japanese with English abstract)

6.2.4 Izu/Tokai Area

Bibliography

Aoki, Y., P. Segall, T. Kato, P. Cervelli, and S. Shimada (1999): Imaging magma transport during the 1997 seismic swarm off the Izu Peninsula, Japan, Science, 286, 928-930, 1999.

Ariyoshi, K., N. Kato, and A. Hasegawa (2001): Numerical simulation study on recent changes in crustal deformation and seismicity in the Tokai area, central Japan, J. Geogr., 110, 557-565. (in Japanese with English abstract)

Cervelli, P., M. H. Murray, P. Segall, Y. Aoki, and T. Kato (2001): Estimating source parameters from deformation data, with an application to the March 1997 earthquake swarm off the Izu Peninsula, Japan, J. Geophys. Res., 106 (B6), 11217-11237.

Kaidzu, M., T. Nishimura, M. Murakami, S. Ozawa, T. Sagiya, H. Yarai, and T. Imakiire（2000）: Crustal deformation associated with crustal activities in the northern Izu-islands area during the summer, Earth Planets and Space, 52, ix-xviii.

Kamigaichi, O., J. Takenaka, N. Miyakoshi, T. Koyama, S. Yoshikawa, A. Kobayashi, and T. Yamamoto (2000): Seismic and volcanic activity around Miyake, Niijima and Kozu islands from June 26, 2000 and volumetric strain data of JMA, Earth Monthly, 22, 757-767. (in Japanese)

Kato, N., and T. Hirasawa (1999): A model for possible crustal deformation prior to a coming large interplate earthquake in the Tokai district, central Japan, Bull. Seis. Soc. Am., 89, 1401-1417.

Kawai, K., K. Koyama, N. Sasahara, K. Fukano, M. Sato, M. Kawada, K. Sakuma, H. Fukura, and T. Hatagami (2002): GPS observations for monitoring of crustal movements at Miyake-jima and Kozu-shima, Tech. Bull. Hydrogr., 20, 11-13. (in Japanese)

Kawawa, H., and F. Suga (2000): Monitoring around Tokai area using high resolution vertical positioning analysis network, J. Geogr. Surv. Inst., 93, 34- 43. (in Japanese)

Kimata, F., S. Kariya, M. Fujita, K. Matsumoto, T. Takao, J. Segawa, and A. Yamada (1999): Crustal movements in Kozu Island, Izu Islands in southern Central Japan, detected GPS measurements (July 1996-November 1997). J.Volcanol.Soc.Japan, 44, 13-22.(in Japanese with English abstract)

Kobayashi, A., T. Yamamoto, Y. Hatanaka, K. Maruyama, J. Takenaka, and M. Ogata (2002): Grouping and Correction of GPS Tokai Area 3-hour Analysis, Papers Meteor. Geophys. 53. (in press)(in Japanese)

Nishmura, T., Mak. Murakami, S. Ozawa, M. Ishimoto, T. SAgiya, H. Yarai, T. Tada, Y. Kaizu, and M. Ukawa (2000): Crustal deformation and estimation of its source of before and after the eruption of Miyake Island in 2000., Bull. Earthq. Res. Inst., 77, 55-65.

Nishimura, T., S. Ozawa, M. Murakami, T. Sagiya, T. Tada, M. Kaidzu, and M. Ukawa (2001): Crustal deformation caused by magma migration in the northern Izu Islands, Japan, Geophys. Res. Lett.,28, 3745-3748.

Ochi, K. (2001): A study on real-time analysis system for Omaezaki underground crtustal movement

observation establishment, Tech. Rep. Geogr. Surv. Inst., A.1-No.242, 23-24. (in Japanese)
Otaki, S., F. Suga, T. Tamura, J. Fujisaku, H. Sato, T. Iizuka, M. Sawada, A. Yamagiwa, S. Nishi, T. Imakiire, K. Aoki, K. Sugita, A. Yamada, and T. Miyazaki (2001): Monitoring of crustal deformation associated with volcanic and seismic activity in the area from Miyakejima to Niijima-Kozushima and 2000 Western Tottori Earthquake, J. Geogr. Surv. Inst., 95, 107-113. (in Japanese)
Ozawa, S. et al. (2002): Detection and monitoring of ongoing aseismic slip in the Tokai region, Central Japan, Science, 298, 1009-1012.
Sagiya, T. (1999): Interplate coupling in the Tokai District, Central Japan, deduced from continuous GPS data, Geophys. Res. Lett., 26, 2315-2318.
Sato, M., K. Kawai, K. Fukano, N. Sasahara, T. Yabuki, and A. Sengoku (2002): A source model to explain crustal deformations by earthquake swarm around Izu-Shoto in 2000., Rep. Hydrogr. Res., 38, 71-83. (in Japanese)
Takayama, H., and A. Yoshida (2002): Temporal change of the vertical crustal movement on the western coast of Suruga Bay, central Japan, Phys. Earth Planet. Inter., 132, 21-38.
Terai, K., T. Yabuki, N. Sasahara, K. Kawai, K. Fukano, M. Sato, and A. Sengoku (2001): Crustal movement observation at small islands in Izu Shoto and crustal movements of peripheral sea area by Miyake-Shima eruption, Rep. Hydrogr. Res., 37, 73-86. (in Japanese)
Todaa

(2001) to be due mainly to snow loads along the western flanks of the backbone range. Snow loads are also suggested to influence inland seismicity (Heki, 2003). Understanding and predicting seasonal signals are important in studying subtle transient crustal deformation signals, and intensive studies are needed in the next four years.

Bibliography

El-Fiky, G. S., and T. Kato (2000): Study of periodic vertical crustal movement in the Omaezaki peninsula, Central Japan, and it's tectonics, Earth Planets and Space, 52, 25-35.

Heki, K. (2001): Seasonal modulation of interseismic strain build-up in Northeastern Japan driven by snow loads, Science, 293, 89-92.

Heki, K. (2002): Snow load and seasonal variation of earthquake occurrrence in Japan, Earth Planet. Sci. Lett. (in press)

Murakami, Mak., and S. Miyazaki (2001): Periodicity of strain accumulation detected by permanent GPS array: possible relationship to seasonality of major earthquakes' occurrence, Geophys. Res. Lett., 28, 2983-2986.

6-4.In-situ Deformation Observations

In this report, works using in-situ methods are classified into measurements of crustal tilt and strain (6.4.1) and of groundwater (6.4.2). The latter studies are done mainly by National Institute of Advanced Industrial Science and Technology (AIST) researchers as a basic study for earthquake prediction, and signals related to earthquakes and volcanic activities are reported (e.g. Kitagawa and Koizumi, 2000; Koizumi et al., 1999; Matsumoto et al., 2002). Tilt- and strainmeter observations have been active in Japan for decades, and it was in such data that slow earthquakes were found before the start of nationwide GPS array (Kawasaki, I. et al. (1995): The 1992 Sanriku-Oki, Japan, ultra-slow earthquake, J. Phys. Earth 43, 105-116). New trends in the in-situ tilt/strain measurements are, deployment in deep boreholes, improvement of sensitivities with new technologies, and experimental studies of responses to artificial disturbances such as water injection (Fujimori et al., 2001). Papers on earth tidal strain signals in various observatories in Japan are included in the J. Geod. Soc. ETS2000 special issue (e.g., Ohya et al., 2001; Omura et al., 2001; Onoue et al., 2001).

6.4.1. Tiltmeter, Strainmeter, etc.

Bibliography

Fujimori, K., H. Ishii, A. Mukai, S. Nakao, S. Matsumoto, and H. Hirata (2001): Strain and tilt changes measured during water injection experiment at the Nojima fault zone, Japan, Island Arc,10, 228-234.

Harada, M., T. Furuzawa, F. Ohya, W. Morii, and M. Yamada (2001): Measurement of earth tidal strain in Amagase Observatory, J. Geod. Soc. Japan, 47, 476-481.

Ishii, H., A. Mukai, K. Fujimori, S. Nakao, S. Matsumoto, and H. Hirata (2001): Multicomponent observation of crustal activity in the DPRI 800 m borehole close to the Nojima Fault, Island Arc, 10, 282-287.

Koyama, T., H. Ogasawara, Y. Tamura, N. Koizumi, and K. Fujimori (2001): A quantitative interpretation of the well-tide observation in Chuo Shaft of the Old Ikuno Mine, Hyogo, Japan, Zisin, 53, 325-335. (in Japanese)

Mitsuhata, Y., Y. Ogawa, M. Mishina, T. Kono, and T. Yokokura (2001): Electromagnetic heterogeneity of the seismogenic region of 1962 M6.5 Northern Miyagi Earthquake, northeastern Japan, Geophys. Res. Lett. 28, 4371-4374.

Morii, W. (2001): Ambient temperature changes caused by atmospheric pressure changes in a long tunnel, J. Geod. Soc. Japan,.47, 773-786.

Mukai, A., and K. Fujimori (2001): Elastic constants in fault zone determined using strain changes obtained at an 800 m borehole, J. Geod. Soc. Japan, 47, 470-475.

Mukai, A., K. Fujimori, H. Ishii, and S. Nakao (2001): Strain changes associated with water injection experiment, Earth Monthly, 23, 240-244 (in Japanese).

Mukai, A., and K. Fujimori (2000): Strain changes due to atmospheric loading observed at an 800 m borehole on Awaji Island, J. Seism. Soc. Japan., 53, 57-63. (in Japanese with English abstract).

Ogasawara, H., K. Fujimori, N. Koizumi, N. Hirano, S. Fujiwara, S. Otsuka, S. Nakao, K. Nishigami, K. Taniguchi, Y. Iio, R. Nishida, and Y. Tanaka (2002): Microseismicity induced by heavy rainfall around flooded vertical ore veins. PAGEOPH, 159, 91-109.

Ogasawara, H., Y. Kuwabara, T. Miwa, K. Fujimori, N. Hirano, and M. Koizumi (2002): Post-seismic effects of an M7.2 earthquake and microseismicity in an abandoned, flooded deep mine. PAGEOPH, 159, 63-90.

Ogasawara, H., and The Research Group for Semi-controlled experiments in South African Gold mine (2002): A review of the semi-controlled earthquake generation experiments in South African deep gold mines (1992-2001). In Seismogenic Process Monitoring (Ogasawara et al. eds.), Balkema, 119-150.

Ogasawara, H., S. Sato, S. Nishii, and Research Group for Earthquake Generation Experiments in South African Deep Gold Mines (2002): Temporal variation of seismic parameters associated with an Mw~2 event monitored at a 100-200 m distance. In Seismogenic Process Monitoring (Ogasawara et al. eds), Balkema, 173-184.

Ogasawara, H., S. Sato, S. Nishii, N. Sumitomo, H. Ishii, Y. Iio, S. Nakao, M. Ando, M. Takano, N. Nagai, T. Ohkura, H. Kawakata, T. Satoh, K. Kusunose, A. Cho, A. Mendecki, A. Cichowicz, R. W. E. Green, and M. O. Kataka (2002): Semi-controlled seismogenic experiments in South African deep gold mines, J. South African Inst. Mining Metallurgy, 102, 243-250.

Ohya, F., M. Teraishi, T. Furuzawa, and Y. Sonoda (2001): Measurement of earth tidal tilts with a liquid-tube tiltmeter of half-filled type, J. Geod. Soc. Japan, 47, 58-63.

Omura, M., S. Otsuka, K. Fujimori, and T. Yamamoto (2001): Tidal strains observed at a station crossing the Otsuki Fault, Kobe, Japan, before the 1995 Hyogo-ken Nanbu Earthquake, J. Geod. Soc. Japan, 47, 441-447.

Onoue, K., A. Mukai, and S. Takemoto (2001): Tidal strains observed with extensometers in Donzurubo Observatory, Nara, Japan, J. Geod. Soc. Japan, 47, 141-147.

6.4.2. Groundwater observations

Bibliography

Akita, F., and N. Matsumoto (2001): Coseismic groundwater level changes in hot spring wells in Hokkaido induced by four earthquakes larger than M7.5 between 1993 and 1994, Zisin II, 53, 193-204.

Kitagawa, Y., and N. Koizumi (2000): A study on the mechanism of coseismic groundwater changes: interpretation by a groundwater model composed of multiple aquifers with different strain responses, J. Geophys. Res., 105, 19121-19134.

Koizumi, N., E. Tsukuda, M. Takahashi, T. Sato, N. Matsumoto, H. Ito, Y. Kuwahara, A. Cho, and T. Satoh (1999): Groundwater level observation of Geological Survey of Japan in and around the Kinki District, Japan for earthquake prediction research, J. Balneol. Soc. Japan, 49, 18-33.

Koizumi, N., E. Tsukuda, O. Kamigaichi, N. Matsumoto, M. Takahashi, and T. Sato (1999): Preseismic changes in groundwater level and volumetric strain associated with earthquake swarms off the east coast of the Izu Peninsula, Japan, Geophys. Res. Lett., 26, 3509-3512.

Koizumi, N., M. Takahashi, T. Sato, N. Matsumoto, H. Ito, Y. Kuwahara, A. Cho, and T. Satoh (2002): Changes in groundwater level and crustal strain in and around the Kinki district related to the 2001 Geiyo Earthquake, Zisin, 55, 119-127.

Matsumoto, N. (1999): Detection of groundwater level change related to earthquake, in The Practice of Time Series Analysis, edited by Akaike, H. and Kitagawa G., 341-352, Springer-Verlag New York Inc.

Matsumoto, N., M. Takahashi, N. Koizumi, and Y. Kuwahara (2001): Groundwater level changes and crustal strain at the Haibara observation well, Shizuoka, Japan, Earth Monthly, Suppl. 33 97-102.

Matsumoto, N., T. Sato, N. Matsushima, F. Akita, T. Shibata, and A. Suzuki (2002): Hydrological anomalies associated with crustal deformation before the 2000 eruption of Usu volcano, Japan, Geophys. Res. Lett., 29, 10.1029/2001GL013968.

Takahashi, M., N. Koizumi, T. Sato, N. Matsumoto, H. Ito, Y. Kuwahara, A. Cho, and T. Satoh (2002): Changes in groundwater level and crustal strain in and around the Kinki district related to the Western Tottori Earthquake in 2000, Zisin, 55, 75-82.

6.5.Geophysical Studies in Antarctica

Geodetic studies in Antarctica are done in Japanese Antarctic Research Expeditions (JARE) organized by NIPR (National Institute of Polar Research). The Japanese Syowa Base is equipped with various space geodetic facilities, e.g. VLBI, permanent GPS, DORIS, etc., and researches at this base cover almost every field in geodesy, e.g. sea level studies (Aoki et al., 2000 and 2002), InSAR studies (Doi et al., 1999; Ozawa et al., 1999 and 2000), VLBI (Fukuzaki, 2002) and GPS (Doi et al., 2002). A superconducting gravimeter is also kept at this base as an observing point of the Global Geodynamics Project (GGP) (Sato et al., 2001). Some international joint researches are also done in Antarctica (e.g., Dietrich et al., 2001).

Bibliography

Aoki, S., T. Ozawa, K. Doi, and K. Shibuya (2000): GPS observation of the sea level variation in Lutzow-Holm Bay, Antarctica. Geophys. Res. Lett., 27, 2285-2288.

Aoki, S., K. Shibuya, A. Masuyama, T. Ozawa, and K. Doi (2002): Evaluation of seasonal sea level variation at Syowa Station, Antarctica, using GPS observations. J. Oceanogr., 58, 519-523.

Aoki, S., T. Ozawa, K. Shibuya, and A. Masuyama (2001): Ocean tide observed with differential GPS technique in Lutzow-Holm Bay, Antarctica. J. Geod. Soc. Japan, 47, 181-186.

Aoki, S. (2002): Coherent sealevel response to the Antarctic Oscillation, Geophys. Res. Lett., 29 (12), 10.1029/2002GL015733.

Dietrich, R., K. Shibuya, A. Poetzsch, and T. Ozawa (2001): Evidence for tides in the subglacial Lake Vostok, Antarctica, Geophys. Res. Lett., 28, 2971-2974.

Doi, K., N. Seo, S. Aoki, and K. Shibuya (2002): Sea surface height determination by GPS in sea ice region of Lutzow-Holm Bay, Antarctica, Polar Geosci., 15, 104-111.

Doi, K., K. Shibuya, Y. Nogi, and T. Ozawa (1999): Interferometric SAR images derived from

ERS-1/2 tandem mission data acquired at Syowa Station, Antarctica, J. Geod. Soc. Japan, 45, 351-354 (in Japanese with English abstract).

Fukuda, Y., S. Aoki, and K. Doi (2002): Impact of satellite gravity missions on Glaciology and Antarctic Earth sciences, Polar Meteorol. Glaciol., 16, 32-41.

Fukuzaki, Y. (2000): Measuring the movement of Antarctica by radio signals from space, Kyokuchi (Polar News), Vol. 71, 12-16. (in Japanese)

Fukuzaki, Y. (2002): First precise results of VLBI observation of the baseline in Antarctic Plate, Bull. Geogr. Surv. Inst., 48, 17- 24.

Jike, T., T. Tanaka, K. Shibuya, S. Manabe, Y. Tamura, K.-H. Sato, P. McCulloch, M. Costa, G. Nicolson, J.F.H. Quick, K.M. Shibata, K. Doi, Y. Fukuzaki, D.L. Jauncey, and J. Reynolds (1999): VLBI experiments at Syowa station, Antarctica, Proc. Int. Workshop on Geodetic Measurements by the Collocation of Space Techniques on Earth, CRL Koganai, 150-156.

Ootaki, O., S. Matsumura, K. Maruyama, M. Iwata, and S. Fujiwara (1999): GPS observations on Antarctica by Geographical Survey Institute, J. Geogr. Surv. Inst., 91, 35-42. (in Japanese)

Ozawa, T., K. Doi, and K. Shibuya (2000): Detection of ice flow and deformation of Antarctic ice sheet using JERS-1 SAR interferometry, J. Geod. Soc. Japan, 46, 43-52. (in Japanese with English abstract).

Ozawa, T., K. Doi, and K. Shibuya (1999): Deformation of the Zubchatyy Ice Shelf, Antarctica derived from synthetic aperture radar interferometry, J. Geod. Soc. Japan, 45, 165-179. (in Japanese with English abstract)

Ozawa, T., K. Doi, and K. Shibuya (1999): A case study of generating a digital elevation model for the Soya Coast area, Antarctica, using JERS-1 SAR interferometry, Polar Geosci., 12, 227-239.

Ozawa, T., K. Shibuya, K. Doi, and S. Aoki (2002): Detection of grounding line and vertical displacement of ice shelf by SAR interferometry - A case study for the Stanjukovicha Ice Shelf, East Antarctica, using ERS tandem SAR data -, Polar Geosci., 15, 112-122.

Sato, T., Y. Fukuda, Y. Aoyama, H. McQueen, K. Shibuya, Y. Tamura, K. Asari and M. Ooe (2001): On the observed annual gravity variations and the effect of sea surface height variations, Phys. Earth Planet. Inter., 123, 45-63.

Shibuya, K., and S. Aoki (2002): Summarizing information to update the SCAR-GGI permanent tide gauge observatory sites, Antarctica, SCAR Report, No. 21, 66-68.

Tsuji, H. (2001): Report of SCAR Working Group on Geodesy and Geographic Information, Kyokuchi (Polar News), Vol.72, 23-25. (in Japanese)

6.6.Sea-level Change and Glacial Rebound

There are some studies focusing on sea-level signals related to large earthquakes that occurred before space geodetic era (Kobayashi et al., 2002), but majority of the studies is on the slow deformation (Okuno and Nakada, 2001) and polar wander (Nakada, 2002) to constrain deep density (Nakada, 1999) and viscosity (Nakada, 2000) structure of the Earth done by the Kyushu University group.

Bibliography

Kobayashi, A., N. Manago, and A. Yoshida (2002): Sea level change at Uragami just before the 1946 Nankai Earthquake, J. Geod. Soc. Japan, 48, 1-12. (in Japanese)

Kobayashi, A., N. Manago, A. Yoshida, and M. Higaki (2002): Sea level change before the1944 Tonankai earthquake deduced from tide gauge records, Quarterly Journal of Seismology, 65, 1-43. (in Japanese)

Nakada, M. (1999): Implications of a non-adiabatic density gradient for the Earth's viscoelastic response to surface loading. Geophys. J. Int., 137, 663-674.

Nakada, M., R. Kimura, J. Okuno, K. Moriwaki, H. Miura, and K. Maemoku (2000): Late Pleistocene and Holocene melting history of the Antarctic ice sheet derived from sea-level variations. Marine Geology, 167, 85-103.

Nakada, M. (2000): Effect of the viscoelastic lithosphere on polar wander speed caused by the Late Pleistocene glacial cycles. Geophys. J. Int., 143, 230-238.

Nakada, M., M. Tahara, H. Shimizu, S. Nagaoka, K. Uehira, and S. Suzuki (2002): Late Pleistocene crustal uplift and gravity anomaly in eastern part of Kyushu, Japan, and its geophysical implications, Tectonophys., 351, 263-283.

Nakada, M. (2002) Polar wander caused by the Quaternary glacial cycles and fluid Love number, Earth Planet. Sci. Lett., 200, 159-166.

Okuno, J., and M. Nakada (2001): Effects of water load on geophysical signals due to glacial rebound and implications for mantle viscosity, Earth Planets and Space, 53,1121-1135.

Okuno, J., and M. Nakada (2002): Contributions of ineffective ice loads on sea level and free air gravity, in Ice Sheets, Sea Level and the Dynamic Earth (Geodynamics Research Series, AGU Monograph) (eds. J.X. Mitrovica and L.L.A. Vermeersen), 177-185.

Sato, H., J. Okuno, M. Nakada, and Y. Maeda (2001): Holocene uplift derived from relative sea-level records along the coast of western Kobe, Japan. Quaternary Science Reviews, 20, 1459-1474.

7. Marine Geodesy

Studies on marine geodetic controls are done mainly by the government institute, Hydrographic Department, Maritime Safety Agency, which was recently renamed as the Japan Coast Guard. They are responsible for issuing nautical charts, which recently employed world geodetic system. There are several papers related to this change (e.g. Sengoku, 2000; 2001). Their research activities also include positioning of remote islands, and laser ranging observations using a mobile SLR system have been done for nearly two decades (e.g. Hydrographic Department, 1999; 2002).

Apart from activities based on subaerial geodetic techniques, importance of seafloor positioning has been increasingly recognized by crustal deformation researchers. There are several groups active in this field; joint team of the Japan Coast Guard and the Institute of Industrial Science, University of Tokyo (e.g., Asada and Yabuki, 2001; Yabuki, 2002), the Tohoku University group (Fujimoto et al., 2001), and the Nagoya University group. In addition to positioning, ocean bottom pressure gauges have been developed and deployed to detect vertical crustal movement as well as change in mass of the seawater above the sensor (Fujimoto, 1999).

7.1.Marine Geodetic Controls

Bibliography

Daimon, H., T. Kato, M. Katayama, and Y. Kubo (2002): A new datum transformation software, MGC2000A, Tech. Bull. Hydrogr., 20, 58-70. (in Japanese)

Hydrographic Department (1999): Satellite Laser Ranging observations in 1997, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 12.

Hydrographic Department (1999): Satellite Laser Ranging observations at the marine geodetic control point (Isigaki Sima) in 1997, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 12. (in Japanese)

Hydrographic Department (1999): Satellite positioning of the off-lying islands in 1997, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 12. (in Japanese)

Hydrographic Department (2002): Satellite Laser Ranging observations at the marine geodetic control point (Isigaki Sima) in 1998, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 13. (in Japanese)

Hydrographic Department (2002): Satellite Positioning of the off-lying islands in 1998, DATA Report of Hydrogr. Observ., Ser. Satellite Geod., 13. (in Japanese)

Hydrographic and Oceanographic Department (2002): Satellite Laser Ranging observations at the marine geodetic control point (Isigaki Sima) in 1999, DATA Report of Hydrogr. Observ., Ser.

Satellite Geod., 14. (in Japanese)
Kato, G., A. Sengoku, and M. Katayama (2001): A datum transformation software, MGC2000, Tech. Bull. Hydrogr., 19, 104-109. (in Japanese)
Sengoku, A., M. Fujita, K. Matsumoto, K. Terai, and M. Sasaki (1999): Determination of precise positions of the mainlands and isolated islands in the Japanese territory --a review of marine geodetic control network developed by the Hydrographic Department--, Rep. Hydrogr. Res., 35, 79-95.
Sengoku, A., G. Katoh, H. Fukura, K. Koyama, M. Fujita, and T. Yabuki (2000): Determination of the position of Shimosato by LageosI and LageosII long-arc analysis and transformation parameters between Tokyo Datum and World Geodetic System, Rep. Hydrogr. Res., 36, 97-109. (in Japanese)
Sengoku, A. (2000): World Geodetic System as a geodetic datum of nautical charts, Navigation, No. 144, 37-42. (in Japanese)
Sengoku, A. (2001): World Geodetic System -- its definition and realization -- , J.. Japan. Soc. Mar. Surv. Tech., 13, Vol. 1, 69-75. (in Japanese)

7.2.Seafloor Geodesy

Bibliography

Asada, A. (1999): Development of sea bottom crustal movement detection system, Earth Monthly, Suppl.,24, 106-112. (in Japanese)
Asada, A., and T. Yabuki (1999): Acoustic ranging system for ocean bottom geodesy and synthetic aperture technique of a multi-beam echo sounder, Proceedings of International Workshop on recurrence of great interplate earthquakes and its mechanism, Jan. 20-21, Kochi, Japan, 65-75.
Asada, A., and T. Yabuki (2000): Seafloor acoustic reference network, SEISAN-KENKYU of Inst. Industrial Sci. Univ. Tokyo, 52, 293-296. (in Japanese)
Asada, A., and T. Yabuki (2001): Development and deployment of seafloor acoustic reference network for the detection of sea bottom crustal movements, Ultrasonic Technology, 13, 5, 23-26. (in Japanese)
Asada, A., and T. Yabuki (2001): Synthetic aperture technique applied to a multi-beam echo sounder: Earth Planets and Space, 53, 321-326.
Asada, A., and T. Yabuki (2001): Progress in the long-term seafloor geodesy on Kumano Trough, J. Geogr., 110, 529-543. (in Japanese)
Asada, A., and T. Yabuki (2001): Centimeter level positioning on the seafloor, Proc. Japan Academy, 77, 7-12.

Fujimoto, H., (1999): Long-term ocean bottom pressure measurement and acoustic ranging across the spreading axis of the Southern East Pacific Rise: JAMSTEC J. Deep Sea Res., 14, 35-42 (in Japanese with English abstract).

Fujimoto, H., K. Koizumi, M. Watanabe, A. Oshida, T. Furuta, N. Takamura, and T. Ura (2000): Underwater gravimeter on board the R-One Robot: Proceedings of the 2000 International Symposium on Underwater Technology, IEEE Catalog No. 00EX418, 297-300.

Fujimoto, H., S. Miura, Y. Osada, H. Shiobara, T. Kanazawa, A. Sweeney, J. Hildebrand, and D. Chadwell (2001): GPS/Acoustic seafloor positioning for monitoring seismic coupling in the subduction zone off Sanriku: a progress report, Proc. International Symposium on Slip and Flow Processes in and below the Seismogenic Region, Sendai, Nov. 5-8, 2001, 375-379.

Fukao, Y., Y. Morita, M. Shinohara, T. Kanazawa, H. Utada, H. Toh, T. Kato, T. Sato, H. Shiobara, N. Seama, H. Fujimoto, and N. Takeuchi (2001): The Ocean Hemisphere Network Project (OHP), workshop report of OHP/ION Joint Symposium on Long-term Observations in the Oceans, B. Romanowicz, K. Suyehiro, and H. Kawakatsu (eds.), 13-29.

Nagaya, Y., T. Urabe, and T. Yabuki (1999): Crustal deformation observation at the crest of EPR 18.5S with the seafloor acoustic ranging method, EOS Trans, AGU, 1999 Fall Meeting, 80, No.46.

Osada, Y., H. Fujimoto, K. Koizumi, T. Kanazawa, and H. Murakami (2000): Precise acoustic ranging and positioning, Proceedings of the 2000 International Symposium on Underwater Technology, IEEE Catalog No. 00EX418, 306-311.

Rydelek, P. A., T. Eguchi, I. Watabe, S. Iwasaki, Y. Fujiwara, E. Fujita, and K. Matsumoto (2001): Tidal analysis of data from pressure sensors located at the Sagami Trough, Central Japan, J. Geod. Soc. Japan, 47, 107-113.

Yabuki, T., and A. Asada (2000): Development of a sea-bottom crustal deformation observation system, Proceedings of The Third EU-Japan Workshop on Seismic Risk, Mar. 27-29, Kyoto, Japan , 9-12.

Yabuki, T., Y. Nagaya, and A. Asada (2000): Approach for the realization of sea bottom crustal deformation observation: targets and tactics in waters around Japan, Int. Hydrogr. Rev. (New Ser.), 1, 62-70.

Yabuki, T. (2002): Challenges to observe sea bottom crustal deformations with acoustic ranging technique, Rep. Hydrogr. Res., 38, 47-58. (in Japanese)

8. Earth Tides and Ocean Tidal Loading

Observational studies of solid earth tides using in-situ methods overlap with the chapter 6-4, many of which are included in the special issue of the Journal of Geodetic Society of Japan, ETS2000 special issue. Ocean tides are studied using floating ice displacement (Aoki et al., 2001; King and Aoki, 2002), and by altimetetry from space (Matsumoto et al., 2000). The ocean tidal model obtained by assimilating TOPEX/POSEIDON altimetry data into hydrodynamical model, known as the NAO-99b Model, has been shown to be accurate in the region near Japan more than past models, and has been utilized in various fields of studies, such as seismological studies of tidal triggering of earthquakes (Tanaka et al., 2002). Ocean tidal loading signals are found to be present in domestic GPS observation data (Hatanaka et al., 2001), and it is now easy to incorporate such displacements into space geodetic data analysis procedure owing to the public release of a program GOTIC2, based on the NAO-99b model, at the website of the National Astronomical Observatory (Matsumoto et al., 2001).

Bibliography

Aoki, S., T. Ozawa, K. Shibuya, and A. Masuyama (2001): Ocean tide observed with differential GPS technique in Lutzow-Holm Bay, Antarctica. J. Geod. Soc. Japan, 47, 181-186.

Dietrich, R., K. Shibuya, A. Poetzsch, and T. Ozawa (2001): Evidence for tides in the subglacial Lake Vostok, Antarctica, Geophys. Res. Lett., 28, 2971-2974.

Furuya, M., and S. Okubo (2001): Inland flexure due to ocean tide loading; a possible detection by satellite radar interferometry at Korean peninsula, CEOS SAR Workshop 2001, Tokyo, 2-5 April 2001, NASDA/EORC.

Geographical Survey Institute (1999): Tidal Report 1998, Tech. Rep. Geogr. Surv. Inst., B-2 No.54. (in Japanese)

Geographical Survey Institute (2000): Tidal Report 1999, Tech. Rep. Geogr. Surv. Inst., B-2 No.55. (in Japanese)

Geographical Survey Institute (2001): Tidal Report 2000, Tech. Rep. Geogr. Surv. Inst., B-2 No.56. (in Japanese)

Geographical Survey Institute (2002): Tidal Report 2001, Tech. Rep. Geogr. Surv. Inst., B-2 No.57(in Japanese)

Harada, M., T. Furuzawa, F. Ohya, W. Morii, and M. Yamada (2001): Measurement of earth tidal strain in Amagase Observatory, J. Geod. Soc. Japan, 47, 476-481.

Hatanaka, Y., A. Sengoku, T. Sato, J. M. Johnson, C. Rocken, and C. Meertens (2001): Detection of tidal loading signals from GPS permanent array of GSI Japan, J. Geod. Soc. Japan, 47, 187-192.

King, M., and S. Aoki (2002): Tidal observations on floating ice using a single GPS receiver, Geophys. Res. Lett., in press.

Lee, J. C., C. S. Kim, K. Matsumoto, and M. Ooe (2001): Computation of tides in the northeast Asian sea by blending the Topex/Poseidon altimeter data, J. Korean Soc. Oceanogr., 6, 1-12.

Matsumoto, K., T. Takanezawa, and M. Ooe (2000): Ocean tide models developed by assimilating TOPEX/POSEIDON altimeter data into hydrodynamical model: a global model and a regional model around Japan, J. Oceanogr. 56, 567-581.

Matsumoto, K., T. Sato, T. Takanezawa, and M. Ooe (2001): GOTIC2: A program for computation of oceanic tidal loading effect, J. Geod. Soc. Japan, 47, 243-248.

Ohya, F., M. Teraishi, T. Furuzawa, and Y. Sonoda (2001) : Measurement of earth tidal tilts with a liquid-tube tiltmeter of half-filled type, J.Geod. Soc. Japan, 47, 58-63.

Omura, M., S. Otsuka, K. Fujimori, and T. Yamamoto (2001): Tidal strains observed at a station crossing the Otsuki Fault, Kobe, Japan, before the 1995 Hyogo-ken Nanbu Earthquake, J. Geod. Soc. Japan, 47, 441-447.

Onoue, K., A. Mukai, and S. Takemoto (2001): Tidal strains observed with extensometers in Donzurubo Observatory, Nara, Japan, J. Geod. Soc. Japan, 47, 141-147.

Otaki, S., T. Miyazaki, M. Yazawa, H. Kaneko, T. Kikkawa, and M. Takahara (2000): Accomplishment of tidal observation database started from Meiji 27 (1894), J. Geogr. Surv. Inst., 94, 87-91. (in Japanese)

Shibuya, K., and S. Aoki (2002): Summarizing information to update the SCAR-GGI permanent tide gauge observatory sites, Antarctica, SCAR Report, No. 21, 66-68.

Takanezawa, T., K. Matsumoto, M. Ooe, and I. Naito (2001): Non-equilibrium characteristics of the long-period ocean tides from dynamics and energetics, J. Geod. Soc. Japan, 47, 551-557.

Takanezawa, T., K. Matsumoto, M. Ooe, and I. Naito (2001): Effects of the long-period ocean tides on earth rotation, gravity and crustal deformation predicted by global barotropic model -periods from Mtm to Sa -, J. Geod. Soc. Japan, 47, 545-550.

Tamura, Y. (1999): Analysis of earth tides data, The Practice of Time Series Analysis, eds. H. Akaike and G. Kitagawa, Springer, 327-339.

Tanaka, S., M. Ohtake and H. Sato (2002): Evidence for tidal triggering of earthquakes as revealed from statistical analysis of global data, J. Geophys. Res. 107 ESE1-1 – ESE1-11.

Vella, M. N. J. P., S. Ses, M. Kadir, and K. Matsumoto (2001): Modeling local tidal constituents using TOPEX/POSEIDON SSH for the Malaysian marine region, Marine Geodesy, 24, 99-106.

9. Earth Rotation

Aoyama and Naito (2000; 2001) studied atmospheric contributions to the excitation of the Chandler Wobble and seasonal changes in length-of-day (LOD). Oceanic contribution to the annual polar motion has been studied by Fujita et al. (2002). Long-term polar wander and its relationship with the Earth's rheology was studied by Nakada (2000; 2002). Studies on the secular increase of LOD due to the mechanical evolution of the Earth-Moon system has been extended to Precambrian ages by Abe and Ooe (2001).

Bibliography

Abe, M., and M. Ooe (2001): Tidal history of the Earth-Moon dynamical system before Cambrian age, J. Geod. Soc. Japan, 47, 514-520

Aoyama, Y., and I. Naito (2000): Wind contributions to the Earth's angular momentum budgets in seasonal variation, J. Geophys. Res., 105, 12417-12431.

Aoyama, Y., and I. Naito (2001): Atmospheric excitation of the Chandler Wobble, 1983-1998, J. Geophys. Res., 106, 8941-8954.

Fujita, M., B. F. Chao, S. V. Sanchez, and T. J. Johnson (2002): Oceanic torques on solid earth and their effects on earth rotation, J. Geophys. Res., 107(B8), 10.10292001JB00339

Furuya, M. (2001): Deciphering excitation sources of polar motion by earth system scientific approach, J. Geod. Soc. Japan, 47, 701-710 (in Japanese with English abstract)

Kakuta, C., T. Tsubokawa, and K. Iwadate (2000): Coupling of long oceanic waves in the Pacific Ocean and the rotating elastic Earth during the 1986-1987 El Nino, J. Geophys. Res., 105, 3089-3094.

Kakuta, C., T. Tsubokawa, and K. Iwadate (2002): Effects of the 1986-1987 El Nino on variations of the vertical and the tilt, J. Geod. Soc. Japan, 48, 67-83.

Nakada, M. (2000): Effect of the viscoelastic lithosphere on polar wander speed caused by the Late Pleistocene glacial cycles. Geophys. J. Int., 143, 230-238.

Nakada, M. (2002) Polar wander caused by the Quaternary glacial cycles and fluid Love number, Earth Planet. Sci. Lett., 200, 159-166.

10.Application to Atmospheric and Hydrological Researches

Exploiting the dense GPS array, research in the GPS meteorology is studied. It is overviewed by Ohtani (2002). Iwabuchi et al. (2000) compared GPS retrieved precipetable water vapor with the numerical weather prediction analysis data over the Japanese Islands. Ohtani et al. (2000) compared GPS-derived precipitable water vapors with radiosonde measurements to assess the retrieval accuracy in Japan. Ohtani (2001) made a case study of water vapor variations using GEONET. Shoji et al. (2002) introduces the outline and results of the Tsukuba GPS Dense Net Campaign Observation carried out for 2.5 month. GPS observations in Thailand is performed at five sites for hydrological applications by Takiguchi et al. (2000). The onset of the Asian Monsoon in Thailand was delineated based on GPS sensing of water vapor. Wu et al. (2001) investigated the effects of atmospheric water vapor on GPS positioning in volcanic area. Local atmospheric profile is investigated by Ichikawa et al. (1999; 2000; 2001) by space geodetic techniques and water vapor radiometers. Quickness of data transfer and analysis and quality of GPS satellite orbit information is listed as problems to be solved for near real-time analysis of GPS for water vapor estimate. It is pointed out that there is trade-off between timeliness and accuracy of results (Hatanaka, 1999). Atmospheric mountain lee waves excited by a strong westerly wind ahead of approaching cold front are shown to have significant effect on GPS positioning (Shimada et al. , 2002)). As a tool for a spaceborne remote sensing, high precision satellite gravimetry to measure a temporal fluctuation of fluid mass redistribution within the Earth system is reviewed by Furuya et al. (2000).

Bibliography

Furuya, M., and I. Naito (2000): A new remote sensing technique of fluid mass distribution --satellite gravity and its role in the next generation-- (in Japanese), Tenki, 47(1), 347-355.

Hatanaka, Y. (1999): Issue of GPS data processing for near real-time estimation of water vapor, Meteorological Research Note, 192, 145-158. (in Japanese)

Ichikawa, R., Y. Koyama, T. Kondo, H. Hanado, K. Aonashi, Y. Shoji, Y. Hatanaka, J. Yamamoto, and T. Takamura (1999): Evaluation of wet troposphere delay estimated by space geodetic techniques using water vapor radiometers in the Kanto district of central Japan –preliminary result-, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 235-239.

Ichikawa, R., Y. Koyama, T. Kondo, H. Okubo, H. Hanado, K. Aonashi, Y. Shoji, Y. Hatanaka, J. Yamamoto, T. Takamura, and K. Matsushige (2000): An experimental campaign for evaluation of wet delay variations using water vapor radiometers in the Kanto district、central Japan, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893, 329-331.

Ichikawa, R., H. Ohkubo, Y. Koyama, and T. Kondo (2001): An evaluation of atmospheric gradient using water vapor radiometers in Kashima, Japan, J. Comm. Res. Lab., 48, pp. 97-103.

Iwabuchi, T., I. Naito, and N. Mannoji (2000): A comparison of global positioning system retrieved precipetable water vapor with the numerical weather prediction analysis data over the Japanese Islands, J. Geophys. Res., 105/D4, 4573-4585.

Ohtani, R., and I. Naito (2000): Comparisons of GPS-derived precipitable water vapors with radiosonde observations in Japan, J.Geophys. Res., 105, 26917-26930.

Ohtani, R. (2001): Detection of water vapor variations driven by thermally-induced local circulations using the Japanese continuous GPS array, Geophys. Res. Lett., 28, 151-154.

Ohtani, R. (2002): Results of GPS meteorology project in Japan - Part 1: GEONET Analyses and Applications -, in Proceedings of the Second Workshop of the COST Action 716 "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications", GeoForschungsZentrum, Potsdam.

Ping, J., Y. Kono, K. Matsumoto, Y. Otsuka, A. Saito, C. Shum, K. Heki, and N. Kawano (2002): Regional ionosphere map over Japanese Islands, Earth Planets and Space, 54, e13-e16.

Shimada, S., H. Seko, H. Nakamura, K. Aonashi, and T. A. Herring (2002): The impact of atmospheric mountain lee waves on systematic geodetic errors observed using the Global Positioning System, Earth Planets and Space, 54, 425-430.

Shoji, Y., T. Iwabuchi, H. Seko, H. Nakamura, K. Aonashi, R. Ichikawa, S. Shimada, K. Mishima, A. Itagaki, and R. Ohtani (2002): Results of GPS meteorology project in Japan - Part 2: Tsukuba GPS dense net campaign observation -, in Proceedings of the Second Workshop of the COST Action 716 "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications", GeoForschungsZentrum, Potsdam.

Takiguchi, H., T. Kato, H. Kobayashi, and T. Nakaegawa (2000): GPS observations in Thailand for hydrological applications, Earth, Planets and Space, 52, 913-919.

Wu, X., M. Tanaka, T. Matsushima, K. Arao, T. Oishi, Y. Shoji, and S. Shimada (2001): The effect of atmospheric water vapor on GPS positioning in volcanic area, The Transactions of the Institute of Electronics, Information and Communication Engineers B, J84-B,12, Dec., 2149-2159. (in Japanese)

11. Planetary Geodesy

Planetary mission plan such as the Japanese Moon exploration program named SELENE (SElenological and Engineering Explore) is on-going. Hence, many kinds of development and study were performed..

11.1 Technical Development

In the lunar and planetary exploration, doppler measurement is one of the most effective methods to track the spacecrafts. It is applied to NOZOMI and SELENE mission taking spin modulation into account (Kono et al, 2001; Ping et al., 2000; Ping et al., 2001b, Ping et al., 2001c). Kubo-oka et al., (1999) developed a new radiation pressure model of relay satellite SELENE. A simulation demonstrate the reduction of observation residuals, comparing with the cannonball model. Currently LLR (Lunar Laser Ranging) observations are performed at limited number of sites due to the extremely weak echo. Yoshino et al, (1999a) proposed a system on the Moon composed of an active optical transponder and multiple radio sources. The LLR echo signal on the Earth is dropped to R^{-2} instead of R^{-4} (R: the distance between the Moon and the Earth).

Bibliography

Kono, Y., T. Iwata, H. Hanada, and N. Kawano (2000): Removal of effect of spin on Doppler frequency by using symmetrical antennas, Proc. Japan Society for Aeronautical and Space Science, 1-4. (in Japanese)

Kono, Y., J. Ping, T. Kato, T. Ichikawa, and N. Kawano (2001): Analysis of short period variation of Doppler frequency caused by the spin of Mars spacecraft, NOZOMI, Trans. Inst. Electr. Inform. Comm. Engin. J84-B, 1071-1078. (in Japanese)

Kubo-oka, T., and A. Sengoku (1999): Solar radiation pressure model for the relay satellite of SELENE, Earth Planets and Space, 51, 979-986.

Ping, J., Y. Kono, A. Tsuchiya, and N. Kawano (2000): Effects on Doppler frequency measurment due to the spin and a phase delay pattern of an antenna onboard a spacecraft, J. Geod. Soc. Japan, 46, 187-202.

Ping, J., F. Weischede, Y. Kono, H. Hanada, and N. Kawano (2001a): High frequency components in LP Doppler data, J. Planetary Geodesy, 36, 15-23.

Ping, J., Y. Kono, N. Kawano, H. Hanada, K. Matsumoto, and RISE Group (2001b): SELENE mission: mathematical model for SST Doppler measurements, Prog. Astr., 19, 354-364.

Ping, J., Y. Kono, N. Kawano, and K. Matsumoto (2001c): How S/C tip-off and free nutation affect

Doppler tracking in SELENE, J. Geod. Soc. Japan, 47, 576-582.
Yoshino, T., U. Schreiber, N. Kawano, H. Kunimori, J. Amagai, T. Kondo, W. Schlueter, and J. Degnan (1999a): Lunar laser ranging by optical transponder collocated with VLBI radio sources on the Moon, Laser Radar Ranging and Atmospheric Lidar Techniques II, SPIE Vol. 3865, 20-26.

11.2 Gravitmetry

SELENE project aims at observing thelunar gravity, libration and topography to study the lunar origin and evolution. Heki et al, (1999) performed numerical studies to verify the benefit of including differential VLBI observations in orbit determination of a lunar orbiter and estimation of the lunar gravity field. Matsumoto et al, (1999) studied the impact of far-side satellite tracking on gravity estimation. Plan and the development status of observing system are overviewed (Iwata et al., 1999; Iwata et al.,2000; Iwata et al., 2001; Iwata et al.,2002; Kawano et al.,2000; Kawano et al.,2001). VLBI radio source on the Moon (VRAD) mission is studied by Hanada (1999; 2002) to contribute to establish a lunar gravity field model. Kono et al, (2000) performed a differential VLBI observations using the Lunar Prospector. Kono et al, (2002) performed a test to resolve the cycle ambiguity of the carrier wave by multi-frequency VLBI.

Bibliography

Hanada, H., T. Iwata, N. Kawano, K. Heki, S. Tsuruta, T. Ishikawa, H. Araki, K. Matsumoto, Y. Kono, Y. Kaneko, M. Ogawa, Y. Iijima, Y. Koyama, M. Hosokwa, T. Miyazaki, N. Namiki, A. Sengoku, Y. Fukuzaki, T. Ikeda, F. Fuke, and RISE group (1999): Observation system of radio sources on the Moon by VLBI in SELENE project, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 126-130.
Hanada, H., T. Iwata, T. Kono, K. Matsumoto, S. Tsuruta, T. Ishikawa, K. Asari, J. Ping, K. Heki, and N. Kawano (2002): VRAD mission;precise observation of sub-satellites in SELENE with international VLBI Network, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893.
Heki, K., K. Matsumoto, and R. Floberghagen (1999): Three-dimensional tracking of a lunar satellite with differential very-long-baseline-interferometry, Adv. Space Res., 23, 1821-1824.
Iwata, T., M. Ogawa, K. Yonekura, T. Babauchi, N. Nonaka, N. Namiki, H. Hanada, N. Kawano, K. Heki, Y. Kozai, T. Takano, M. Hosokawa, and RSAT/VRAD mission group, (1999): A conceptual study of the mission instruments for selenodesy using SELENE relay satellite, Proceedings of the

international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 122-125.

Iwata, T., Y. Nagae, M. Takahashi, N. Namiki, and H. Hanada (2000): System design of SELENE relay satellite for selenodesy mission, Proc. 22nd Int. Symp. Space Technology and Science, 1582-1587.

Iwata, T., N. Namiki, N. Kawano, T. Takano (2000): System design of SELENE relay satellite for selenodesy, Proc. 31th Lunar and Planetary Science Conference.

Iwata, T., M. Takahashi, N. Namiki, H. Hanada, N. Kawano, K. Heki, K. Matsumoto, and T. Takano (2001): Mission instruments for lunar gravity measurements using SELENE sub-satellites, J. Geod. Soc. Japan, 47, 558-563.

Iwata, T., T. Sasaki, Y. Kono, H. Hanada, N. Kawano, N. Namiki (2002): Results of the critical design for the selenodetic mission using differential VLBI methods by SELENE, International VLBI Service for Geodesy and Astrometry General Meeting Proceedings, NASA/CP-2002-210002, 377-380.

Iwata, T., T. Sasaki, T. Izumi, Y. Kono, H. Hanada, N. Kawanon, and T. Takano (2002): Properties of the release mechanism of SELENE relay satellite and their influences for the lunar gravity observation, in Proc. 23rd International Symposium on Space Technology and Science, in press.

Kawano, N., H. Hanada, T. Iwata, and Y. Koyama (2000): Differential VLBI observations among a lunar orbiter, the Moon and a QSO, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893, 160-163.

Kawano, N., H. Hanada, T. Iwata, and T. Tsubokawa (2001): Japanese lunar explorer "SELENE" and geodetic observations of the Moon, Astronomy and geodesy in new millennium, 157-160.

Kono, Y., H. Hanada, K. Iwadate, H. Araki, N. Kawano, Y. Koyama, Y. Fukuzaki (2000): Differential VLBI observations of the Lunar Prospector, International VLBI Service for Geodesy and Astrometry 2000 General Meeting Proceedings, NASA/CP-2000-209893, 346-349.

Kono, Y., H. Hanada, N. Kawano, K. Iwadate, Y. Koyama, T. Fukuzaki (2002): Precise positioning of spacecrafts by multi-frequency VLBI, International VLBI Service for Geodesy and Astrometry General Meeting Proceedings, NASA/CP-2002-210002, 179-183.

Matsumoto, K., K. Heki, and D. D. Rowlands (1999): Impact of far-side satellite tracking on gravity estimation in the SELENE project, Adv. Space Res., 23, 1809-1812.

11.3. Rotation Measurements

Hanada et al, (2000a) proposed In situ Lunar Orientation Measurement (ILOM) to study lunar rotational dynamics by direct observations of the lunar physical libration from the lunar surface with an accuracy of 1 milli-arc-second by using a PZT type telescope in the post-SELENE project.

Scientific goals are overviewed by Hanada et al, (2000b) and Heki et al, (1999). Feasibility study of ILOM mission are performed by Kawachi et al. (2000), Takanezawa et al. (2000), Takanezawa et al. (2001), and Yokoyama et al. (2000). Feeasibility study of planetodesy by the inverse VLBI was investihgated (Kawano et al, 1999; Hanada et al, 2001).

Bibliography

Hanada, H., K. Heki, N. Kawano, M. Ooe, T. Tsubokawa, S. Tsuruta, T. Ishikawa, H. Araki, K. Matsumoto, T. Takanezawa, Y. Kono, H. Karoji, T. Iwata, Y. Kaneko, and T. Yokoyama (2000a): Advanced observations of lunar physical librations and gravitational fields in Japanese lunar missions in the near future, ASP Conference Series,208, 623-630.

Hanada, H., K. Heki, T. Iwata, M. Ooe, K. Matsumoto, H. Araki, and ILOM research group (2000b): Scientific goal of in-situ Lunar Orientation Measurement (ILOM), Proc. 22nd Int. Symp. Space Technology and Science, 1609-1614.

Hanada, H., N. Kawano, M. Hosokawa, and M. Imae, (2001): Possibility of observations of rotational fluctuations and tidal deformations of planets by the inverse VLBI method, J. Geod. Soc. Japan, 47, 521-527.

Heki, K., N. Kawano, H. Hanada, M. Ooe, S. Tsuruta, H. Araki, K. Matsumoto, Y. Kono, and RISE group (1999): In-situ Lunar Orientation Measurement (ILOM) with an optical telescope on the lunar surface, Proceedings of the international workshop on GEodetic Measurements by the collocation of Space Techniques ON Earth (GEMSTONE), (Jan., 1999, Koganei), 137-141.

Kawachi, M., K. Funazaki, T. Takanezawa, H. Hanada, and ILOM research group (2000): Technical aspect of ILOM (in-situ Lunar Orientation Measurement) Project - Research and development in a mercury pool -, Proc. 22nd Int. Symp. Space Technology and Science, 1692-1697.

Kawano, N., M. Hosokawa, H. Hanada, and M. Imae (1999): Feasibility study of planetodesy by use of inverse VLBI method, J. Geod. Soc. Japan, 45,181-204.

Takanezawa, T., H. Hanada, S. Tsuruta, Y. Kono. T. Tsubokawa, and ILOM research group (2000): Design of ILOM telescope operating on the Moon, Proc. 22nd Int. Symp. Space Technology and Science, 1615-1620.

Takanezawa, T., H. Hanada, Y. Kono, S. Tsuruta, T. Tsubokawa, M. Kawachi, K. Funazaki, and ILOM research group (2001): Feasibility studies for ILOM (in-situ Lunar Orientation Measurement) Telescope, J. Geod. Soc. Japan, 47, 564-569.

Yokoyama, T., T. Iwata, H. Hanada, N. Kawano, and H. Karoji (2000): Conceptual study for the system of ILOM: in-situ Lunar Orientation Measurement, Proc. 22nd Int. Symp. Space Technology and Science, 1603-1608.

11.4 Topography and others

Araki et al, (1999) reported that RISE (Research In SElenodesy) group in National Astronomical Observatory at Mizusawa developed a laser altimeter (LALT) for the Moon exploration which can measure distance from a satellite to the lunar surface with an accuracy of 5m in every one second. Tsubokawa et al, (2002) summarized the Laser Altimeter for SELENE orbiter. It will acquire the information of smaller scale topographic features to investigate also lunar internal structure, tectonics, and thermal history for selenodesy. Ooe et al, (2001) investigated the lunar tidal effects to the SELENE mission which is planned as a Japanese space program. Araki et al, (1999) showed the focal processes are classified to the tide driving type and tide –triggring type from the 30 major deep Moonquakes investigation. .

Bibliography

Araki, H., M. Ooe, T. Tsubokawa, N. Kawano, H. Hanada, and K. Heki (1999): Lunar laser altimetry in the SELENE project, Adv. Space Res. 23, 1813-1816.

Araki, H. (2001): Focal processes of deep moonquakes, J. Geod. Soc Japan, 47, 508-513.

Ooe, M. and K. Matsumoto (2001): Estimation of lunar tidal effects to the orbits of the lunar orbiters in the SELENE mission, J. Geod. Soc. Japan, 47, 629-639. (in Japanese)

Tsubokawa, T., H. Araki, S. Tazawa, K. Asari, and N. Kawano (2002): Development of Laser Altimeter (LALT) on board SELENE orbiter, Proc. of the 23rd International Symp. on Space Technology and Science, 1986-1991.