The Global Geodetic Observing System (GGOS) - its Role and its Activities

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The Global Geodetic Observing System (GGOS) has been organized under the International Association of Geodesy (IAG) since 1999 to work with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change for both scientific research and to help give us the opportunity to make intelligent decisions for societal benefit. Observations include those of the Earth's shape, gravity field and rotational motion, and those such as precision satellite orbits to support space based systems (such as altimetry and gravity sensors). GGOS contributes to the emerging Global Earth Observing System of Systems (GEOSS) not only with the accurate reference frame required for many components of GEOSS but also with observations related to the global hydrological cycle, the dynamics of atmosphere and oceans, and natural hazards and disasters.

GGOS advocates for implementation of core and co-location network sites to satisfy GGOS requirements, monitors the present state of the networks and projects their future status, and supports and encourages maintenance and improvement in the infrastructure critical for the development of data products essential to GGOS.

GGOS is focused on the IAG Services and the products they derive on an operational basis for Earth monitoring making use of various space geodetic observation techniques such as VLBI, SLR/LLR, GNSS, DORIS, altimetry, gravity satellite missions, etc. GGOS builds upon existing observing and processing systems of the IAG, supporting its goal of obtaining products of highest possible accuracy, consistency, and temporal and spatial resolution, which should refer to a consistent reference frame, stable over decades in time. To achieve these important IAG goals, GGOS supports the fundamental requirement that common standards and conventions are used by all IAG components for the analysis of the different geometric and gravimetric observations.

In this talk, we will discuss the role of GGOS, its current status and structure, and plans as we move forward.

Keywords: Space Geodesy, VLBI, SLR, GNSS, Gravity , Co-located geodetic measurements

International and Japanese Activities of Satellite Laser Ranging for Global Geodesy

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For more than 50 years, the Satellite Laser Ranging (SLR) technique has played a key role in geodesy and orbital dynamics. SLR data have been used continuously to to study the dynamic Earth, the Earth-Moon system, and fundamental constants, and to provide a better understanding of our global environment.

In cooperation with the IAG’s (International Association of Geodesy) Global Geodetic Observing System (GGOS), space and ground based techniques are working together to develop and improve data products that rely on their combination of strengths and unique capabilities. A good example is Terrestrial Reference Frame (TRF), which is the basis for our metric measurements of global change, including the detection and monitoring of small global-scale signals. The TRF is a product of the combination of SLR with GNSS (Global Satellite Navigation System), VLBI (Very Long Baseline Interferometry) and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) combined into a product of accurate fiducial station positions and velocities. SLR uniquely provides the reference frame origin and with VLBI, its scale. Laser ranging is also now an emerging tool for accurate time transfer between clock in the Earth and in space.

One great strength of SLR lies in the use of optical wavelengths. It can yield a high-precision, unambiguous two-way distance between a ground station and a satellite, and its measurement is not affected by ionosphere and less affected by troposphere. SLR systems are operating at sub-centimeter precision. Newer technologies, already implemented at some of the stations, are approaching 1 mm precision.

The number of SLR targets is increasing rapidly. In addition to the spherical geodetic satellites, laser reflectors are being carried on altimetry, gravimetry, Earth observation, navigation, and space engineering satellites. The ILRS presently tracks about 90 satellites.

Since the late 1960s when Tokyo Astronomical Observatory (current National Astronomical Observatory of Japan) tested SLR at Dodaira, Japanese stations have participated in the international SLR community. Three SLR stations, Shimosato, Koganei and Tanegashima, are being operated in Japan. In addition, JAXA (Japan Aerospace Exploration Agency) has launched a number of SLR satellites including the 30-year-old Ajisai satellite, which is still being tracked for orbit dynamics and Earth science. The Japanese SLR community and space geodesy community hope to explore new challenges in SLR observations, data analysis and satellite missions so as to effectively yield the global-scale geodetic products in cooperation with International Laser Ranging Service.

Keywords: GGOS, Satellite Laser Ranging

Performance Aspects of the Next Generation Lunar Retroreflector

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The ability of the Next Generation Retroreflector (NGR) (a.k.a. The Lunar Laser Ranging Array Retroreflector for the 21st Century and/or MoonLIGHT) depends heavily upon a detailed thermal simulation to assure that the NGR will perform according to the requirements of the nominal design. This performance objective is to assure 80% of the peak return at all times during a lunation (assuming the NGR is pointed correctly at the earth). There are three phases in addressing this issue: Phase 1 consists of using a rigorous Solar/Orbital/Optical/ Thermal/Optical (SOOTO) simulation. This has been described briefly in earlier presentations. The SOOTO is used to evaluate the effects of the reflectivity, emissivity and conductivity of various elements of the NGR, to allow the selection (where feasible) of these parameter to obtain the design performance. Phase 1 will be the primary focus of this talk, illustrating some initially surprising results. Phase 2 addresses the effects of angular offsets of the back faces of the CCR and the effects of the phase shifts due to Total Internal Reflection. This allows the optimization of the angular offsets of the back faces of the CCR and the orientation of the CCR. Phase 3 consists of incorporating the Phase 2 results and re-evaluating the effect of the parameters studied and selected in Phase 1. Further, several other topics will be briefly reviewed: The new design to address the second landing site, the effects of break-through in solid CCRs, detailed simulations of the effects of atmospheric propagation and the testing of a candidate for a low visible absorption high thermal infrared emissivity coating.

Keywords: Lunar Laser Ranging, Next Generation Retroreflector, Solar/Orbital/Optical/Thermal/Optical Simulation

VGOS development for Ishioka 13-m antenna

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The Geospatial Information Authority of Japan (GSI) constructed a new VLBI facilities in Ishioka. It is designed for the next-generation VLBI system called VGOS, which is promoted by the International VLBI Service for Geodesy and Astrometry (IVS) in order to meet the requirements of Global Geodetic Observing System (GGOS). In addition to the VGOS facilities, Ishioka has GNSS Continuously Operating Reference Stations and a gravity measurement facility in order to contribute to GGOS as a core observatory.
Since February 2015, the Ishioka 13-m antenna observed legacy S/X sessions with Tsukuba 32-m to obtain accurate positions of the new site. Then, Ishioka has started the international observations dedicated for Earth rotation measurement taking over the role of Tsukuba 32-m from the beginning of 2017. In parallel with these legacy observations, we have carried out several broadband observations compatible with VGOS frequency setup. From August to September 2016, we installed a new signal chain including QRFH (Quadruple-ridged flared horn), up-down converters, and high speed digital samplers at Ishioka in order to participate in VGOS Trial sessions which were broadband observations coordinated by IVS. Several experimental broadband observations with Kashima 34-m of NICT and Hobart 12-m of AuScope were also performed, and the compatibility of equipment between Ishioka and other overseas stations was confirmed. We report on the recent development of VGOS equipment and results of the legacy and broadband sessions for Ishioka.

GGOS and the Gravity Field Studies

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During the IUGG General Assembly in Prague 2015, the IAG adopted two Resolutions; No. 1 (R1) for the definition and realization of an International Height Reference System (IHRS) and No. 2 (R2) for the establishment of a Global Absolute Gravity Reference System (GAGRS). As ITRF is the realization of ITRS, IHRF and GAGRF are the realization of IHRS and GAGRS, and they should be visible outcomes of GGOS. IAG R1 describes that the vertical coordinate of a point P is given by the difference between the gravity field potential at the point and at the geoid (W0). This procedure is nothing but the precise geoid determination. IAG R2 describes the direction to establish GAGRS and its meanings, and it looks more directly related to the gravity field studies. In addition, International Geodynamics and Earth Tide Service (IGETS), which is a service of IAG, have officially started during the IUGG in Prague. IGETS is expected to monitor temporal variations of the Earth gravity field. It is an important conponent of GGOS. In this talk, by reviewing the IAG resolutions and the role of IGETS, GGOS and the gravity field studies are discussed.

Keywords: International Height Reference System, Global Absolute Gravity Reference System, International Geodynamics and Earth Tide Service , Earth Gravity Field

The Contribution of Global Geodetic Observations to Understanding Dynamic Earth Processes

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The Earth is a dynamic system—it has a fluid, mobile atmosphere and oceans, a continually changing global distribution of ice, snow, and water, a fluid core that is undergoing some type of hydromagnetic motion, a mantle both thermally convecting and rebounding from the glacial loading of the last ice age, and mobile tectonic plates. In addition, external forces due to the gravitational attraction of the Sun, Moon, and planets also act upon the Earth. These internal dynamical processes and external gravitational forces exert torques on the solid Earth, or displace its mass, thereby causing the Earth's figure, rotation, and gravitational field to change. Geodetic observing systems, both space-based and ground-based, provide the measurements of the Earth's figure, rotation, and gravitational field that are used to study these dynamical processes and the response of the Earth to them. Geodetic observations also provide the metrological foundation for Earth observations and provide the means to determine mass transport in the Earth system. Geodetic observations are therefore a cornerstone of the Earth observing systems needed for scientific research and societal applications. In this presentation, selected examples of the contribution of geodetic observations to understanding the dynamic Earth system will be presented.

Keywords: GGOS

The United Nations General Assembly Resolution on A Global Geodetic Reference Frame for sustainable development

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The United Nations General Assembly adopted its resolution, “A Global Geodetic Reference Frame for Sustainable Development”, on February 26, 2015, recognizing that Global Geodetic Reference Frame (GGRF) is essential fundamental infrastructure for social, economic and scientific activities. This resolution is the first resolution on the importance of a globally-coordinated approach to geodesy and urges Member States to jointly develop and maintain sustainable GGRF under globally-coordinated multilateral cooperation. The resolution includes six Operational Paragraphs which urge Member States to establish a Roadmap for the enhancement of GGRF, enhance technical assistance and capacity building on geodesy, and maintain and improve their geodetic infrastructure and so on. Working Group established by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) for drafting the resolution also drafted the Roadmap and the Roadmap was adopted by UN-CCIM at its sixth session in August 2016. In the roadmap, the Working Group clarifies current issuers for maintenance of sustainable GGRF, then suggests the possible solutions and finally presents future vision for the further enhancement of GGRF on the five items indicated in the resolution, that is Geodetic Infrastructure, Data Sharing, Policies, Standards and Conventions, Education, Training, and Capacity Building, Communication and Outreach, and Governance. The Geospatial Information Authority of Japan (GSI) has contributed to drafting of the Roadmap as a member of the WG and will participate in the sub-committee and contribute to drafting of the implementation plan.

In the presentation, I will brief the resolution on Global Geodetic Reference Frame for Sustainable Development and current situation on International Terrestrial Reference Frame (ITRF) which is practical de-facto standard for GGRF.

Keywords: Global Geodetic Reference Frame (GGRF), the United Nations, GGRF Roadmap

SLR continuous observation at the Shimosato Hydrographic Observatory after 1982

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Satellite Laser Ranging (SLR) plays an important role for the Global Geodetic Observation System (GGOS). The Hydrographic and Oceanographic Department of the Japan Coast Guard (JHOD) has conducted the SLR observation at the Shimosato Hydrographic Observatory (SHO) since 1982. For 35 years, the SLR observation at the SHO made a great contribution to establishing a world geodetic system as a national geodetic system in Japan in 2002. The Shimosato station also observed crustal movements of the 2004 Kii Peninsula earthquakes and the 2011 Tohoku-oki earthquake. In addition, the Shimosato station also plays a role as the mainland reference point of the marine geodetic control network based on MGC2000. In this presentation, we review results of the SLR observation at the SHO. The fact that the SLR observation was continuously performed at the same point for 35 years is significant for not only a framework of a national geodesy in Japan but also a global geodetic framework. It is also valuable to discuss a framework of the future GGOS.

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Keywords: SLR, Laser ranging

Satellite Laser Ranging Network: Where Should a New Station Be Placed? [Part II] For Better Satellite Orbits

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Precise orbits of artificial satellites are not only useful for flight dynamics and geodetic products but also important for monitoring the phenomena of the changing Earth such as sea level rise and ice melting. Satellite Laser Ranging (SLR) is one of the most precise techniques to determine the orbits of satellites. About 35 SLR stations are being operational all over the world but the distribution of the current station network is not uniform. In particular, there are only 7 stations in the Southern hemisphere and there is no stations below 37 degrees latitude. It is found that this results in relatively less accurate orbit determination in the southern hemisphere.

A virtual station is added to the existing SLR network to evaluate the impact of a future station. The simulation procedure is similar to our previous study (Otsubo et al., EPS, 2016). Combining a simulated data set of a virtual station to the real existing data set, orbit determination procedures are simulated. For instance, assuming an active SLR station at Syowa (69S, 39E), the time-varying formal errors of Jason-2 and Cryosat are improved in the southern high latitude region by 20 to 30%.

Keywords: GGOS, Satellite Laser Ranging, Precise Orbit Determination

Time variation of solar radiation pressure acceleration acting on geodetic satellites

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Solar radiation pressure is one of the major error sources in satellite geodesy. Solar radiation pressure acting on a satellite varies in accordance with how sunlight illuminates its surface and how it is reflected. The cannonball model widely applied for spherical geodetic satellites rests on the following assumption: the satellite is a perfect sphere and the optical properties of its surface is spherical symmetry. Applying this model, a solar radiation pressure coefficient C_R is often adjusted as a scale factor. This study focuses on the time variation of the C_R solutions.
We use the geodetic analysis software "c5++" (Otsubo, 2016) to estimate the C_R coefficients of the six geodetic satellites: Ajisai, LAGEOS-1, LAGEOS-2, LARES, Starlette and Stella. Satellite laser ranging data for the past 20 years are analyzed where the C_R coefficients are estimated per 30 days.
An interesting behavior is observed in the time series of Ajisai’s C_R estimates. It ranges from 1.022 to 1.064, and shows a clear semiannual pattern maximizing in summer and winter. The 0.04 variation of Ajisai’s C_R value is equivalent to a 1.0 nm/s^2 difference in the acceleration acting on the satellite (Hattori, 2016).
Sengoku et al. (1995) constructed a solar radiation pressure model of Ajisai based on its surface materials. The C_R is predicted to vary in a range from 1.020 to 1.035 and show a dominant annual pattern with a maximum in summer. This does not agree well with our solutions above.
We attribute the reason of the discrepancy to the following two facts. One is that a 5-cm-height metallic ring is attached to one of the pole the satellite and the effective cross-section area becomes larger when the satellite is illuminated from inclined angles in summer and winter. This seasonal variation of the effective cross-section area results in a semi-annual variation of the C_R estimates. The other is that the difference of optical reflectivity between its equatorial region and the polar regions are found to be more than the difference between the two polar regions.

Keywords: satellite laser ranging, solar radiation pressure, Ajisai

SLR monthly gravity solutions using the C5++ software

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This study presents monthly gravity solutions up to degree and order 4 for the period 1993-2015 derived by Satellite Laser Ranging (SLR) data using the C5++ software [Otsubo et al., 1994]. Here, we apply the following modifications to the previous solutions by Matsuo et al. (2013). First, Range bias is estimated for per station and per satellite. Secondly, station coordinates are solved for using no-net-rotation constraints. Thirdly, non-tidal effects for atmosphere, ocean, hydrology are corrected using geophysical fluid models. Last, one-per-rev empirical accelerations are estimated in along-track and cross-track. Consequently, our new SLR solutions exhibited better consistency with those from Gravity Recovery And Climate Experiment (GRACE) than the previous solutions in the degree 3 and 4 components. The improvements of SLR gravity solutions provides further insight into the mass variability of the earth prior to the launch of GRACE in 2002.

Keywords: Time-variable gravity, Satellite Laser Ranging, Space geodesy

Activities of the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV)

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The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) was established in 2014 as a subgroup of the International VLBI Service for Geodesy and Astrometry (IVS) in order to foster regional collaboration of VLBI. AOV coordinates six regional sessions in a year on regular basis by sharing resources of scheduler, stations, and correlators. AOV members are also enhancing their close collaboration by sharing information of recent activities in several face-to-face meetings. Successful broadband VLBI experiments with telescopes in Australia and Japan in August 2016 marked the start of VGOS in this region under the collaboration of AOV. We talk on the recent activities of the AOV.

Keywords: VLBI, IVS

The GSI contribution to the IGS

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Geospatial Information Authority of Japan (GSI) has started GNSS continuous observation in tracking stations since 1991. Five years later, GSI started operation of nationwide continuous observation system called GEONET (GNSS Earth Observation Network System), which now consists of more than 1300 stations.

Some stations of GEONET operated by GSI are registered as International GNSS Service (IGS) stations. GSI has participated in IGS since the establishment of the IGS and has played an important role as an operational data center and Regional Network Associated Analysis Center (RNAAC).

GSI operates 7 IGS stations including 6 stations in Japan, and SYOG station located in Antarctica. Some equipment satisfying IGS specification are installed at these stations, e.g. atomic clock to keep precise time stamp at each station. We have also participated in recently launched M-GEX project and RTS Service for further contribution to IGS. These data support the high-quality IGS products and construction of International Terrestrial Reference Frame, which also benefit us to conduct coordinate analysis of GEONET stations in Japan. We will continue to cooperate with IGS.

We show the GSI contribution to IGS from beginning of continuous GNSS observation.

Keywords: GEONET, IGS, GNSS

Verification of accelerated vertical crustal movements in the Tohoku region prior to the 2011 Tohoku-Oki earthquake by reanalysis of GEONET data using Precise Point Positioning

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Homogeneous coordinate time series data over a decade from GNSS analysis is essential for investigation of various phenomena preceding massive earthquakes such as the Tohoku-Oki earthquake. Kurokawa (2016) found a significant difference between vertical velocities obtained from GNSS and those from tidal record during 2003~2011. This suggests that the long-term homogeneity of the GNSS result is questioned. Routine processing of GEONET, the GNSS continuous observation network in Japan, currently adopts the network analysis strategy (F3 solution). However, such strategy may generate bias in analysis result because the combination of baselines has changed in response to the increase of the number of stations. In this study, we reanalyze the daily coordinate of 30 GEONET stations along the coast of Tohoku region for the last 20 years by using Precise Point Positioning method (PPP) in order to get rid of bias due to network analysis. We compare the velocities obtained from the F3 solution and our PPP result. In the horizontal components, the differences are about 1~1.5 mm/yr before the Tohoku-Oki earthquake. In the vertical component, large differences of about 2~3 mm/yr are found before 2003, and gradually decrease to smaller than 0.5 mm/yr just before the Tohoku-Oki earthquake. Even if the difference is small, there exist systematic differences in many cases. We estimate the vertical acceleration before the Tohoku-Oki earthquake. Our PPP result shows no significant change along the Japan Sea coast, and accelerated subsidence along the Pacific coast (about -0.3 mm/yr^2). This result is consistent with the horizontal acceleration indicated by Mavrommatis et al. (2014) and the accelerated subsidence by Kurosawa (2016). Furthermore, this suggests that the construction of a network for the F3 solution is one of the causes of the common mode error, because Mavrommatis et al. (2014) and Kurokawa (2016) eliminated such errors by using spatial filtering technique.

Keywords: Precise Point Positioning, accelerated vertical crustal movements, GEONET

Implementation of Domestic Comparison of Absolute Gravimeters Ishioka Geodetic Observing station and construction of Japan Gravity Standardization Net 2016 (JGSN 2016)

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Geospatial information authority of japan (GSI) has held the Domestic Comparison of Absolute Gravimeters (DCAG) annually since 2002 with several domestic organizations which own absolute gravimeters. By comparing with the results of the FG5 absolute gravimeters, which is operated by the National Institute of Advanced Industrial Science and Technology (AIST) and routinely participate in the International Comparison of Absolute Gravimeters supported by BIPM, we could expect to confirm the consistency of our equipment with international standard.
While DCAG had been held at a hotel located in Mt. Tukuba area until 2015, it was done at GSI’s new Ishioka Geodetic Observing Station (Ishioka city, hereinafter referred to as Ishioka station) in 2016. Since Ishioka station has a special room for DCAG as described later, it is expected that we can conduct DCAG much more precisely under better environment.
The gravity measurement facility of Ishioka station is very unique in several respects. It is firmly coupled to the support layer with a plurality of concrete piles and its base plate is isolated from the building in order to reduce the effect of ground vibration. It is designed to set up six absolute gravimeters simultaneously on each points which have precise coordinates decided by GNSS and leveling before the construction. Since Ishioka station also has the VLBI facility, we can utilize the distributed hydrogen maser 's signal to minimize clock errors between absolute gravimeters. Of course, we can expect less artificial noise because of its suburban location. Thanks to those improvements, we successfully achieved good results in the latest DCAG within the range of instrumental error.
GSI has released a new Japan Gravity Standardization Network (JGSN) 2016 in March 2017 for the first time in 40 years. It was composed of both absolute and relative gravity measurement data carried out by GSI between 2002 and 2016. On the course of its measurements, we used our FG5 calibrated by DCAG to determine the absolute gravity values. DCAG obviously played a key role in making JGSN2016 highly reliable and consistent with the global gravity standards.
We will report the results of past DCAG and its contribution to the JGSN2016.

Keywords: Japan Gravity Standardization Net 2016 (JGSN2016), Absokute gravity measurement, Domestic comparison of Absolute Gravimeters

On-site Frequency Measurements of a Rubidium Oscillator for Gravimeters

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It is important for precise gravity measurement to calibrate the frequency of a rubidium oscillator as a time frequency standard. We demonstrate simple on-site frequency measurement by using a time frequency calibration tool (FT-001A) with a GPS common view method. We equipped one at F-net IGK station, Ishigaki, Japan and measured frequency variation of the internal rubidium oscillator of gPhone gravimeter (S/N 133). As a result, we could measure its frequency with uncertainty of approximately 10^{-12} (0.01 mHz) on the gravity station 2,000 km apart from AIST Tsukuba where UTC(NMIJ) is maintained.