Development of New GEONET Analysis Strategy: Incorporating GLONASS Observations Data

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1. GSI of Japan

Geospatial Information Authority of Japan (GSI) has been operating CORS system involving over 1300 GNSS stations, called GEONET (GNSS Earth Observation Network System), since 1996. The daily coordinates for each station are estimated by Bernese GNSS software to monitor the crustal deformation in Japan. The analysis strategy was updated three times. Current version is called F3, which was established in 2009. We are now developing new strategy (F4), because the software, reference frame, and other physical models used in F3 have been obsolete. Major topics of F4 development are 1) Updating reference frame, 2) GPS and GLONASS integration, 3) Improvement of the troposphere model, and 4) Stabilizing the daily coordinates of the reference station (TSUKUBA-1) for the whole GEONET analysis.
In this paper, we focus on the topic 2: GPS and GLONASS integration. Only GPS was used for F3 or older strategies. However, the receivers and antennas in GEONET were already updated into the multi-frequency type in 2013, preparing for the multi-GNSS environment. Furthermore, the final orbit for GLONASS provided by IGS has reached almost the same accuracy in comparison with the one for GPS (according to IGS web site, ~3cm for GLONASS and ~2.5cm for GPS). Such circumstances enable us to process GLONASS data by Bernese software. We process GPS and GLONASS data independently to estimate the ambiguities, and then combine the solutions with normal equations. The result based on GLONASS observations data shows the apparent fluctuation with the period of 8 days that was not found on the GPS result. Such a phenomenon is significant for the stations apart from the reference station. Several IGS analysis centers using GLONASS observations reported the same phenomenon that seemed to be caused by the GLONASS constellation geometry (Ray et al., 2013, Rebischung et al., 2016). We discuss the method to suppress the apparent 8-day fluctuation in our presentation.

Keywords: GEONET, GNSS, F4, ITRF2014, GLONASS

Elucidation of the internal evolution and rotation effect of the Earth based on high sensitive observations of earth strain

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There is a fluid core in the Earth consisting of about half radius of the whole Earth and it can rotate around the axis different from that of the mantle. It is thought from theoretical estimation that the motion of the fluid core is related with the figure of the core-mantle boundary (CMB), density distribution, temperature distribution, a magnetic field, viscosity, but the details are still unclear. It is an effective way for this study to observe the free core nutation (FCN) which is a rotational motion of the whole earth caused by the motion of the fluid core. Because its period is very close to that of diurnal tides, they are amplified by resonance. Their amplitude must be terribly big if their periods coincide.

The Z-term which is a great discovery by Hisashi Kimura is a good example showing the motion of the Earth's axis caused by the fluid core. The Very Long Baseline Interferometer (VLBI) has observed the CMB as a motion of the rotational axis of the Earth relative to the inertial space and discovered that the CMB is a little oblate. However, there is few geodetic observations succeeded in detection of FCN as surface deformation because of its small amplitude. We expect to know the density structure of the core, electromagnetic coupling at CMB other than the figure of CMB if we observe the effect of FCN on the ground.

The tidal components having periods close to that of FCN are ψ_1 and ϕ_1, and they are not amplified very much because the periods are still apart at present. However, if the Earth changes its rotation speed, the relation between the periods of the tidal components and FCN will change, because the former is related to only the rotation speed but the latter depends on both the rotation speed and the figure of MB. Therefore, there might have been a time when both periods coincided. Based on a model of the Earth’s rotation history, we estimated the yearly variation of the relation between the periods of tidal components and the FCN. We suppose that only the rotation speed changes and the orbits of the sun and the Moon do not change. The dynamic flattening of the core is supposed to be in proportion to the square of the angular velocity of FCN. The history of the rotation speed in the geologic time is based on the result of Ooe and Abe (2002) which went back to 1,200 million years ago.

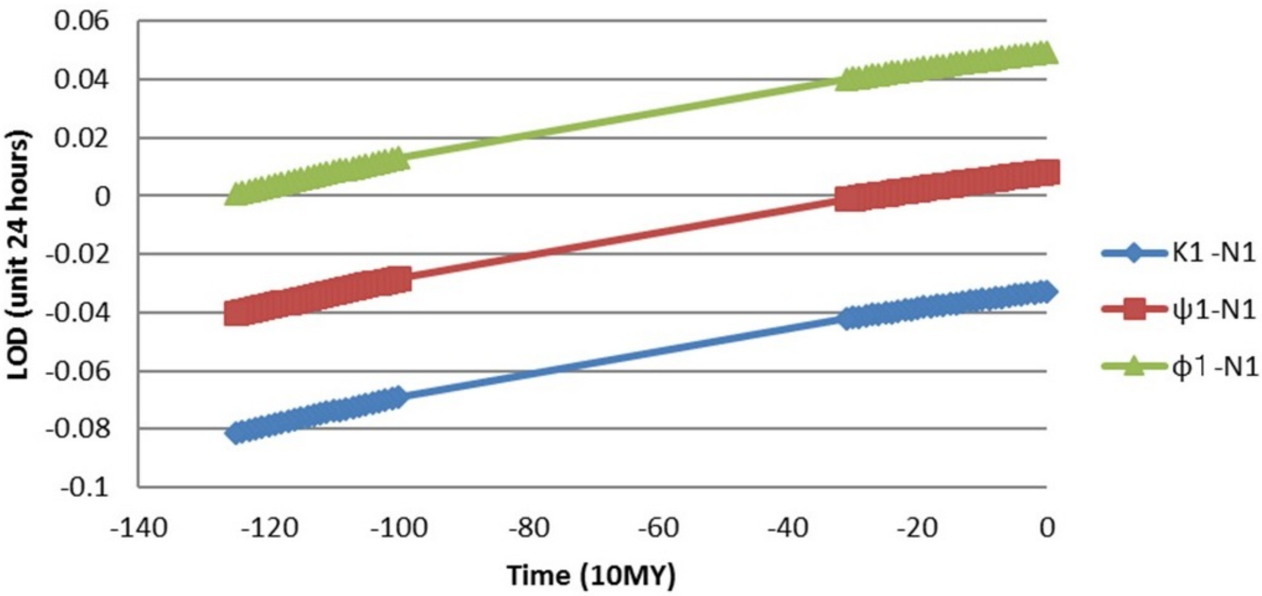
Figure shows the result of calculations from present to 1.4 billion years ago. The vertical axis indicates length-of-day (LOD) in the unit of the mean solar day at present and the difference between the periods of tidal components and FCN is shown. We find that the period of N_1 coincided with that of ψ_1 at approximately 280 million years ago, and that ϕ_1 coincided with it at 1.25 billion years ago. There must have been catastrophic at those times. The model of the history of the Earth rotation used here does not include the effects of such as the continental drift and ups and downs of glaciers, which might have big influence on the Earth rotation. However, we can say that the periods of tides could be the same as that of FCN in the past even in the simple model.

It was recently revealed that the change of the rotation speed with the period of several million years had some relation with the change of the strength of the magnetic field of the Earth (Miyakoshi, Hamano, 2013). The simulation shows that the speed change of approximately 2% in the Earth rotation causes

change of approximately 20-30% in the strength of magnetic fields. Physical mechanism governing the fluid core may become more clear if we can observe the effect of FCN on the deformation of the Earth, and it will contribute to the prediction of the future environment related to slowdown of the rotation speed and disappearance of the magnetic field.

We are planning to measure deformation of the Earth in high sensitivity with the optical fiber interferometer of long baseline.

Keywords: Free Core Nutation, Fluid Core Resonance, Earth strain, Optical Fiber Interferometer



On the Interpretation of oceanic variations in terms of ocean bottom pressure

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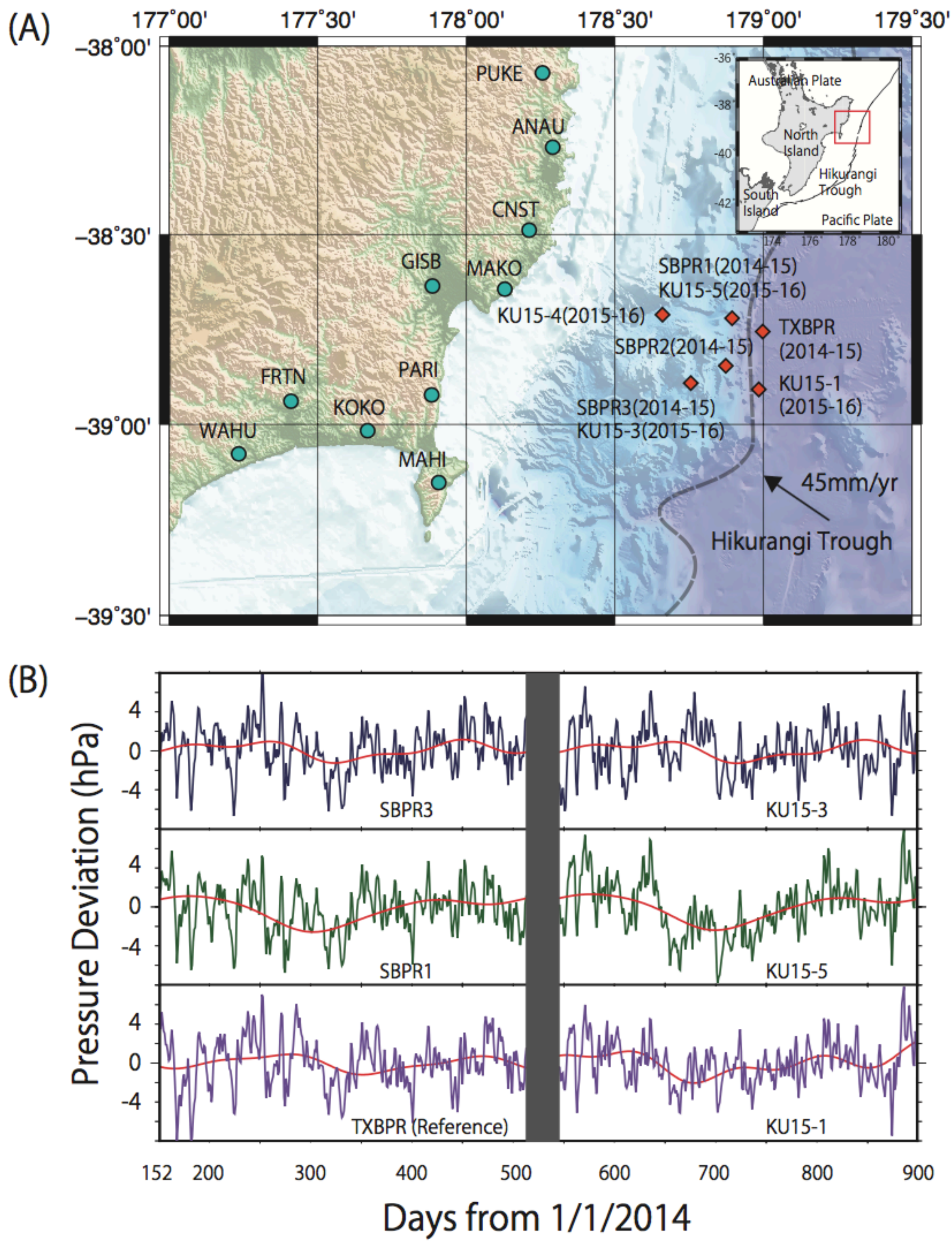
SSE is the phenomenon that rupture progress slowly compared with regular earthquake. Many examples are reported all over the world. (e.g. Yoshioka et al., 2004) Also, this phenomenon was observed before 2011 Tohoku earthquake. It is thought that deformation in the SSE area at the time of the main shock contribute to tsunami damage. (e.g. Ito et al., 2013) In general, the detection of SSE on the subduction zone, especially at the shallower part is difficult using only GNSS data. Therefore, the study for the sea floor crustal deformation observation and monitoring are receiving attention recently. Among them, the observation using Ocean Bottom Pressure Recorder is useful for observing crustal deformation due to SSE at a point where it can observe pressure change including vertical crustal deformation component in high resolution continuously. On the other hand, to extract the pressure change due to crustal deformation from Ocean Bottom Pressure Record, it is essential to understand exactly what caused the observed pressure change.
In this study, we consider about the factor of sea floor pressure change, especially temporal variation of several months to annual cycle from observed data. In this study, we use observed pressure records which spanned from June 2014 to June 2016 at off the coast of north island in New Zealand and Kumanonada using independent type Ocean Bottom Pressure Recorders. By using Baytap-G, we calculated the tidal component and subtracted it from the raw data. Then, we calculated sea-level anomaly (non-tidal oceanic variation) driven by air pressure and wind using barotropic ocean model. Comparing with Ocean Bottom Pressure Record after removing tidal component and calculated sea-level anomaly using ocean model, we found that there is a long-term component included in the Ocean Bottom Pressure Record that cannot be expressed by calculating ocean model. This long-term component's amplitude is about 1.5hPa and has about a 90-day cycle. In evaluating the pressure change derived from crustal deformation due to SSE, the amplitude of this component we detected in this study cannot be ignored. In this study, we consider the origin of this tong-term component from multiple viewpoints such as gravity observation satellite GRACE or tide gauge record etc. As a result, we found that there is a "Fluctuation" which can be approximated as summation of harmonic mode. After subtracting the long-term component we identified in this study, we detected crustal deformation due to SSE at off the coast of north island in New Zealand. Then, we estimated fault slip due to the SSE from vertical displacement observed by Ocean Bottom Pressure and horizontal displacement observed by GNSS.

Keywords: Ocean bottom pressure, Nontidal oceanic variation, Hikurangi subduction zone, Kumanonada, Slow slip event, Fluctuation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SBPR1(2014-15)
KU15-5(2015-16)
KU15-4(2015-16)
TXBPR
(2014-15)
SBPR2(2014-15)
KU15-1
(2015-16)
SBPR3(2014-15)
KU15-3(2015-16)
45mm/yr
Hikurangi Trough
Australian Plate
North Island
Hikurangi Trough
South Island
Pacific Plate
(B)
Pressure Deviation (hPa)
SBPR3
KU15-3
SBPR1
KU15-5
TXBPR (Reference)
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GPS Data, Analysis Methods and Products from the EarthScope Plate Boundary Observatory and Other Regional Networks: Spanning the Geodetic Temporal Spectrum from Decadal Time Series and Velocity Fields to Real-Time Data Streams

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We present an overview of 1) GPS data, analysis methods, and derived products from the EarthScope Plate Boundary Observatory (PBO) and other large scale regional networks including decadal position time series, velocities, and other parameters for 2000+ continuously operating GPS stations distributed throughout a quadrant of Earth’ s surface encompassing the high Arctic, North America, and Caribbean, and 2) high-rate real-time GPS/GNSS data streams available from 700+ stations operated by UNAVCO. All 2000+ station data are freely and publicly available as RINEX files. This continent-spanning distribution represents an essential contribution to the current high-precision global geodetic coverage, with a rich data set collected over more than a decade.

The Geodesy Advancing Geosciences and EarthScope (GAGE) Facility, operated by UNAVCO, provides a diverse suite of geodetic data, derived products and cyberinfrastructure services to support community Earth science research and education. GPS derived products are generated by two Analysis Centers, at Central Washington University (CWU) and the New Mexico Institute of Mining and Technology (NMT), and an Analysis Center Coordinator at the Massachusetts of Institute of Technology (MIT). GAGE GPS data analysis involves formal merging within a Kalman filter of two independent, loosely constrained solutions: one is based on precise point positioning using GIPSY/OASIS (v6.x) software at CWU and the other is based on a network solution from double-differencing produced with the GAMIT (v10.60) software at NMT. The primary data products are station position time series that show motions relative to a North America reference frame called NAM08 (IGb08 rotated to a fixed North America Plate), and secular motions of the stations represented in the velocity field. The position time series contain a multitude of signals in addition to the secular motions. Examples of time series displacements due to geophysical phenomena such as coseismic and postseismic signals, as well as seasonal signals associated with hydrologic processes, are presented. Examples of displacements resulting from anthropogenic phenomena and site maintenance events are also shown.

Position time series, and the signals they contain, are inherently dependent upon analysis parameters, such as network scaling and reference frame realization. The estimation of scale changes (a common practice) has large impacts on vertical motion estimates. Reference frames and realizations evolve through time, and on 29 January 2017 (GPS week 1934 day 0), the IGS switched its operational products to use the IGS14 system, replacing the current IGb08 system. For GAGE, our plan is to reprocess all data from all 2000+ stations and release a full set of time series in NAM14 and IGS14 reference frames when the reprocessing is complete.

UNAVCO also provides high-rate (1 Hz), low-latency (<2s) data streams from 700+ GPS/GNSS stations from the PBO, COCONet (circum-Caribbean), and TLALOCNet (Mexico) networks as well as networks in Nepal and Tanzania funded by the U.S. National Science Foundation. Some of these stations have been augmented with accelerometers to facilitate studies of broadband waveforms. Beyond increasing uses for science and engineering, real-time GPS/GNSS data streams have the potential to significantly enhance Hazard Early Warning applications.

Keywords: Geodesy, GPS/GNSS Networks, GPS/GNSS Data Analysis, Hazard Early Warning, Plate Tectonics, Deformation

Coastal Sea Level Variations Derived from GNSS SNR Data –A Case Study in Taiwan

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Global sea level rise has caused many disasters, damaging the lives and property of numerous human beings, especially in low-lying coastal regions. Therefore, understanding and monitoring coastal sea level changes are of great importance for human society. The traditional method to measure coastal sea level is using tide gauges; however, the records consist of vertical land motions and sea level variations that are difficult to separate. Recently, Global Navigation Satellite System (GNSS) reflected signals are widely used for determination of soil moisture, snow depth and sea surface height. On the other hand, GNSS Reflectometry (GNSS-R) technique based on the analysis of Signal-to-Noise Ratio (SNR) data has a great potential to derive local sea level height variations. Taiwan is an island and most populated cities are located near the coasts, where sea level rise has a significant impact. Therefore, accurate estimation of sea level changes around Taiwan is extremely important. In this research, we aim to assess the feasibility of GNSS-based tide gauges in Taiwan and develop a procedure to improve the accuracy of the sea level variations derived from GNSS SNR data. The procedure contains (a) constraints of GNSS station azimuth angles and elevation angles (b) sea level variations derived from all satellites using the dominant frequency of detrend SNR data by Lomb Scargle Periodogram (LSP) (c) constraint of sea level heights using tidal harmonic analysis (d) inverse modeling of detrended SNR data through nonlinear least squares adjustment. In this study, GNSS SNR data from Kaohsiung, Suao and TaiCOAST sites were used for retrieval of sea level changes and the results were compared with co-located or nearby tide gauge records. For comparison, standard deviation of differences between tide gauge and GNSS-derived sea level and correlation coefficient of the two time series were used for assessing the GNSS-derived result and the adaptability of the processing system.

Keywords: GNSS-R, SNR, Lomb Scargle Periodogram, Sea Level Variation

The Retrieval of Multi-Mission Altimetry Heights by Combined Retracking Procedure near Coastline around Taiwan

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Satellite radar altimetry has been successfully applied to accurately map global sea surface topography with weekly to monthly sampling during the past 2–3 decades and progressively extended the applications for interdisciplinary field like geophysics, climate and earth science. However, retrieving accurate measurements over the non-ocean surfaces remain a challenge by reason of variable land contamination adjacent to the desirable targets. For solving the problems of complicated waveforms from diverse surfaces, the recently launched advanced altimeters, including SARAL/Altika (Ka-band altimeter), CryoSat-2 (SAR Interferometric Radar Altimeter, SIRAL), Sentinel-3 (SAR altimeter) and Jason-3, were expected to improve the drawback of satellite altimetry in variable surfaces like coastal and land regions by the developed instruments and higher spatial resolution data. In this study, the multi-mission altimetry data including Envisat, SARAL/Altika, CryoSat-2 and Jason-2 are used. The complex returned waveforms over land surface or near coast are to be retracked by respective optimal waveform retracking algorithms pertaining to each altimeter system. In order to make more efficient retracking work and eliminate the serious contamination waveforms, we will build an innovative waveform classification method to exactly classify the ocean and non-ocean waveforms based on its physical property over seacoast region before retracking. Eventually, the retrieved heights will be validate with available *in situ* measurements to demonstrate interdisciplinary scientific applications over or near Taiwan.

Keywords: Satellite altimetry, waveform retracking, waveform classification, SARAL/Altika, CryoSat-2, Envisat

Activities of the United Nations for the enhancement of Global Geodetic Reference Frame

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1. GSI of Japan

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. In the sixth session, the committee also decided to officially escalate the WG to sub-committee and asked the sub-committee to develop an implementation plan which encourages further implementation of recommendations in the Roadmap. The sub-committee will start drafting the implementation plan on the five items and take over the activities of the WG as a key player for cooperation on sustainable GGRF. 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 report on recent activities of the group of geodetic experts under the United Nations on development of sustainable GGRF.

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

Preparatory research on the development of rapid and accurate GNSS routine analysis system

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1. GSI of Japan

The Geospatial Information Authority of Japan routinely analyzes GNSS data obtained by GEONET and monitoring crustal deformation all over Japan. The results, crustal deformation data and seismic fault models associated with main shock or postseismic movement, are used to evaluate earthquake activity by the Earthquake Research Committee (ERC) of the Headquarters for Earthquake Research Promotion and the Assessment Committee for Areas under Intensified Measures against Earthquake disaster. Also, the crustal deformation data are used by the Coordinating Committee for Prediction of Volcanic Eruptions as fundamental data for monitoring deformation of mountain body of active volcano and, when eruption occurred, monitoring eruptive activity.
However, even up-to-date routine analysis result sometimes do not have enough rapidness or time resolution. At present, even the result of the most rapid routine analysis, Q3-solution, needs three hours after GEONET data acquisition. In case of the 2016 Kumamoto Earthquake occurring at the night of April 14, crustal deformation information by Q3-solution is obtained on the morning of April 15. Special meeting of the ERC is usually held half a day after the large earthquake occurred. So for the case of the Kumamoto Earthquake, it had possibility that the crustal deformation information offered by GSI would have been late for the meeting and understanding of the earthquake would have got delayed.
Another problem is the time resolution of the solution. For even Q3-solution, which has highest time resolution, the time resolution is six hours. In case of the Kumamoto Earthquake again, three hours after the shock of M6.5 on April 14, an aftershock of almost same magnitude occurred and it also seemed to cause crustal deformation in addition to those caused by the first shock. However, the crustal deformation information using Q3-solution given to the special meeting of the ERC on the afternoon of April 15, cannot distinguish between the crustal deformation caused by the first shock of M6.5 and those caused by the aftershock, which had some difficulties in the understanding of the earthquake. Moreover, present routine analysis do not have enough time resolution for monitoring inflation and deflation of volcanic body before and after eruption. It may have difficulty in evaluating volcanic activity.
These days the GNSS analysis method called Precise Point Positioning (PPP) gains publicity, which is more rapid, has high time resolution and has comparable accuracy to the routine analysis method of GEONET. The principle of PPP is that using precise orbit and clock information of GNSS satellites, GNSS point positioning is performed on each station. The feature of PPP is that the position of the stations in every epoch can be calculated with small calculation load. Moreover, adding corrective information called Fractional Cycle Bias (FCB), which differs for each satellite, enables ambiguity resolution in PPP (called PPP-AR), which is likely to result in the accuracy almost same as GNSS interferometric analysis. In addition, PPP-AR does not need fixed reference station which has advantage when crustal deformation occurs over wide area by large earthquake and it is difficult to find the point that is not subjected to the deformation.
On the background above, GSI has started a three-year research project since the April of 2017. In the project, we will develop more rapid and accurate GNSS analysis method based on PPP-AR and make prototype system implementing this method envisioning future GEONET routine analysis. The goal of this research is routinely and stably obtaining the solution of one-second interval within about two hours after data acquisition with typical repeatability of about 1cm in horizontal component.
In this presentation, I introduce a framework of the system under consideration and the result of the

preparatory research.

Keywords: GNSS, PPP-AR, GEONET routine analysis, GEONET

Technical development for expanding availability of GNSS precise positioning in urban environment

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1. Geospatial Information Authority of Japan

Geospatial Information Authority of Japan (GSI) is developing new software-based techniques mitigating multipath effects in order to expand availability of GNSS precise positioning in urban environment.
In FY 2015, we have selected four promising techniques from previous studies related to mitigating multipath effects, and developed validation programs as follows.
1) Selecting line-of-sight satellites with cutoff masks generated by fish-eye lens photos taken at observation stations
2) Selecting line-of-sight satellites with cutoff masks generated from 3D maps
3) Quality check of observation data based on phase differences of Doppler observables
4) Improvement of precision based on velocities from Doppler observables
In FY 2016, we conducted 12 hour observations under severe conditions in Kobe city, Hyogo prefecture for examining the effects of satellite constellations. We also conducted 5 minute observations at various stations for examining the effect of obstruction of the sky. We validated the four selected techniques by applying them to observation data.
In this presentation, we report the result of FY 2016 and future plan.

Keywords: GNSS positioning, multi-path, urban environment

Analysis of GEONET network data applying ITRF2014 reference frame and IGS14 antenna PCV model

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On the meeting of the Geodetic Society of Japan in 2016 fall, we have introduced the difference of coordinates of IGS fiducial sites in and around Japan from ITRF2008 to ITRF2014 coordinate system, as well as the preliminary result of the analysis of GEONET sites applying the ITRF2014 coordinate system.
On the other hand, IGS switches reference frame from ITRF2008 to ITRF2014 staring GPS week 1934 (29th January 2017). Actually IGS adopts the reference frame IGS14 closely related to ITRF2014 (IGSMAIL-7399). At the same time IGS introduces a new SV and ground antenna model, IGS14.
Mainly because of the SV antenna offset, scale differs by around 0.4 ppb by this revision. In addition, the revised calibrations for numerous ground antennas causes 10mm in height and 5mm in horizontal coordinates solutions (King, private communication).
Before IGS switched reference frame from ITRF2005 to ITRF2008 from 1632 GPS week (11^{th} April 2011), as well as the SV and ground antenna PCV models from IGS05 to IGS08. At that time also mainly according to antenna PCV offset causes around 1 ppb scale and 3mm vertical and 1.2mm horizontal coordinates offset (IGSMAIL-6354). On the other hand, in the analysis of the GEONET network sites in Kanto-Tokai district applying GAMIT/GLOBK program, around 2ppb scale and around 2mm in height and 3mm in horizontal coordinates offset are detected (Shimada, 2011, 2012). The difference between the analysis of the global and the GEONET networks may be caused because GEONET adopts original antenna radome, and the PCV models of GEONET sites are determined by the original field test carried by GSI. Moreover, GSI determines only IGS05 PCV model, thus we determined ourselves GEONET sites IGS08 PCV model using the GEONET IGS05 PCV model and the difference between the IGS05 and IGS08 PCV models released by IGS.
In this paper, we present the scale and coordinates offsets of the GEONET network sites, determined applying the analysis of eight weeks GEONET network observation before and after 29th January 2017, when IGS switches reference frame to IGS14.

Keywords: ITRF2014, ISG14 PCV model, GEONET

Soft Computing and Conventional Interpolation Methods in Geoid Modelling: A Case Study in Istanbul

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Geoid is the fundamental geodetic infrastructure for rational use of Global Navigation Satellite System (GNSS) technology. For this reason, definition a "cm geoid" is an actual subject in all countries. Development of geoid modelling is based on geodetic, gravimetric and astrogeodetic techniques, which are maintained using the geopotential models produced by the combination of gravity measurements, astrogeodetic vertical deflections, GNSS/Levelling data, satellite gravity data, satellite altimetry data and the combination of these data. GNSS/Levelling geoid determination has great importance with regard to the transformation of GNSS-derived ellipsoidal height (h), into the orthometric height (H), which is used in engineering projects and determined by levelling. Instead of levelling, which is an expensive and time-consuming method, orthometric heights can be calculated by using a well-defined geoid models. These geoid models enable us to compute the geoid height (N), which is the difference between ellipsoidal and orthometric height values (N=h-H). Then orthometric heights can be computed using these geoid heights and known ellipsoidal heights. Therefore, this will reduce the measurement work in the basic land surveying to a great extent and make economic contribution. In geoid modelling several methods can be employed. Such a geoid model has been developed for the metropolitan area of Istanbul city. In this context, Istanbul GPS Triangulation Network (IGN) and the Istanbul Levelling Network (ILN) provided reliable data, ellipsoidal and orthometric heights, respectively. This study focuses on the development of Istanbul geoid model with soft computing techniques and its comparison with conventional interpolation algorithms used for modelling. For this purpose, geoid heights in Istanbul metropolitan area have been computed by soft computing methods, namely Adaptive Network based Fuzzy Inference System (ANFIS) and Artificial Neural Networks (ANN) and modeled by twelve different interpolation methods. For computations and modelling in the study area, homogenously distributed 1005 model and 178 test points were selected. These are the common points in IGN and ILN whose latitude, longitude, ellipsoidal heights and orthometric heights are known to construct ANFIS and ANN models in Istanbul. To construct these models in model and test points, latitude and longitude are taken as inputs and geoid heights are taken as outputs. The results obtained from ANFIS and ANN methods are quite satisfactory. The model derived orthometric heights were compared with the known orthometric heights for model and test points. The standard deviation has been obtained in ANFIS as ±4.3cm and ±4.0cm for model and test areas, respectively. On the other hand, the standard deviation in ANN model are ±4 cm and 3.1 cm, for model and test areas, respectively. In addition, conventional interpolation methods as modified Sheapard’s method, radial basis function, Kriging, Nearest neighbor, minimum curvature, inverse distance to a power and local polynomial yield better results than ANFIS and ANN in model and test areas. The others interpolation methods such as polynomial regression, moving average, triangulation with linear interpolation, natural neighbor and data metrics yield worse results than ANFIS and ANN in each area.

Keywords: geoid modelling, soft computing, interpolation methods

The Geoid High and Temperature Variations near the CMB

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1. none

Anderson(1982)showed that the 40m geoid high near the African super plume after the Pangea supercontinent formation(330 Ma),and suggests upwelling heat flow under the African super plume. Heat flow flux in the mantle relates to Joule heating in the Earth and the inner core growth. The age of the inner core is studied to be 2.7 Ga(Hale,1987;Kumazawa et al.,1994).But Labrosse et al.(2001) pointed out that the age of the inner core is most likely around 1 Ga. It is interesting that both ages of formation of the seismic anisotropy layer 235 km and 375 km in the inner core from the ICB (inner core boundary) and the African supercontinent formation may be close each other, if the inner core age is young. In this report the effects of heat flux from the CMB(core mantle boundary) on the African geoid high are studied. This problem has been reported that periodic supercontinent cycles are unlikely if thermal instabilites originating at the CMB are of sufficient strength (Phillips and Bunge,2001).Here,however,we revisit this problem in consideration of the inner core growth. Effects of variations of heat flux from the CMB on the mantle geoid high are small,but heat flow changes rapidly depending on the rate of decay (1/e decay),that is changes of convective patterns.The rate of decay,which consists with the geoid high as shown by Anderson (1982),is about 1/500km.

Keywords: geoid high, Pangea supercontinent, heat flow in the mantle

Design and operation of a 1.5-km laser strainmeter installed in the KAGRA underground site (II)

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Laser interferometers are widely used for precise measurement in experimental physics, engineering, metrology, etc. In geophysics, as one of its applications, laser strainmeters are used for measuring deformation of the ground based on accurate wavelength of a highly frequency-stabilized laser. The advantages of the laser strainmeter over conventional strainmeters using mechanical references are high resolution with a long baseline, resonance-free response with optical reference, and low-drift detection using absolutely stabilized laser wavelength.
A laser strainmeter with a baseline of 100m was constructed in Kamioka underground site (Gifu Prefecture in Japan) and has been operated since 2003. The observation results were reported in Refs. [1-4]. Construction of a new laser strainmeter, having a longer baseline (1.5km), was reported in [5]. The strainmeter is located in a new tunnel for the large-scale gravitational-wave detector, KAGRA [6]. Along one of the arms of the KAGRA detector, the laser strainmeter is formed by an asymmetric Michelson interferometer with two retro-reflectors and other optics in vacuum. A frequency-doubled Nd:YAG laser, emitting wavelength of 532nm and frequency stabilized at a level of ~10^{-13}, is used as a light source. Fringe signals are converted to displacement between the retro-reflectors with a separation of 1.5km using a quadrature fringe detection [7].
A test run of the new laser strainmeter started in August 2016, and strain data were obtained. Earth tides were clearly observed and were almost consistent with theoretical waveforms, except for slight reduction in amplitudes likely due to topographic effect [2]. Strain detectability was estimated to be ~10^{-12}, which is better than the 100-m strainmeter. Estimated performance of the 1.5-km laser strainmeter in comparison with the 100-m strainmeter and other conventional straineters will be presented based on the results of the test run.

[1] S. Takemoto et al., A 100 m laser strainmeter system installed in a 1 km deep tunnel at Kamioka, Gifu, Japan, Journal of Geodynamics, 38, 477-488, 2004.
[2] S. Takemoto et al., A 100m laser strainmeter system in the Kamioka Mine, Japan, for precise observations of tidal strains, Journal of Geodynamics, 41, 23-29, 2006.
[3] A. Araya et al, Analyses of far-field coseismic crustal deformation observed by a new laser distance measurement system, Geophys. J. Int., 181, 127-140, 2010.
[4] A. Araya et al., Broadband observation with laser strainmeters and a strategy for high resolution long-term strain observation based on quantum standard, J. Geod. Soc. Japan, 53, 81-97, 2007.
[5] A. Araya et al., Design and operation of a 1.5-km laser strainmeter installed in the KAGRA underground site, in abstract of Japan Geoscience Union Meeting 2016, SGD23-12, 2016.
[6] Y. Aso et al, Interferometer design of the KAGRA gravitational wave detector, Phys. Rev. D, 88, 043007, 2013.
[7] P. L. M. Heydemann, Determination and correction of quadrature fringe measurement errors in interferometers, Appl. Opt., 20, 3382-3384, 1981.

Keywords: strainmeter, laser, crustal deformation, KAGRA, Kamioka, gravitational wave

Simulation study for crossover orbit analysis of Hayabusa2 (2)

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The asteroid explorer “Hayabusa2” launched in 2014 is currently sailing towards the target asteroid, Ryugu, and will arrive there in the middle of 2018. Hayabusa2 will stay there for one and a half years, and perform various observations.
For mapping of acquired observation data, precise orbit determination of Hayabusa2 is very important. Further, Ryugu’s geodetic parameters, which will be simultaneously estimated with Hayabusa2 orbit, are also required to be determined in high precision for understanding of Ryugu. However, such precise determinations are difficult by using radiometric tracking data only, because of current limited knowledge of Ryugu’s ephemeris and physical parameters. To overcome this problem, in Hayabusa2 mission, crossover orbit analysis using laser altimeter (LIDAR) data between Hayabusa2 and Ryugu is planned, in addition to radiometric tracking data analysis.
In this study, we performed offline simulation of Hayabusa2 orbit analysis. We developed a simulation program for Hayabusa2 orbit analysis, including crossover orbit analysis. Test data of Hayabusa2 orbit, Ryugu ephemeris, and Ryugu shape model were also created for the simulation. From these test data, input observation data to the simulation program were prepared. After adding some errors to Ryugu ephemeris and the observations, recovery of “true” Hayabusa2 orbit from these data sets were simulated in the following order: 1) Hayabusa2 orbit determination with range and range rate observations from ground tracking stations to Hayabusa2, 2) Determination of Hayabusa2 orbit with respect to Ryugu center by crossover orbit analysis using LIDAR-observed ranges between Hayabusa2 and Ryugu, 3) improvement of Ryugu ephemeris using 1) and 2) results, 4) improvement of Hayabusa2 orbit by performing 1) again with updated Ryugu ephemeris, and 5) iteration of 1) to 4). We discuss how much the precision of determined Hayabusa2 orbit changes by changing error magnitudes of each observations and Ryugu ephemeris.

Keywords: Hayabusa2, Orbit Analysis Simulation

