Development of New GEONET Analysis Strategy: Incorporating GLONASS Observations Data

*Naofumi Takamatsu[1], Satoshi Abe[1], Norihiko Ishikawa[1], Kazunori Yamaguchi[1], Yuki Kamakari[1], Satoshi Kawamoto[1], Yohei Hiyama[1], Yuki Hatanaka[1], Hiromichi Tsuji[1]

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

*Hideo Hanada[1], Masatsugu Ooe[2], Satoshi Miura[3]

1. RISE Project, National Astronomical Observatory, 2. Oshu Space and Astronomy Museum, 3. Graduate School of Science, Tohoku University

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 ϕ_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.

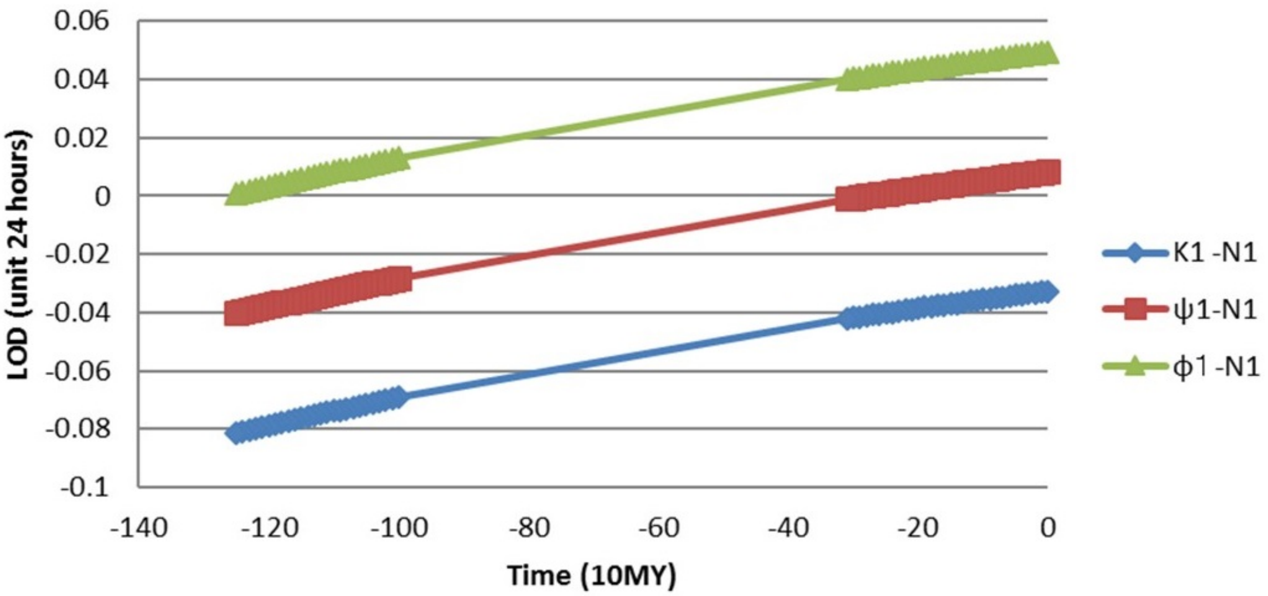
Figure shows the result of calculations from present to 1.4 billion years ago. The vertical axis indicates length-of-day (LOD) in the unit of the mean solar day at present and the difference between the periods of tidal components and FCN is shown. We find that the period of N_1 coincided with that of ϕ_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



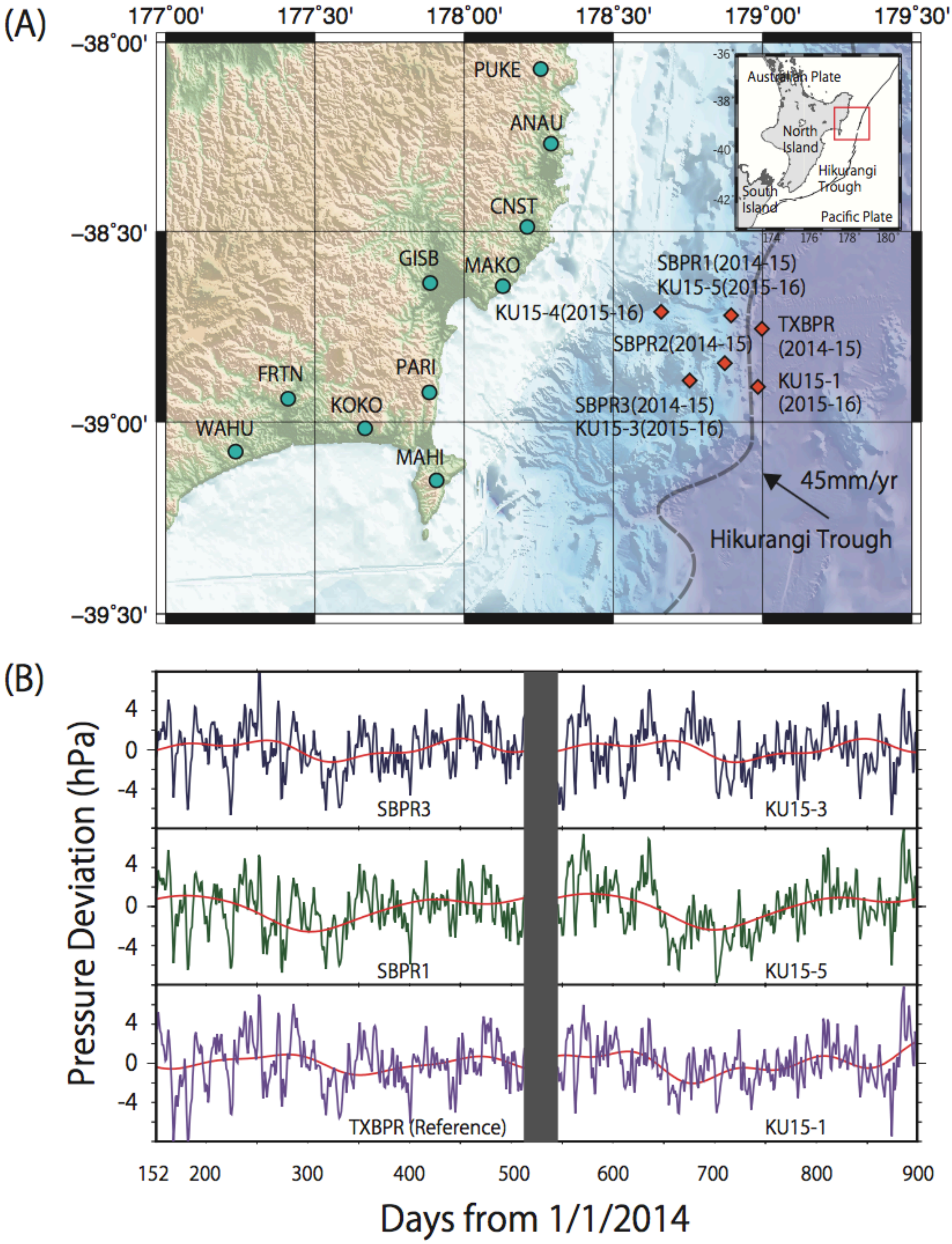
On the Interpretation of oceanic variations in terms of ocean bottom pressure

*Tomoya Muramoto[1], Yoshihiro Ito[1], Daisuke Inazu[2], Stuart Henrys[3], Laura Wallace[3], Stephen C Bannister[3], Kimihiro Mochizuki[5], Ryota Hino[4], Syuichi Suzuki[4]

1. Research Center for Earthquake Prediction, Disaster prevention research institute, Kyoto University, 2. Department of Ocean Sciences, Faculty, Tokyo University of Marine Science and Technology, 3. GNS science, 4. Graduate School of Science, Tohoku University, 5. Earthquake Research Prediction Center, Earthquake Research Institute, The University of Tokyo

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
South Island
Hikurangi Trough
Pacific Plate
(B)
Pressure Deviation (hPa)
SBPR3
KU15-3
SBPR1
KU15-5
TXBPR (Reference)
KU15-1
152
200
300
400
500
600
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800
900
Days from 1/1/2014

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

*David A Phillips[1], Thomas Herring[2], Timothy Melbourne[3], Mark Murray[4], Michael Floyd[2], Walter Szeliga[3], Robert King[2], Christine Puskas[1], Glen Mattioli[1], David Mencin[1], Kathleen Hodgkinson[1], Charles Meertens[1]

1. UNAVCO, 2. Massachusetts Institute of Technology, 3. Central Washington University, 4. New Mexico Institute of Mining and Technology

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

*Chi-Ming Lee[1], Chung-Yen Kuo[1], Jian Sun[2], Tzu-Pang Tseng[3], Kwo-Hwa Chen[4], CK Shum[2], Yichan Yi[2], Kuo-En Ching[1]

1. National Cheng Kung University, Taiwan, 2. Ohio State University, Columbus, USA, 3. National Central University, Taiwan, 4. National Taipei University, Taiwan

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

*Kao Huan Chin[1], Chung-Yen Kuo [1], Ting-Yi Yang[2], C.K. Shum[2,3], Yu chan Yi[2]

1. Department of Geomatics, National Cheng Kung University, Tainan, Taiwan, 2. Division of Geodetic Science, School of Earth Sciences, Ohio State University, Columbus, USA, 3. State Key Laboratory of Geodesy & Earth's Dynamics, Institute of Geodesy and Geophysics, CAS, Wuhan, China

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

