GEONET新解析戦略（F4）の検討 ～解析のマルチGNSS化に向けた取り組み～

Development of New GEONET Analysis Strategy: Incorporating GLONASS Observations Data

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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.

キーワード：GEONET、GNSS、F4、ITRF2014、GLONASS
Keywords: GEONET, GNSS, F4, ITRF2014, GLONASS

高感度地殻歪観測を基にした地球の内部進化と自転効果の解明
Elucidation of the internal evolution and rotation effect of the Earth based on high sensitive observations of earth strain

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地球の内部には半径の約半分を占める流体核があり、独自の回転や対流運動を行っている。その運動は、流体核とマントルとの境界（CMB）の形、密度分布、温度分布、磁場、粘性等と関係しているといわれるが詳しいことはわかっていない。それを調べる一つの方法が、自由コア章動（FCN）という、流体核が引き起こす地球全体の回転運動を観測することである。これは、流体核の軸とマントルの軸がずれることによって起こる自由運動であり、その周期が地球に対して約1日と、潮汐の1日周期と非常に近いので、共鳴現象によって振幅が増大される。もし両者が一致すれば、とんでもなく大きな変動になると考えられる。

この流体核によって引き起こされる地軸の運動は、緯度観測所の木村榮が発見し世界を驚かせたZ項の原因としても知られていて、これまで、電波を用いた超長基線干渉計（VLBI）による観測データを解析し、宇宙空間に対する地球の自転軸の運動としてFCNの周期を求め、CMBの形がわずかに南北につぶれていることを発見した例はあるが、その振幅が小さいことから、FCNを自転軸が異なる流体核の突き上げによって起こるマントル上部の地表面の歪み変化として高精度に観測した例はほとんど無い。もし、地上でこのFCNの効果を観測すれば、CMBの形以外に、核の密度構造、CMBでの電磁気的、力学的な結合強度など、他の観測では困難な貴重なデータを得ることが可能であると理論的に予測される。

このFCNに近い潮汐の成分(分潮)は、現在ψ_1とϕ_1である。しかし、これらはFCNの周期から少し離れていて、大きな振動にはなっていない。しかし、地球潮汐の周期は地球の自転速度が変れば変化するが、FCNの周期は、地球自転速度だけでなく流体核の力学的扁平率と自転速度の複合作用で変わる。従って、潮汐とFCNの角速度の差は、地質年代的に無視できない変化を示す。この変化を具体的に見るために、これまでの地球自転進化モデルの情報をもとに、年代的な変化を見積もってみた。
潮汐の角速度は地球自転速度だけを変え、太陽と月の軌道運動は不変とした。FCNの角速度では流体核の力学的扁平率が自転速度の2乗に比例して変わると仮定した。地質年代での自転速度の変化は、大江・安部(全地球史解読、2002年)の結果から12億年前までの値を用いた。

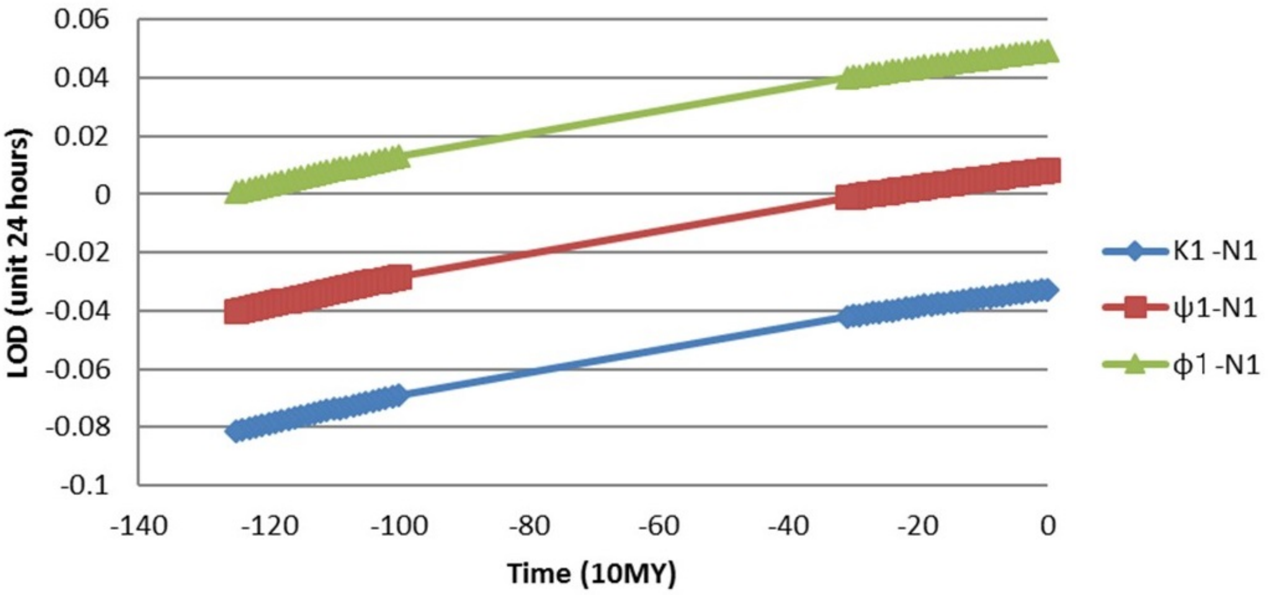
図はこの計算から得られた結果で、横軸は現在からの時間(1000万年単位)、縦軸は現在の平均太陽時1時間を基準とする角速度とし、潮汐成分のそれぞれ、K_1、ψ_1、ϕ_1から自由コア章動N_1の角速度を引いたものをプロットしている。図から、およそ2.8億年前にψ_1とN_1が重なり、およそ12,5億年前にϕ_1とN_1が重なることが分かる。これらの時点で、大きな振動が起こると考えられる。ここで用いた地球自転速度の変化モデルは、大陸移動のような現象は含まれておらず、氷河の消長と同様、これらも地球自転に大きな影響を与えていたことが考えられるが、地球では潮汐の作用だけでもこれだけ自転周期が変わり、しかも、FCNの効果が大きな作用を持ち得た年代があったことは確かであろう。

最近、地球の氷河の消長による地質学的データから、自転速度変動が地球磁場の強度変化が強い相関関係を示すことが明らかになった（宮腰・浜野、2013）。シミュレーション解析によって地球自転の約2%の速度変動が、約20～30%の磁場強度変化を引き起こすというものである。ここで述べた流体核共鳴によって増幅さ

れるFCNを観測すれば、その周期や振幅から、磁場変動に結びつく流体核の物理的な性質がさらに明らかになる可能性があり、人類の将来の環境にも大きく影響する、自転速度の減速、磁場の消失や反転の予測、その物理機構の解明にも貢献できると思われる。

現在、長基線の光ファイバー干渉計を利用して地殻歪みを高感度に計測することを計画している。

キーワード：自由コア章動、流体核共鳴、地殻歪み、光ファイバー干渉計
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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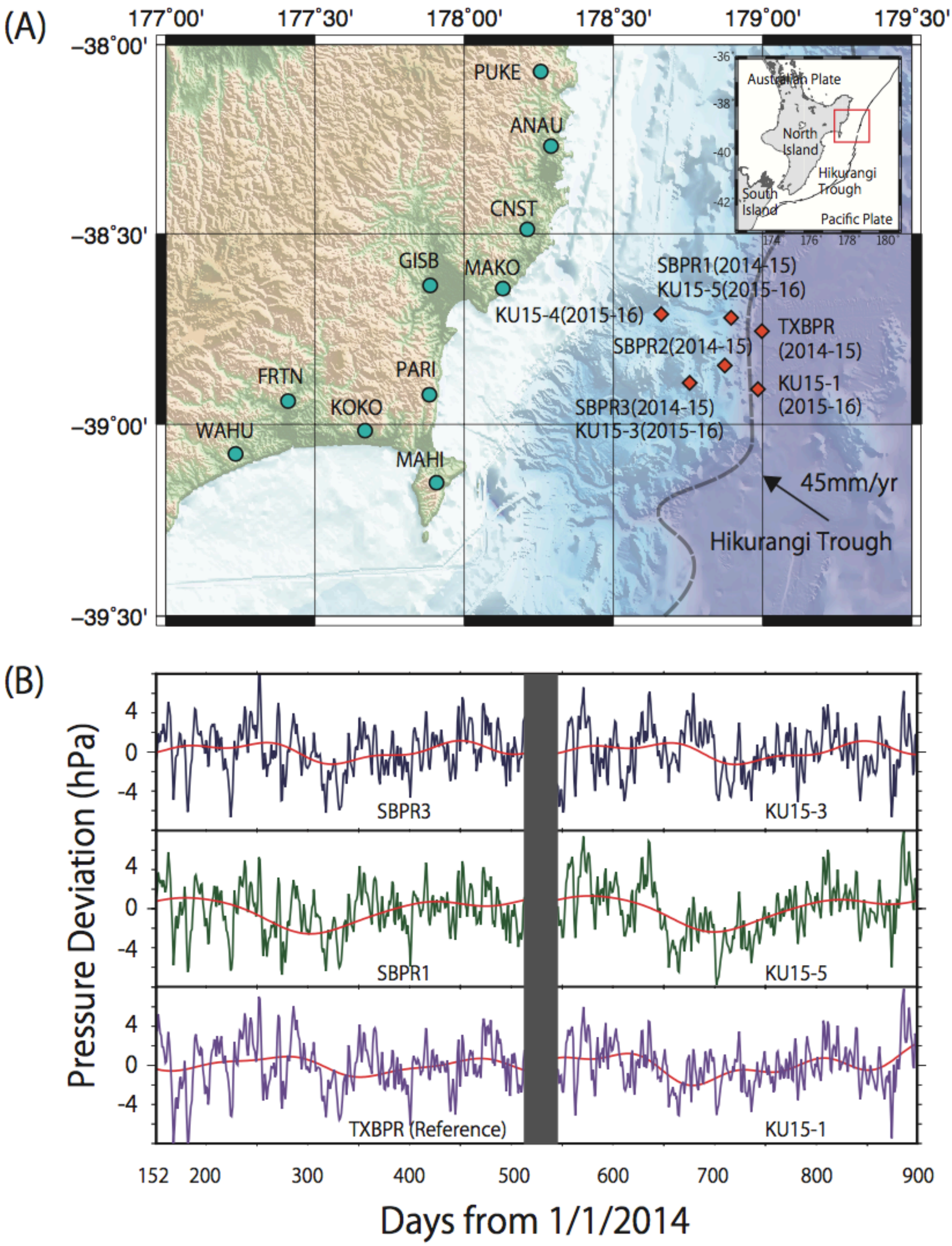
SSE is the phenomenon that rupture progress slowly compared with regular earthquake. Many examples are reported all over the world. (e.g. Yoshioka et al., 2004) Also, this phenomenon was observed before 2011 Tohoku earthquake. It is thought that deformation in the SSE area at the time of the main shock 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.

キーワード：海底圧力、非潮汐海洋変動、ヒクランギ沈み込み帯、熊野灘、スロースリップイベント、ゆらぎ
Keywords: Ocean bottom pressure, Nontidal oceanic variation, Hikurangi subduction zone, Kumanonada, Slow slip event, Fluctuation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PUKE
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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)
KU15-1
152 200 300 400 500 600 700 800 900
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

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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

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.

キーワード：GNSS-R、SNR、Lomb Scargle Periodogram、Sea Level Variation
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