Determination of geopotential values at the optical lattice clocks based on geodetic approaches

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Introduction

Optical lattice clock can provide not only ultra-stable time frequency standard, but also difference of geopotential values by comparing difference in the clock ticks between two connected clocks. The performance of optical lattice clock has been drastically improved and now is capable to measure difference of geopotential values equivalent to the centimeter-level height difference. This achievement could make the clocks applicable for realization and maintenance of the geopotential-based height reference frame resolved in the general assembly of the International Association of Geodesy in 2015 (Miyahara et al. 2018). As a part of the efforts of implementing the optical lattice clocks to the society, we determined the geopotential values at the optical lattice clocks owned by the National Institute of Information and Communications Technology (NICT) and the National Metrology Institute of Japan (NMIJ) based on geodetic approaches. In this presentation, we'll report the determined geopotential values and their uncertainties.

Method

The geopotential value can be determined using the ellipsoidal height, geoid height, and gravity values (Sánchez et al. 2021). The geopotential values W(P) at the clock owned by NICT were determined as follows:

$$W(P)=W_0-(H_A+\Delta H_{AP}-N_p)g_p$$

where W_0 is the geopotential value at the geoid (62,636,853.40 m^2/s^2), H_A is the ellipsoidal height at GEONET station "Koganei" which is derived from averaging the daily solution (Muramatsu et al. 2021) of "Koganei" for a year, ΔH_{AP} is the height difference between "Koganei" and the clock obtained by the spirit leveling in 2021, N_p is the geoid height at the clock which is obtained by the gravimetric geoid model (JGEOID2021b) constructed by Matsuo and Forsberg (2021), and g_p is the average gravity value between the clock and geoid determined by the gravity measurement in 2021 and the Poincaré-Prey reduction.

The geopotential values W(Q) at the clock owned by NMIJ were determined with the geopotential value W(R) at GEONET station "Tsukuba 1" and the geopotential differences between "Tsukuba 1" and the clocks. The geopotential difference can be obtained by height difference and gravity values following Heiskanen and Moritz (1967). We determined W(Q) as follows:

$$W(Q)=W(R)-\Sigma_i \Delta h_i(g_i+g_{i+1})/2$$

where Δh_i is the height difference in the benchmarks obtained by the spirit leveling conducted from 2014 to 2021, and g_i is the gravity value at the benchmark from the gravity estimation method of Kuroishi (1998) or the gravity measurement in 2021. W(R) was determined by the same method as NICT:

$$W(R)=W_0-(H_R-N_R)g_R$$

where H_R is the ellipsoidal height from the daily solution of "Tsukuba 1", N_R is the geoid height from JGEOID2021b, and g_R is the average gravity value between "Tsukuba 1" and the geoid from the gravity estimation method of Kuroishi (1998) and the Poincaré-Prey reduction.
The uncertainties of the determined geopotential values were estimated by the law of error propagation using the uncertainties of the data used. The uncertainty of W_0 is 0.02 m^2/s^2 (Sánchez et al. 2016), that of the daily solution of GEONET station is the standard deviation of the coordinate values over a year (8 mm for "Koganei", 6 mm for "Tsukuba 1"), that of JGEOID2021b is 5 cm (standard deviation of the difference with GNSS/leveling geoid heights), that of gravity measurement is the standard deviation of the net adjustment calculation, that of the estimated gravity value by Kuroishi (1998) is 2.5 mGal, and that of the height difference obtained by the spirit leveling is 2.5√(S km) mm (S is the measurement distance of the spirit leveling).

Results

The geopotential value of the optical lattice clock at the east side of building 2 of NICT (NICT1) was 62,636,102.84±0.50 m^2/s^2, and that of the optical lattice clock at the west side (NICT2) was 62,636,103.41±0.50 m^2/s^2.
The geopotential values of the optical lattice clock at laboratory 013 of NMIJ building 3-7 (NMIJ1) was 62,636,648.59±0.50 m^2/s^2, and that of the optical lattice clock at laboratory 011 (NMIJ2) was 62,636,648.69±0.50 m^2/s^2.
The geopotential values determined in this study can be used for calibrating the time frequency of the optical lattice clock based on the definition of International Atomic Time through the correction of the time frequency shift caused by the gravitational redshift. In addition, the calibration of the time frequency shift enables mutual comparison of optical lattice clocks.

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Keywords: Geodesy, Geopotential, Gravity, Geoid, Optical lattice clock

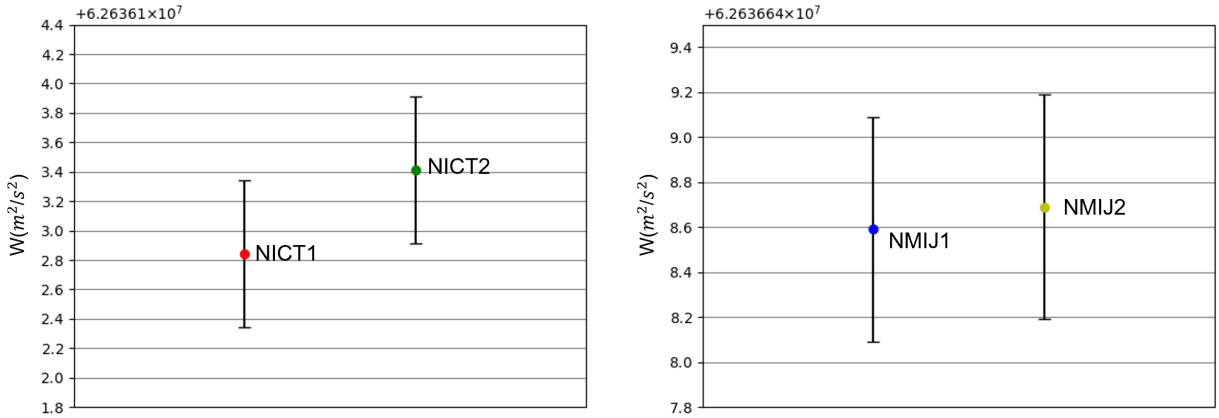

Fig. Geopotential values at the optical lattice clocks determined in this study
(NICT1: the optical lattice clock at the east side of building 2 of NICT, NICT2: the optical lattice clock at the west side of building 2 of NICT
,NMIJ1: the optical lattice clock at laboratory 013 of NMIJ building 3-7, NMIJ2: the optical lattice clock at laboratory 011 of NMIJ building 3-7)

図. 今回決定した光格子時計の設置位置における重力ポテンシャル値
(NICT1: NICTの2号館の東側に設置された光格子時計, NICT2: NICTの2号館の西側に設置された光格子時計
,NMIJ1: NMIJの3-7棟の研究室013に設置された光格子時計, NMIJ2: NMIJの3-7棟の研究室011に設置された光格子時計)

