

## **IAG WG Q.3 – Relativistic geodesy with clocks**

### **Minutes of the Kick-off Meeting**

21.12.2020, 14:00–17:00 (CET) 13:00–16:00 (UTC)

Online, via Zoom

### **Participants**

**WG members:** Gérard Petit (GP), Jakob Flury (JF), Claude Boucher (CB), Simon Stellmer (SS), Ulrich Schreiber (US), Yoshiyuki Tanaka (YT), Andrew Ludlow (AL), Jürgen Kusche (JK), Chris Hughes (CH), Paul-Eric Pottié (PEP), Claus Lammerzahl (CL), Ropesh Goyal (RG), Guillaume Lion (GL), Bijunath Patla (BP), Sergei Kopeikin (SK), Peter Visser (PV), Pascale Defraigne (PD).

**Invited:** Jürgen Müller (JM)

### **1 Welcome**

GP opened the meeting, thanking everyone for participation. He briefly reminded the past Joint WG active over 2015-2019, to which many members of this WG already participated.

All participants presented themselves.

GP recalled the main objectives of the new WG Relativistic Geodesy with clocks (RGC) and noted that the planned short presentations will touch all main issues from the development of clocks and time links to the relativistic theory, through IAG-related activities and geophysical applications.

### **2 Short presentations (slides at <https://quge.iag-aig.org/quge-meetings/ko-meeting-wgg3> )**

**2.1** JM presented an overview of the various goals of the QuGe Project, and its three WGs respectively on Quantum gravimetry in space and on ground, Laser interferometry for gravity field mission and Relativistic geodesy with clocks. He emphasized that there are only two Projects within IAG (the other one is GGOS) which shows the importance of the topics carried by QuGe: to promote new approaches to observe the Earth gravity field, to contribute improving the realization of a gravimetric reference system matching the improvements in the geometric system, to improve the knowledge of mass variations on Earth and of the associated geophysical processes. He finally mentioned the planned contributions to the scientific conferences in 2021 (IAG, COSPAR, EGU ...).

**2.2** GP presented activities related to RGC at the BIPM and the Consultative Committee for Time and Frequency (CCTF). He stated that in recent years 6 optical clocks have been approved for use in TAI and the computation of their relativistic shift has been documented at the best level, quite often below  $1 \times 10^{-17}$ . He also mentioned the current work of the WG on Frequency Standards that is preparing the 2021 issue of the list of recommended frequencies. The WG reviewed more than 30 recently published comparisons of optical clocks and the associated documentation of their relativistic shift. The CCTF also initiated a Task Force in view of a future redefinition of the SI second which aims at characterizing all effects to the  $10^{-18}$  level. GP finally mentioned recent developments in transportable optical clocks and in optical fiber networks for clock comparisons in Europe, all essential tools for RGC.

In the following discussion, PEP mentioned that optical fiber networks are also building in China and Japan, and that projects for optical clocks in space should not be forgotten as they should be accompanied by the development of new comparison techniques. Similarly the ACES mission should be closer and may provide some gain in the meantime.

CB mentioned the survey initiated by the CCTF which should be answered by the IUGG and indicated he would help coordinate answers.

**2.3** JF presented a summary of recent IAG activities on the establishment of an International Height Reference System (IHRIS) and International Height Reference Frame (IHRF). Over the past 10 years, several working Groups within the GGOS Focus Area Unified Height System (UHS) developed basic standards and definitions for IHRIS/IHRF that were adopted in IAG resolutions in 2015 and 2019, as well as a preliminary reference network. For the computation of potential values combining terrestrial gravity data and global gravity models, standardization will remain challenging, and a centralized computation may not be feasible for the near future. On this field, an upcoming special issue of Journal of Geodesy on the "Colorado 1cm geoid experiment" is relevant.

In the discussion, CB emphasized conceptual differences between IHRF and ITRF, the latter clearly being a pointwise reference. JM suggested to invite an IHRIS expert to this Working Group.

**2.4** YT presented progresses of chronometric leveling in Japan, which main driver is a Project "Space-time information platform with a cloud of optical lattice clocks" led by Prof. Katori. Several optical clocks comparisons have been carried out at the  $10^{-18}$  level and more are planned with fiber links under development, including a 400 km link. Comparisons between chronometric leveling and geodetic methods show that optical clocks could improve on geodesy techniques at sub-daily and seasonal time scales.

**2.5** CL presented new results from relativistic geodesy. He reminded the classical general relativistic modeling of clock comparisons, interferometry, measurement of gravity acceleration and rotations. Based on developments in terms of a gravito-electric and a gravito-magnetic potential for the Schwarzschild and Kerr metrics, he outlined the magnitude of post-Newtonian effects applicable to RGC.

**2.6** CH presented Global hydrodynamic levelling, indicating that two methods of determination of the dynamic topography of the ocean may differ by 10 cm and more at tide gauges. Thus new techniques are needed to determine the ocean topography on the coasts where it matters most. Accurate measurements of the geopotential at tide gauges with optical clocks could provide boundary values useful for the global ocean circulation models. To do measurements along the continental slope would be even more interesting but challenging.

During discussions that followed, the topic was recognized as a major application of RGC, and in close relation with the topic of height system(s). The optimal localization of a set of optical clocks for global hydrodynamic studies should be one goal of the WG.

### **3 Discussion, planned activities**

GP expressed the hope to be able to hold a hybrid workshop by the end of 2021 to continue the series initiated in 2017 and 2018 with the previous JWG. However a more realistic approach commands to start with virtual events. The next meeting should be scheduled within about six months, at a date to be determined. More regular meetings in the form of a seminar + discussion are envisioned.

Another aim of the WG could be a white paper towards a continental network of optical clocks in Europe, where the developments are somewhat advanced. This would serve as a guide for similar projects in other areas.

Minutes by GP and JF (29 January 2021)