Could optical atomic clocks contribute to the study of the Earth's temporal gravity field variations?

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Abstract

Atomic clocks went through tremendous evolutions and ameliorations since their invention in
the middle of the twentieth century. The constant amelioration of their accuracy and stability
permitted numerous applications in the field of metrology and fundamental physics. For a long
time cold atom Caesium fountain clocks remained unchallenged in terms of accuracy and
stability. However, this is no longer true with the recent development of optical clocks. This
new generation of atomic clock opens new possibilities for applications in chronometric
geodesy. With this progress in clock technology heading towards a relative clock accuracy of
10–18, geodetic applications become feasible, such as determining gravity potential differences
over large distances at the level of 0.1 m2 s–2. In this context, the effect of temporal gravity field
variations on the new observable has to be considered. In addition, the clocks could provide
results with a high temporal resolution (e.g. 7 to 1 h or less) for understanding the daily to
annual evolution of corresponding phenomena, which makes the clocks unique in their ability
to continuously monitor regional variations of the gravity potential field, especially when using
a well-distributed clock network.
The object of this paper is to analyze and asses the contribution of a ground network, consisting
of optical atomic clocks, to the monitoring of the Earth's temporal gravity field variations. For
this reason, we developed a simulation study, which exploits the monthly gravity field solutions
of the GRACE FO mission that the International Centre for Global Earth Models (ICGEM)
provides them freely. In this study, different regional clock networks were formed where each
one covers a different part of the Eurasian plate. We assume that the clocks are connected to
each other via fiber links, the stability of which is characterized by a predefined accuracy. The
range of the relative clock accuracy varies from 10-16 until 10-19 depending on the tested
scenario. Some of them assumes that the clocks are characterized by a uniform relative

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accuracy, whereas, some others asses networks which consists of different type of clocks, the accuracy of which vary.
The least-squares adjustment procedure was applied for the solution of the temporal clock networks. In this procedure different strategies were implemented and assessed for the datum definition in the clock networks. Depending on the applied scenario, different time-series of the
gravity field values were estimated for each one clock. We analyze and asses these time-series with respect to the strategy of the datum definition, the network's geometry and the relative accuracy of the clock measurements.