Potential and scientific requirements of optical clock networks for validating satellite gravity missions

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The GRACE mission, now continued as the GRACE-FO mission, has provided an unprecedented quantification of large-scale changes in the water cycle. Meanwhile, stationary optical clocks show fractional instabilities below \(10^{-18}\) when averaged over an hour, and continue to be improved in terms of precision and accuracy, uptime, and transportability. The frequency of a clock is affected by the gravitational redshift, and thus depends on the local geopotential; a relative frequency change of \(10^{-18}\) corresponds to a geoid height change of about 1 cm. This effect could be exploited for sensing temporal geopotential changes via a network of clocks distributed at the Earth’s surface.

Here, we concentrate on how the measurements of an ensemble of optical clocks connected across Europe via optical fibre links could be used to validate and complement gravity field solutions from GRACE-FO and potential future gravity missions. Through simulations it is shown how hydrology (water storage) and atmosphere (dry and wet air mass) variations over Europe could be observed with clock comparisons in a future network. We assume different scenarios for clock and GNSS uncertainties, where we deem the latter to be necessary to separate local height changes from the mass redistribution signals. Our findings suggest that even under conservative assumptions — a clock error of \(10^{-18}\) and vertical height control error of 1.4 mm for daily measurements — hydrological signals at the annual time scale and atmospheric signals down to the weekly time scale could be observed.

However, the requirements to an optical clock network used for validation of GRACE-FO and future gravity missions are higher than that, which is demonstrated along with the according spatial resolutions.