Perspectives for relativistic potential and height reference

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Continental-scale optical clock networks enabling the determination of relativistic gravity potential and height differences from frequency redshift seem feasible. But will we be able to combine relativistic results with classical potential information? We expect that continental-scale networks of optical atomic clocks linked with phase-stabilized optical frequency transfer will become feasible within the next decade. On the long run, also frequency transfer by way of optical satellite links is expected to evolve. Before this background, the question arises how relativistic gravity potential differences from chronometric leveling in such networks can be used for geodetic applications. Here, we discuss perspectives for global and regional gravity potential and height reference. A key point is how "point-wise" potential differences from chronometric leveling (Fig. 1) can be combined with classical gravity potential data.

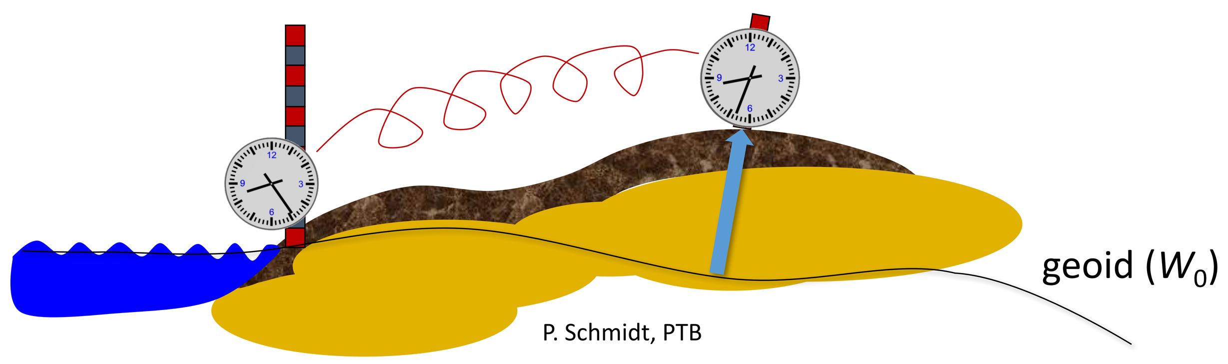

Fig. 1 *Principle of chronometric leveling: gravity potential difference ΔW is related to the difference in frequency redshift ($\Delta W = \frac{\Delta f}{f} c^2$) as determined by way of phase-stabilized optical frequency transfer between optical atomic clocks*

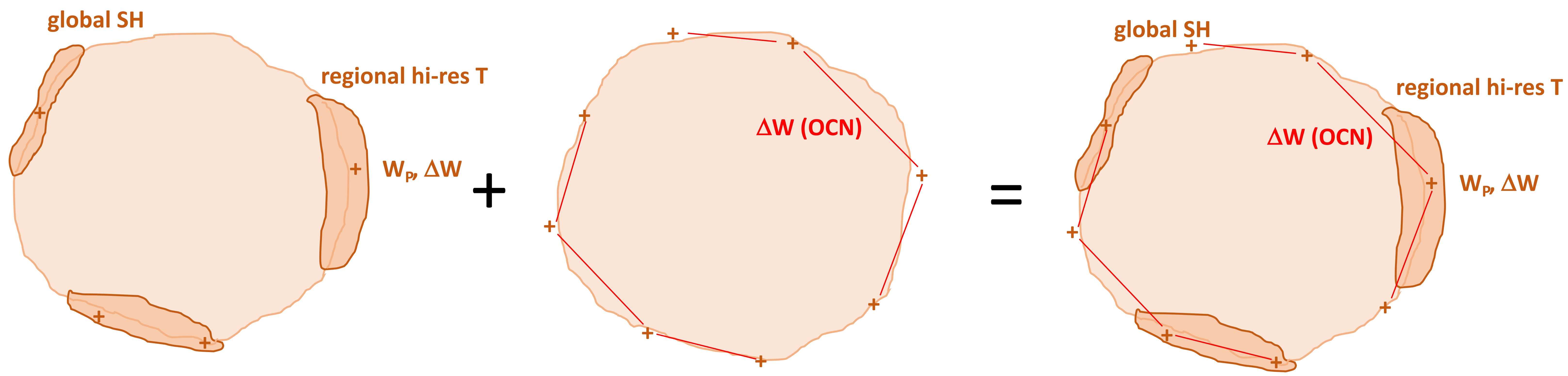

Fig. 2 *Point-wise classical gravity potential reference from bandlimited spherical harmonic (SH) model and high-resolution regional disturbing potential (T) modelling (left), point-wise relativistic potential reference from optical clock networks (OCN, center), combination for joint potential reference (right). Note that W_P can be referenced to different W_0 realizations such as W_0(IERS2010) or W_0(IHRS)*

Point-wise combination of classical and relativistic potential reference

- Denker et al (2018) demonstrated that well-defined point-wise values of gravity potential *W* can be obtained, e.g., in clock sites, from classical data using the GNSS/geoid approach by combining (Fig. 2)
  - GNSS ellipsoidal heights
  - a state-of-the-art spherical harmonic global gravity field model
  - regional high-resolution modeling of the disturbing potential *T* based on dense regional gravity anomaly data, Molodensky integration and remove-compute-restore topographic mass modeling
- In well surveyed areas, e.g., around the clock sites PTB Braunschweig and Observatoire de Paris, an accuracy of **few cm** is achieved with the classical approach.
- Denker et al (2018) also showed that point-wise *W* results can be referred to any realization of W_0 in a well-defined way, i.e., that transformations between different $W_0^{(i)}$ can be done consistently
- When one or several continental-scale networks become available, a weighted point-wise combination of the classical and relativistic techniques (Fig. 2) is expected to improve the joint solution and can serve as combined gravity potential and height reference, in the sense of an International Height Reference System (IHRS, Sanchez & Sideris 2017, cf. IAG Resolution No. 1, 2015)
- The absolute *W* reference will come from the classical approach (in fact, from satellite orbits), whereas relativistic chronometric leveling will strengthen the ΔW ties and make the scale of the network consistent with atomic standards
- Residuals from the combination will show the quality of the involved contributions and serve as incentive for further standardization and homogenization
- Details of the combination model and options to improve the contributions of the classical potential reference (SH model, hi-res *T* modeling) based on the combination results are to be explored

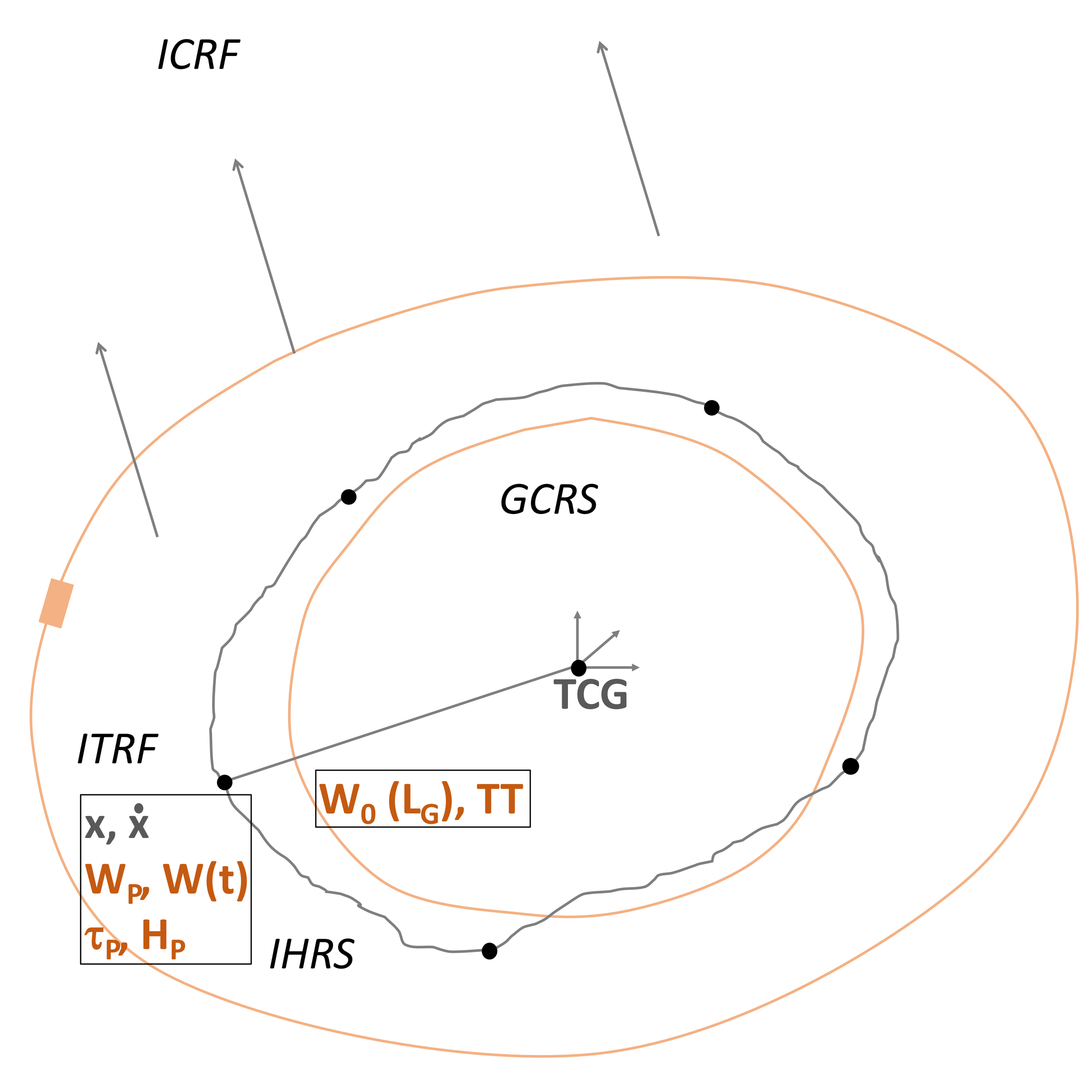

Fig. 3 *Some key elements of geodetic reference frames. GCRS: Geocentric Celestial Reference System; ICRF: International Celestial Reference Frame; ITRF: International Terrestrial Reference Frame. Brown color indicates elements related to the gravity potential. ICRF orientation is indicated by arrows; its origin is not in the figure.*

Gravity potential *W* as part of geodetic reference frames

- Gravity potential reference is to be considered as integral part of geodetic reference frames (Fig. 3)
- For heights, height systems (IHRS etc.), sea level, marine geodesy, vertical land movement, …
- Potential is linked to other elements of geodetic reference frames, e.g.:
  - geocenter and classical point-wise potential are linked to satellite orbits
  - potential is integral part of time reference including time transformations, e.g.: TCG(GCRS) – TT(W_0) – τ(clock sites)
- Well-defined point-wise *W* reference will strengthen this role
- Complementarity to ITRF

IAG Joint Working Group JWG 2.1 "Relativistic Geodesy: Towards a new geodetic technique"

- 1st Workshop May 15-16, 2017 Hannover
- Presentations: https://www.ife.uni-hannover.de/569.html
- 2nd Workshop planned Oct 2018

References:

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Sanchez L, Sideris M (2017) Vertical datum unification for the International Height Reference System (IHRS). Geophys J Int doi:10.1093/gji/ggx025