Summary of the joint meeting of

IAG JWG 2.2.2: The 1 cm geoid experiment (chair: Y.M. Wang)
GGOS JWG: Strategy for the realisation of the IHRS (chair: L. Sánchez)
IAG SC 2.2: Methodology for geoid and physical height systems (chair: J. Ågren)
ICCT JSG 0.15: Regional geoid/quasi-geoid modelling - Theoretical framework for the sub-centimetre accuracy (chair: J. Huang)

held at the GGHS2018 Symposium (Copenhagen, Denmark)

Date Wednesday 19 September 2018, 3:30 to 5:00 pm

Attendees D. Roman (USA), J. Ågren (Sweden), M. Véronneau (Canada), L. Sánchez (Germany), Y.M. Wang (USA), D. Avalos (Mexico), J. Mäkinen (Finland), M. Sideris (Canada), E. Antokoletz (Argentina), R. Barzaghi (Italy), U. Marti (Switzerland), H. Wziontek (Germany), I. Oshchepkov (Russia), H. Abd-Elmotaal (Egypt), R. Grebenitcharsky (Saudi Arabia), D. Arana (Brazil), V. Grigoriadis (Greece), R. Pail (Germany), M. Willberg (Germany), Th. Gruber (Germany), S. Varbla (Estonia), H. Denker (Germany), G. Vergos (Greece), K. Ahlgren (USA), H. Drewes (Germany), B. Erol (Turkey), Ö. Kog (Turkey), S. Erol (Turkey), K. Matsuo (Japan), A. Ellmann (Estonia), V. Ferreira (China), M. Buday (Czech Republic), R. Čunderlík (Slovakia), S. Valcheva (Bulgaria), S. Karagkialidou (Denmmark), V. Andritsanos (Greece), E. Nicacio (Brazil), M. Varga (Hungary), D. Smith (USA), D. Blitzkow (Brazil).

Topics
1) Report about updates in the IHRF station selection
2) Compilation of standards for the determination of IHRF coordinates
3) Preparation of a four-year report and a paper about IHRS/IHRF for IUGG2019
4) Colorado experiment
   - Processing GRAV-D data (down sampling 20 Hz data, de-biasing data). Should NGS provide "cleaned data" or leave it to individual groups?
   - If GSVS17 data becomes available next summer, would the groups complete/refine their models for IUGG2019?
   - After completion, what would be the best format to collect the results, e.g., a special issue of some kind of journal?
   - Should we start a discussion group at social media for easy information/data exchange?
5) Others

1) **Report about updates in the IHRF station selection** (L. Sánchez)

The preliminary IHRF station selection completed in April 2017 was extended with three stations recommended by the Geospatial Information Authority of Japan (Ishioka, Osumi, Wakkanai). In addition, the IAG JWG 2.1.1 'Establishment of a global absolute gravity reference system' (chair H. Wziontek) is evaluating an optimal co-location between the IHRF and reference stations of the International Gravity Reference Frame (IGRF). At present, 59 co-located sites have been identified, and the objective is to include additional IHRF or absolute gravity stations according to the necessities of IGRF or IHRF, respectively. During the Symposium GGHS2018, it was also possible to establish contact with Israel (Survey of Israel), Nepal (Ministry of Land Reform and Management,

Geodetic Survey Division), and Saudi Arabia (General Commission for Survey) to identify potential IHRF sites in those countries.

2) **Compilation of standards for the determination of IHRF coordinates** (L. Sánchez)
Based on the results of the Colorado Experiment (s. annexes 1 and 2) and the existing literature related to the gravity field modelling, a first version of basic standards and conventions for the determination of IHRS/IHRF coordinates might now be prepared. The first draft should be ready for discussion in April 2019. A refined version (including changes after the discussion) should be presented in the next IUGG General Assembly to be held in Montreal in July 2019.

3) **Preparation of a four-year report and a paper about IHRS/IHRF for IUGG2019** (L. Sánchez)

To close the term 2015-2019, an executive report should be prepared to be presented to the IAG and GGOS at the IUGG General Assembly 2019. This executive report has to be supported by a peer-reviewed paper describing the strategy for the realization of the IHRS and a first solution for the IHRF. Aim of this first solution is to evaluate the achievable accuracy under the present conditions (data availability, computation methods, etc.) and to identify key actions to improve the determination of the IHRS/IHRF coordinates. These key actions should be faced in the next term 2019-2023. For the same term, a joint working group of the GGOS FA-UHS, the IAG Commission 2 and the IGFS should investigate the best way to establish an „IHRS/IHRF element“ within the IGFS to ensure the maintenance and availability of the IHRF. This implies regular updates of the IHRFyy to take account for new stations, coordinate changes with time, improvements in the estimation of coordinates (more observations, better standards, better models, better computation algorithms, etc.), geodetic products associated to the IHRF (description and metadata), and the organizational and operational infrastructure to ensure the IHRF sustainability.

4) Colorado Experiment

The NOAA/NGS Colorado data (terrestrial and airborne gravity, terrain model and GNSS/levelling) were distributed together with a set of basic computation standards (specifications) in February 2018. Participants in the experiment should provide geoid heights, quasi-geoid heights and potential values on the Earth surface at about 220 test marks of the NOAA/NGS project “Geoid Slope Validation Survey 2017”. Until August 2018, ten contributions were delivered:

- Faculty of Engineering, Minia University, Egypt
- İstanbul Teknik Üniversitesi, Istambul, Turkey
- Department of Geodesy and Surveying, Aristotle University of Thessaloniki, Thessaloniki, Greece
- National Geodetic Survey, USA
- Natural Resources Canada, Canada
- Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden
- School of Earth and Planetary Sciences and The Institute for Geoscience Research, Curtin University, Australia
- Universidade Federal do Parana, Brazil
- Escola Politécnica, Universidade de São Paulo; Centro de Estudos de Geodesia, Brazil
- Deutsches Geodätisches Forschungsinstitut, Technische Universität München, Germany

Seven additional groups intend to join the experiment. They expect to deliver first results in the next months (October, November 2018).

From the available solutions, six provided geoid, quasi-geoid and potential values; one solution provided only geoid; one solution provided only potential values; and one solution provided disturbing potential values. The comparison of the potential values is presented in annex 1 and the comparison of the geoid and quasi-geoid solutions is presented in annex 2.

Main conclusions:

- Two solutions are declared as outliers. They present large discrepancies (at the 1.5 m level) in (quasi-)geoid heights as well in the potential numbers with respect to the other solutions.
- In the geoid comparison, six solutions agree within 3 cm to 10 cm in terms of standard deviation with respect to the mean value.
- In the quasi-geoid comparison, the same six solutions agree within 1 cm to 4 cm in terms of standard deviation with respect to the mean value.
- In the comparison of the potential values, four solutions agree within 1 cm to 2 cm in terms of standard deviation with respect to the mean value.
- The discrepancies present a high correlation with the topography.
- Possible sources of discrepancy:
    - Different handling of terrain corrections/reductions
    - Inconsistent use of the zero-degree term: $T_0 = \Delta GM - \Delta W_0$; $\Delta W_0 = W_0 - U_0$; $\Delta GM = \left(GM - GM_{GRS80} \right) / R$
    - Precision degradation due to the conversion of quasi-geoid heights to geoid heights and vice versa
    - Uncertainties in the processing of the airborne gravity data

Recommendations:

- Participants in the experiment should provide a description with the main features of their computations in order to identify possible sources of discrepancies.
- Participants should follow the basic standards/specifications distributed with the data, especially in the handling of corrections/reductions like the effect of the atmosphere, the consistent use of the zero-term, the global gravity models, etc.
- The document with the standards/specifications will be modified/extended by Ågren, Sánchez, Wang, and Huang to present more clearly some confusing issues like the handling of the zero degree term and the conversion from quasi-geoid to geoid. In this particular case, geoid heights should be computed under the constant topographic density hypothesis (2.67 g cm^{-3}).
- NGS will provide a pre-processed (cleaned) version of the GRAV-D data (down sampling 20 Hz data, de-biased data) by the end of September 2018. After that, participants in the experiment should use the pre-processed airborne gravity data. The method to be applied for the downward continuation of these data is up to the participants.
- The comparisons presented in annexes 1 and 2 show how consistent are the different solutions with each other. To validate the results, it is necessary to have independent control data; the best option are potential differences inferred from levelling and gravimetry. NGS is working on the adjustment of the levelling along the test marks and it will provide these data as soon as possible.

Next actions:

- Based on this first comparison, participants in the experiment will refine some aspects of their computations using the pre-processed GRAV-D data. Results should be delivered by middle December 2018.
- A second iteration should be ready in March 15, 2019, in order to discuss/present the details at the next EGU General Assembly.

- Based on the second iteration, it will be decided if a new iteration is needed. If yes, the results of this iteration should be ready well before the IUGG General Assembly 2019.
- It is highly recommended to report the results of this experiment. A suggestion is a special issue of the Journal of Geodesy. The contribution of all participants is expected and welcome.
- The data exchange and discussion should continue using the Google drive prepared by Wang. All the contributing solutions should be stored there.

Annexes

1) Advances in the establishment of the International Height Reference Frame (IHRF), Sánchez et al. presentation at GGHS2018.
2) Report on Colorado geoid comparisons, Wang et al. presentation at GGHS2018.

More details about the actions to implement the IHRS/IHRF at https://ihrs.dgfi.tum.de/en/working-groups/012-ihrs-realization/