Physical Height and the GGRF

- Earth Gravity Field and the GGRF -

- GGRF an Integrated Approach -

Johannes Ihde[(1)], *Laura Sánchez*[(2)]

GGOS Days 2015

Bureau of Products and Standards Meeting

[(1)] Bundesamt für Kartographie und Geodäsie, Germany

[(2)] Deutsches Geodätisches Forschungsinstitut, Technische Universität München, Germany

Contents

1) Physical heights, Gravity, GGRF
2) Physical Heights and Earth Gravity Field
3) What is a Global Geodetic Reference Frame - GGRF?
4) IHRS and GGRF – GGOS Product Discussion

1) Physical heights, Gravity, GGRF

The two IAG Resolutions 2015

No. 1 for the definition and realization of an International Height Reference System (IHRS)

- Five conventions for the IHRS definition plus W_0 (as reference for IHRF)
- Requirements for the realization:
  - long-term stability and worldwide homogeneity
  - an integrated global geodetic reference frame with millimeter accuracy
  - removal of inconsistencies between analysis strategies, models, and products related to the Earth's geometry and gravity field
  - outlining of standards that allow a consistent definition and realization.

(An IAG inter-commission working group should be established to investigate the necessity and usefulness of replacing GRS80 with a new GRS until IUGG 2019).

The two IAG Resolutions 2015

- No. 2 for the establishment of a global absolute gravity reference system resolves :
  - initiate a working group to compile standards for the definition of a geodetic gravity reference system based upon the international comparisons of absolute gravimeters,
  - to establish a gravity reference frame by globally distributed reference stations linked to the international comparisons of absolute gravimeters where precise gravity reference,
  - link the reference stations to the International Terrestrial Reference System by co-location with space-geodetic techniques,
  - initiate the replacement of the International Gravity Standardization Net 1971 (IGSN71) by the new Global Absolute Gravity Reference System (until IUGG 2019).

1) Physical heights, Gravity, GGRF

The UN Committee of Experts on Global Geospatial Information Management (UN-GGIM) (http://www.unggrf.org/)

- In February 2015 the UN GA adopted the resolution ***A global geodetic reference frame for sustainable development.***
- A broad interpretation of the GGRF will be adopted.
- The GGRF is intended to include as a priority the geometric reference frame and its components observing systems, data centers, analysis centers, and combination and product centers.
- The GGRF also include gravimetric products and physical height systems. (And the celestial reference system.)
- The focus of the roadmap is mainly related about the operational production of these products. Some considerations will also be given to the associated research and innovation activities.

2) Physical Heights and Earth Gravity Field

The representation of the Earth gravity field is independent possible with to different kind of fields.

Both fields

- geo-potential scalar field $W(X)$
- the outer Earth gravity vector field $\vec{g}(X)$

connected by the relationship

$$\vec{g}_P = grad\, W_P = -g_P \begin{pmatrix} \cos\Phi \cos\Lambda \\ \cos\Phi \sin\Lambda \\ \sin\Phi \end{pmatrix},$$

$$\boldsymbol{g_P = g(X) = |grad\ W_P|}$$

X position in natural coordinates: Φ astronomical latitude,

Λ astronomical longitude, W potential of Earth gravity field.

Physical Heights and Earth Gravity Field - Principles

$$g_P = g(X) = |grad\ W_P|$$

1) A Global Height Reference Frame (IHRF) must be consistent in parameterization with the International Terrestrial Reference Frame (ITRF) and a Global Gravity Network (IGSN)
2) In sense of GGOS, the consistency in the IERS conventions has to be established (i.e. tidal system problem).
3) It has to be investigated the need of a new GRS (Mean Earth Ellipsoid parameter under the constraint of the new W_0 value).

3) What is a Global Geodetic Reference Frame - GGRF?

The Global Geodetic Reference Frame is the Realization of the Global Geodetic Reference System.

The Global Geodetic Reference System is the concept for a common reference for geometry and gravity field of the Earth: $W(\mathbf{X})$, or $\boldsymbol{P}(\mathbf{X}, W)$ or $P(\mathbf{X}, W, g) = P(\mathbf{X}, W, -\partial W/\partial H)$. (Position/coordinate $\mathbf{X}$ of a physical point P, Potential of the Earth gravity field W, representing the physical height H, gravity value g).

1. The spatial reference of the position P for the potential $W_P = W(\mathbf{X})$ is related as coordinates $\mathbf{X}$ of the International Terrestrial Reference System.
2. The unit of length is the meter (SI). The unit of time is the second (SI).
3. The physical heights as the differences $-\Delta W_P = C_P = W_0 - W_P$ between the potential W_P of the Earth gravity field at the considered points P, and the geoidal potential of the level ellipsoid W_0.
4. The gravity $\boldsymbol{g}$ as the gradient of the potential of the Earth gravity field
5. Parameters, observations, and data shall be related to an agreed tidal system/crust.

What is a GGRF?

The Global Geodetic Reference Frame (GGRF) shall be a terrestrial (and a celestial network) with physical points with parameters describing the physical state in geometry, gravity field and time.

The terrestrial network is global with regional/national densifications. This network shall be collocated with:

- fundamental geodetic observatories (connection between $\mathbf{X}$, W, TAI, and absolute gravity g);
- geometrical GNSS reference stations of different densification levels;
- reference tide gauges (local vertical datum points);
- gravity points.

What is a GGRF?

Fundamental geodetic observatories (connection between $\mathbf{X}$, W, TAI, and absolute gravity g) shall fulfill the GGOS requirements and should include time laboratories regarding future use of optical clocks for ΔW determination (relativistic geodesy) and gravity laboratories (IAG Res. 2015 No. 2).

These stations must be at least:

- continuously monitored to detect deformations of the reference frame;
- referred to the ITRS/ITRF to precisely know their geometric coordinates;
- connected by levelling with the local vertical datum to precisely know their local geopotential numbers (to allow the vertical datum unification).

What is a GGRF?

Additionally,

- A Global Gravity Model (GGM) is part of the GGRF.
- The Earth gravity potential W_P at the GGRF stations must be estimated with accuracy of 1 x 10^{-2} m^2s^{-2} by gravity densification measurements $\boldsymbol{g(X)}$ in relation to the convened GGM.
- A standardization of the different data is required (tide system, reference epoch for station positions, reference gravity field for the solution of the GBVP, etc.).
- The celestial network is part of the GGRF (needs more specifications).

All the elements mentioned above form the physical infrastructure of the GGRF. For the realization we need an organizational/operational infrastructure in form of services and organizations.

GGRF as integrated network combine the ITRF, IHRF and IGSN in geodetic observatories. Densifications networks shall represent $\boldsymbol{X}$, $\boldsymbol{W(X)}$, $\boldsymbol{g(X)}$.

4) IHRS and GGRF – GGOS Product Discussion

According to this, the main expected products associated to the IHRS are:

An International Height Reference Frame (IHRF) is a terrestrial network with:

- geometric coordinates X, dX/dt (ITRF coordinates);
- potential values $W_P = W(X)$, dW_P/dt;
- geopotential numbers C_P, dCp/dt with respect to the conventional value W_0 introduced by the 2015 IAG Resolution No. 1;
- normal heights H_P, dH_P/dt;
- vertical offsets between the global reference level and the local height systems (as a global vertical datum unification is desired).

Regular updates of the IHRF*yy* would be necessary to take account for:

- new stations;
- coordinate changes with time $\boldsymbol{dX/dt}$, $\boldsymbol{dW_P/dt}$;
- improvements in the estimation of $\boldsymbol{X}$ *and* $\boldsymbol{W_P}$ (more observations, better standards, better models, better computation algorithms, etc.)

The generation of these products has to be necessarily supported by a detailed description of the applied standards, conventions and procedures; i.e. an equivalent documentation to the IERS conventions is needed for the IHRS/IHRF.

At present, the main deficits are

- the precise estimation of the potential $W_P = W(X)$ in
- the repetition rate of ITRF of 5+ years (…, 2008, 2015, …?)
- the accuracy and modelling of the ITRF vertical components.

For the combination of geometrical coordinates of a GGRF with gravity field modelling, there are the following three different approaches:

- Basic solution: A satellite-only GGM combination model
- Ideal case: satellite-only GGM + high resolution potential modelling in the regions or around (solution of the geodetic boundary value problem, GVBP, using the so-called *remove-restore* technique);
- "At present, most recommended" case: GGM including high degrees, i.e., the so-called EGM2008 Follow-On models (EGM2008FO) (My comment: The data and the procedure must be open – that is not the case for EGM2008. Only under that condition the EGM would be a GGOS product)

According to Rummel et al. 2014 (ESA project: HSU with GOCE), the expected accuracy after applying an EGM2008FO model is:

- in well surveyed regions: 40 to 60 cm^2s^{-2}, equivalent to 4 to 6 cm;
- in sparsely surveyed regions: 200 cm^2s^2 to 400 cm^2s^2, equivalent to 20 to 40 cm (with extreme cases of 1 m!).

As input for the discussion during the GGOS Days:

Differences between the potential values obtained at some SIRGAS reference stations after applying different GGM are considered. The South America region was selected, because of its average geodetic infrastructure: it is not as good as in Europe or North America, but it is better than in other regions of the world.

Discussion Points

- What are the user needs for IHRS products
- The products shall not restricted to special regions or users – but the application should recommended – which applications should considered
- How the IHRF can installed
- How we get consistent processing procedures and who can do it
- How are the control mechanism, quality check?