Title:

Methodology for improving the accuracy of GNSS leveling based on local correction of the heights of global geoid models

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Level of study or work: Ph.D. research

Information about you (and your team): Since 2016, Alina Fedorchuk has started conducting scientific research on the possibility of performing GNSS leveling based on the heights of global geoid models. Her personal research motivation is to improve GNSS leveling techniques so that engineers and scientists can obtain more accurate data for their researches and projects. The choice of this research direction is related to her desire to make a personal contribution to the improvement of geodetic methods and measurements by solving the important scientific and applied problem of improving the accuracy of GNSS leveling results. In 2018, she defended her master's thesis "The determination of the heights of the Earth's surface points by GNSS observation data and geoid models on the territory of Lviv" at the Department of Geodesy and Astronomy and received a master's degree from Lviv Polytechnic National University. Thereafter, in 2019, Alina Fedorchuk continued her research by entering postgraduate studies. In 2023, she defended her dissertation for the scientific degree of Doctor of Philosophy in the field of "Architecture and Construction" with the specialty "Geodesy and Land Management" at the Lviv Polytechnic National University. On the topic of the dissertation, 4 articles were published in specialized publications in Ukraine, 2 articles were indexed in the Scopus database, 8 publications were published in conference proceedings, and the results were presented at 12 scientific and technical conferences. The dissertation was prepared under the supervision of a Doctor of Technical Sciences, Professor Stepan Savchuk.

Area of interest

With the advent and development of GNSS systems, a new method of height determination appeared, which is called GNSS leveling. This method is based on the use of ellipsoid heights obtained from GNSS measurements and geoid or quasi-geoid heights obtained from the corresponding models. Until recently, the implementation of the GNSS leveling method was based on the use of geoid or quasi-geoid model heights of regional/local scale only. However, for some regions of the planet, such a model may not be available, or the heights of the available models may not correspond to a high level of accuracy.
With the advent of global geoid models of high degree and order, it became possible to use them to implement the GNSS leveling method. Today, the field accuracy of the static GNSS measurements results is 1-2 cm in height, and the root-mean-square (RMS) error of global models heights ranges from 7 to 30 cm depending on the regions of the planet. It is obvious that such accuracy of model heights does not satisfy the majority of geodetic works. Therefore, to implement the GNSS leveling method with higher accuracy, it is necessary to correct the height of the selected global geoid model. From the results of numerous scientific

studies, it is known that such a problem can be solved only at the local level, since the accuracy of correcting the heights of global models depends on many factors and therefore require an individual approach.

Approach to the problem

The general flowchart of the methodology for local correction heights of global geoid models is shown in Figure 1.

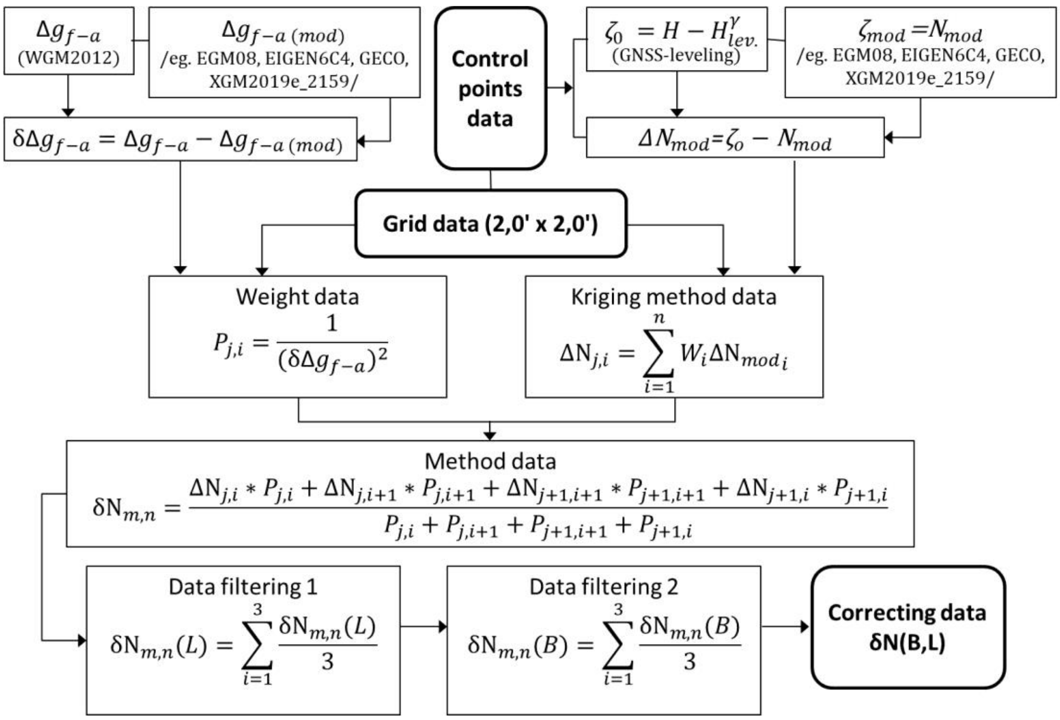

Figure 1. Flowchart of the proposed methodology

The methodology consists of the following steps:
1) GNSS leveling is performed at control points of high-precision geometric leveling, and geometric geoid/quasi-geoid heights (ζ_0) are calculated;
2) for the control points are also calculated geoid/quasi-geoid heights of the selected global model (N_m) through the ICGEM site utility;
3) for the control points are founded the errors of the geoid/quasi-geoid heights ΔN_m, as the difference between ζ_0 and N_m;
4) the errors obtained at the control points are transformed into a regular grid with a step of $2' \times 2'$ and with nodes $\Delta N_{j,i}$ using the Kriging interpolation method (Figure 2 – black line);
5) for the nodes of the created grid, the differences in free-air gravity anomalies ($\delta\Delta g_{f-a}$) are computed as the difference between the gravity anomalies of the World Gravity Map – WGM2012 (with a high resolution of $2' \times 2'$) and the anomalies of the selected global geoid model (computed through the ICGEM website with a resolution of $2' \times 2'$);

6) differences of gravity anomalies are transformed into weight coefficients $P_{j,i} = \frac{1}{(\delta\Delta g_{f-a})^2}$;

7) based on the data of the interpolated errors grid $\Delta N_{j,i}$ and the weighting coefficients $P_{j,i}$ are calculated the grid of average weighted errors $\delta N_{m,n}$ with a step of 2′ × 2′, but with the size $\Delta N_{j-1.i-1}$ (Figure 2 – blue line) as $\delta N_{m,n} = \frac{\Delta N_{j,i} * P_{j,i} + \Delta N_{j,i+1} * P_{j,i+1} + \Delta N_{j+1.i+1} * P_{j+1.i+1} + \Delta N_{j+1.i} * P_{j+1.i}}{P_{j,i} + P_{j,i+1} + P_{j+1.i+1} + P_{j+1.i}}$;

8) it is performed the first filtering of $\delta N_{m,n}$ values by longitude using the moving average method $\delta N_{m,n}(L) = \sum_{i=1}^{3} \frac{\delta N_{m,n}(L)}{3}$;

9) it is performed the second filtering by latitude $\delta N_{m,n}(B) = \sum_{i=1}^{3} \frac{\delta N_{m,n}(B)}{3}$.

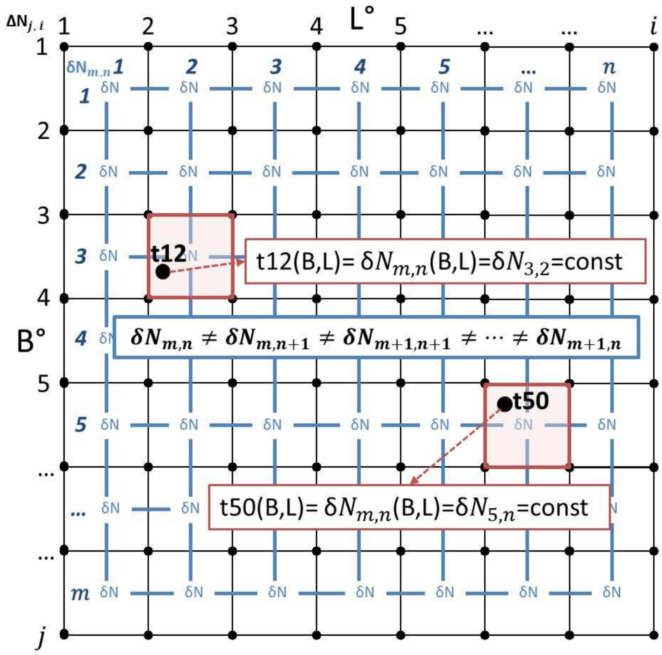

Figure 2. Methodology for creating error grids and the principle of their use

The obtained values on step (9) will correspond to the interpolated, balanced and modeled data for correcting the geoid/quasi-geoid heights of the selected global model.

Results, conclusions and next steps

The efficiency of the proposed methodology for the correction height was tested by examining experimental data for different geographical areas, including different relief (Figure 3), taking into account the different dimensions of the research areas and number of control and evaluative points.

For testing the methodology, the regional quasi-geoid PL-quasi-geoid2021 is chosen as the zero surface. Calculated errors (ΔN) by this quasi-geoid data are taken as true errors. Modeled errors (δN) are found by proposed methodology, and residual errors ($\delta\Delta N$) received as a difference between ΔN and δN (Figure 4).

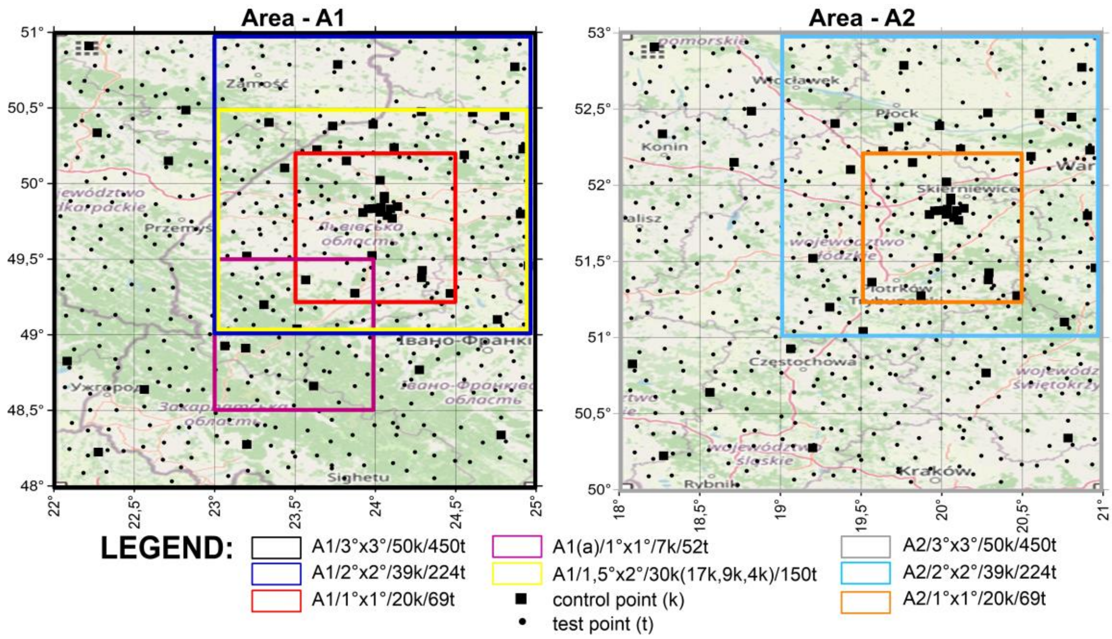

Figure 3. Study areas and their classification

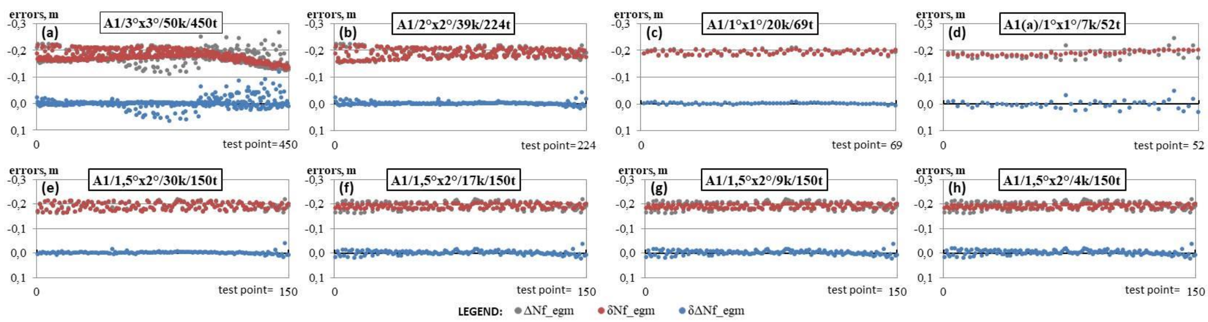

Figure 4. Changes in calculated, modeled and residual errors of the EGM08 model in the "free-tide" system for different areas

The methodology is effective because residual errors provide a standard, RMS deviations are $< 1\ \mathrm{cm}$, and the correlation coefficient between ΔN and δN is $0.8 - 1$ (Figure 5).

Model name and criterion compliance				Description of parameters of the study areas
EGM08	EIGEN6C4	GECO	XGM2019e_2159	
> 1cm	> 1cm	> 1cm	> 1cm	A1/3°x3°/50k/450t
< 1cm	< 1cm	< 1cm	> 1cm	A1/2°x2°/39k/224t
< 1cm	< 1cm	< 1cm	> 1cm	A1/1°x1°/20k/69t
> 2cm	< 2cm	> 2cm	> 2cm	A1(a)/1°x1°/7k/52t
< 1cm	< 1cm	< 1cm	> 1cm	A1/1,5°x2°/30k/150t
< 1cm	> 1cm	> 1cm	> 1cm	A1/1,5°x2°/17k/150t
< 1cm	> 1cm	> 1cm	> 1cm	A1/1,5°x2°/9k/150t
< 1cm	> 1cm	> 1cm	> 1cm	A1/1,5°x2°/4k/150t
< 1cm	< 1cm	< 1cm	> 1cm	A2/3°x3°/50k/450t
< 1cm	< 1cm	< 1cm	> 1cm	A2/2°x2°/39k/224t
< 1cm	< 1cm	< 1cm	> 1cm	A2/1°x1°/20k/69t

Figure 5. Estimation of residual errors

In summary, it should be noted that:

– the optimal area for modeling errors is 1° × 1°;

– the height correction of models EGM08, EIGEN6C4, and GECO is performed up to 1 cm for flat and foothill relief;

– for mountainous relief, only the heights of EIGEN6C4 can be corrected up to 1.5 cm.

The obtained results show that the proposed methodology can improve the accuracy of GNSS leveling up to the III–IV class of geometric leveling.
Future research could continue to connect the GNSS stations of the Ukrainian networks ZAKPOS and GEOTERRACE with the traditional leveling network.

References

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