Preparations for new realizations of vertical reference systems in Slovakia

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EUREF 2016 annual symposium
May 25-27 2016, San Sebastian, Spain

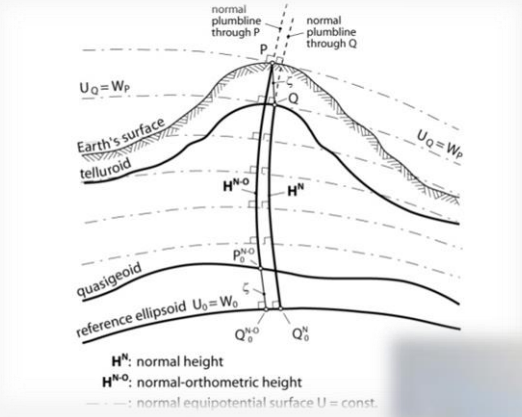
Motivation

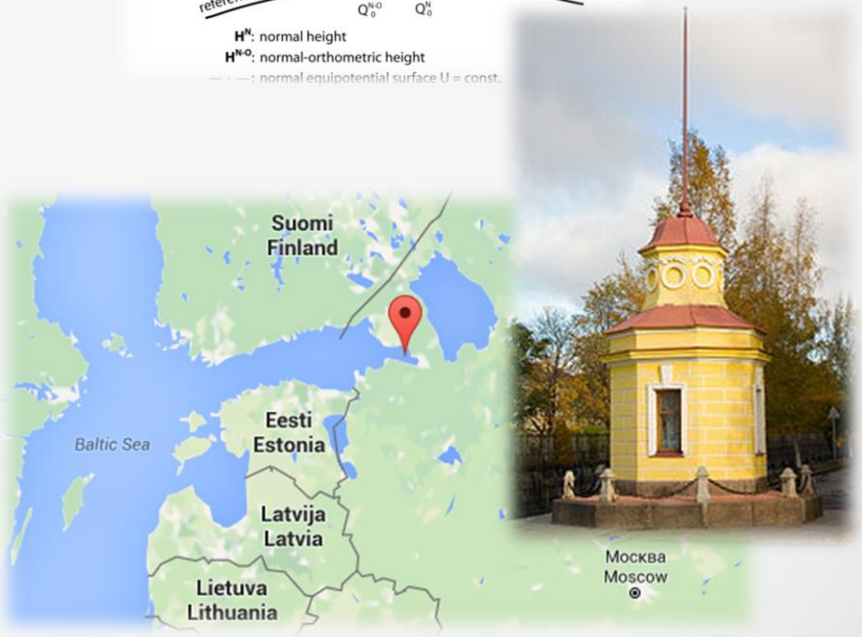
- Facts
  - Recently some European countries have presented implementation of the new vertical reference systems in their territory (Latvia, Lithuania) or plan to do it in near future (Germany)
  - Vertical reference system currently obligatory in Slovakia is Baltic vertical system after adjustment with realization from 1957!!!
  - GKÚ (geodetic control administrator) asks:
    - Are provided heights still accurate?
    - Is relative precision of points sufficient for surveyors?

  - GKÚ has also interest to increase the accuracy of transformation ETRS89-h to Bpv/EVRS (target accuracy is 1,5cm)

Baltic vertical system after adjustment (Bpv)

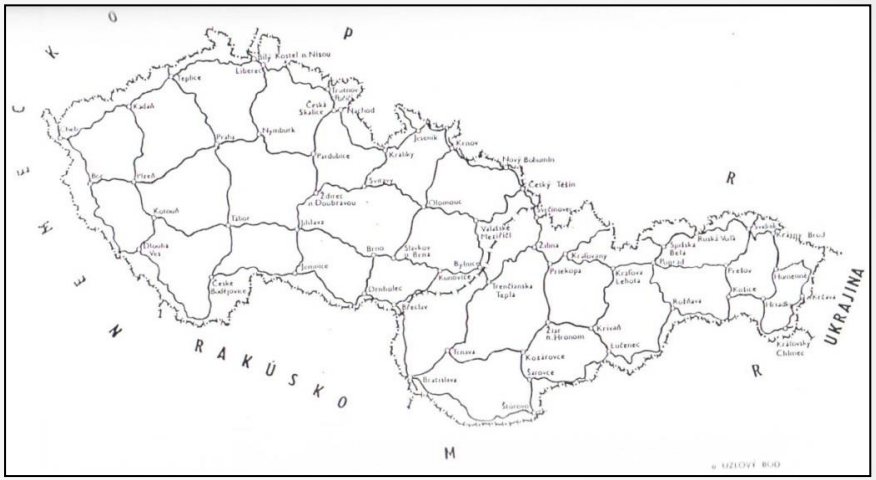
CRS identifier	SK_KRON/NH
Tidal effects	mean tide
Datum point	Kronstdat, Russia
Datum alias	Baltic
Datum type	Vertical
Datum realization epoch	Sea level 1833 (Kronstdat)
Coordinate system identifier	Normal heights
Coordinate system type	Gravity related
Dimension	1
Axis name	Height
Axis direction	up



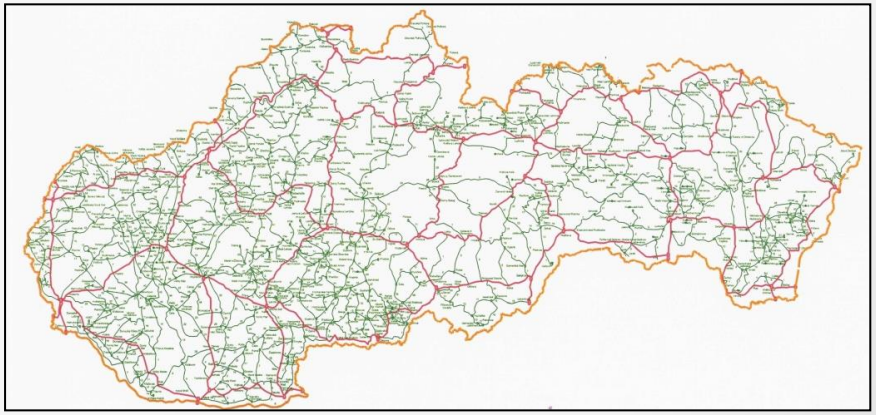


(Czecho)Slovakian vertical network development

- **1947 – 1960** - creation of the Czechoslovakian vertical network
  - name: Czechoslovak unified leveling network
  - abbreviation: ČSJNS
  - number of closed polygons: 26/12 (SVK)



- **1993** - Creation of the Slovakian vertical network
  - name: National leveling network Abbreviation: ŠNS
  - number of closed polygons: 15



ČSJNS/ŠNS Leveling lines measurement development

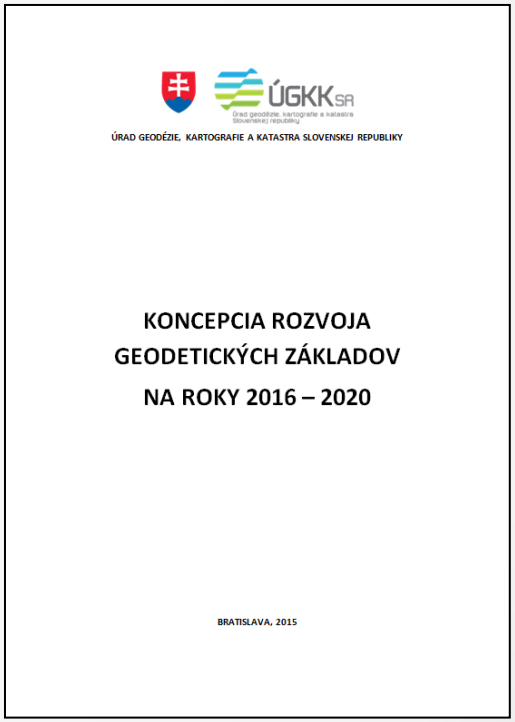
- ČSJNS leveling - basic epoch
  - 1st order ČSJNS measurement: up to 1952
  - 2nd and 3rd order ČSJNS measurement: up to 1960
- 1st repeated leveling - complete network 1961-1972
- 2nd repeated leveling - complete network 1973-1981
- „3rd“ repeated leveling – cca. 35% of network 1984–1996
- ŠNS leveling - basic epoch
  - 1st order ŠNS measurements - complete network 1996-2002
  - 2nd order ŠNS measurements - 76% of network 2003-2016

Bpv realizations development

	Bpv57 Current realization	**Bpv83 Not implemented**	**Bpv07 Not implemented**
Datum point	Kronstdat		
scale	SI – Meter		
realization of the scale	rod scale correction	rod scale correction	rod scale and temperature correction
adjustment	normal height correction + normal height adjustment	normal height correction + normal height adjustment	1. normal height correction + normal height adjustment 2. geopotential numbers adjustment
realization of the datum	58 nodal points (TCH) / 25 nodal points (SVK)	72 points (TCH)/ 35 points (SVK)	1 point (EH-500)
heights of the datum points	Common adjustment of socialist countries leveling networks – Moscow 1957	Common adjustment of socialist countries leveling networks – Moscow 1983	1. Common adjustment of socialist countries leveling networks – Moscow 1957 2. geopotential number from EVRF2000
physical parameter	normal gravity field of Krassovsky (Helmert form. 1901)	normal gravity field of Krassovsky (Helmert form. 1901)	normal gravity field of 1. Krassovsky (Helmert form. 1901) 2. GRS80
kind of heights	normal heights		
tidal effects	mean tide		

Modernization of Slovakian vertical reference system realization

- **2015** Decision of modernization
  - set by Slovak Republic geodetic authority geodetic control conception for the years 2016-2020
- Objectives:
  - Modernization of Slovakian vertical reference system realizations (Bpv as well as EVRS)
  - Improved possibility of height determination with GNSS methods (and SK*POS*®)
  - Detection of height variations (creation of recent vertical movements map)
  - Integration of new geometric and new physical components
  - New quasigeoid implementation



Concept of modernization

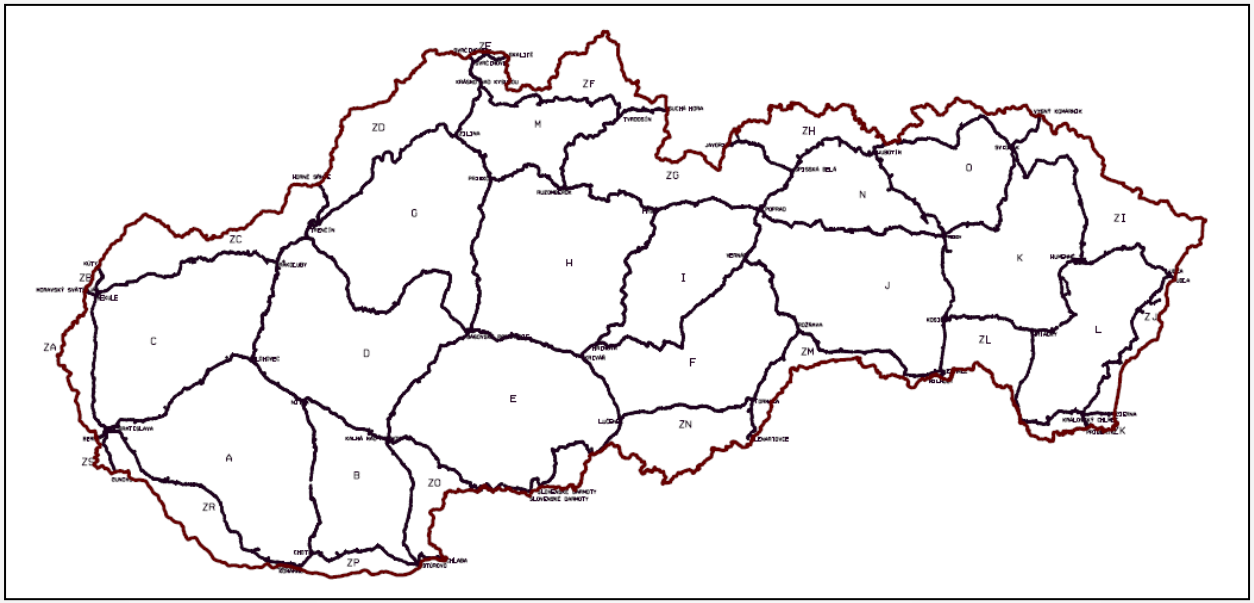
- **Leveling data homogenization + preparation (2015/2016)**
  - Usage of the newest leveling measurements
  - Usage of the newest gravity measurements/information

- **Adjustment (2018)**
  - Geopotential numbers adjustment
  - Normal height adjustment
  - 2 step adjustment: 1st order separate adjustment, 2nd order adjusted to 1st order results with covariance matrix consideration

- **Implementation realizations into routine (+2020)**
  - New geoid fitting to new realizations (GNSS/leveling point)
  - Model determination for the transformation between old and new realizations

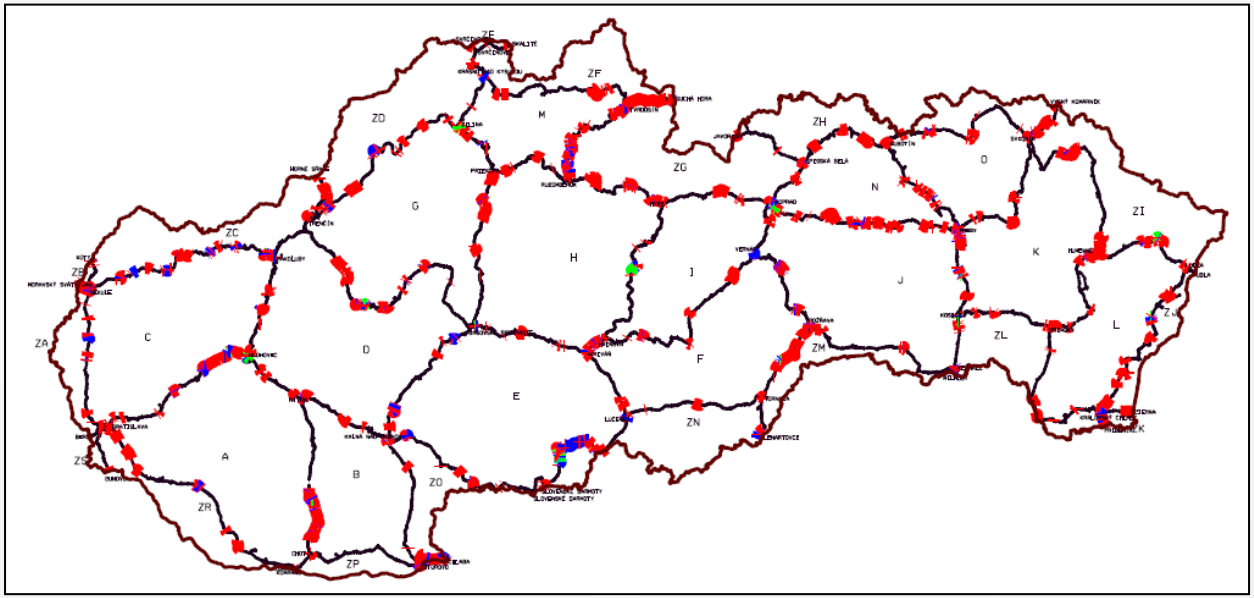
The newest leveling measurements

- 1st order ŠNS
  - 15 polygons, 68 leveling lines, 3787 km, 11 035 points
  - Complete measured between **1996 - 2002**



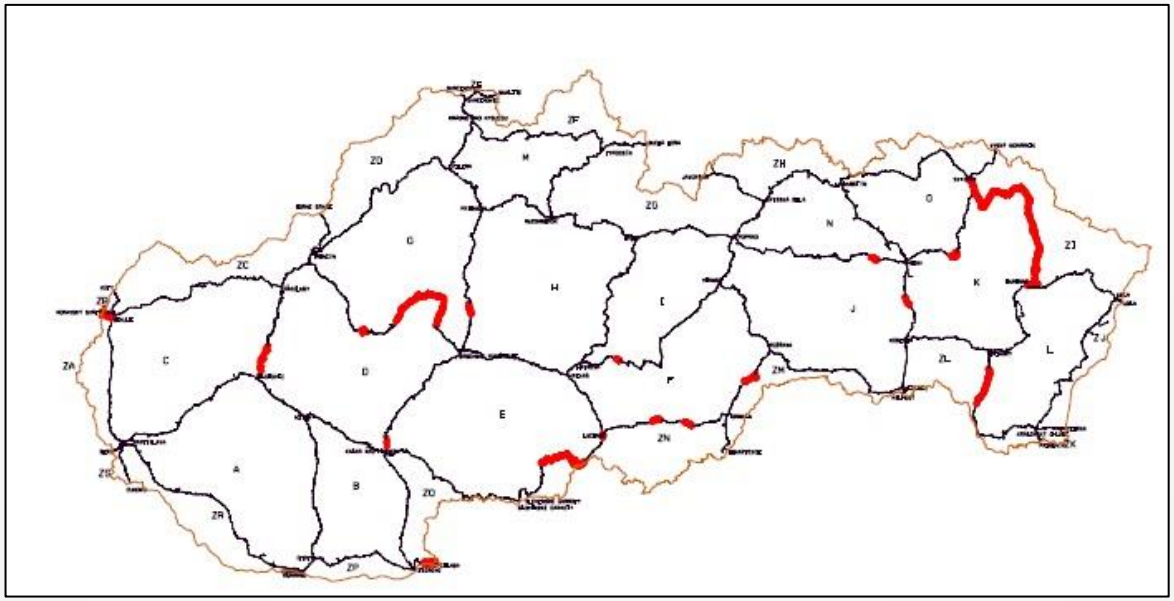
The newest leveling measurements

- Control measurements on the 1st order ŠNS leveling lines
  - done when the 2nd leveling lines were connected to the 1st order points
  - measured between 1996 – 2016;
  - Statistics: 1026 km; 3292 height differences



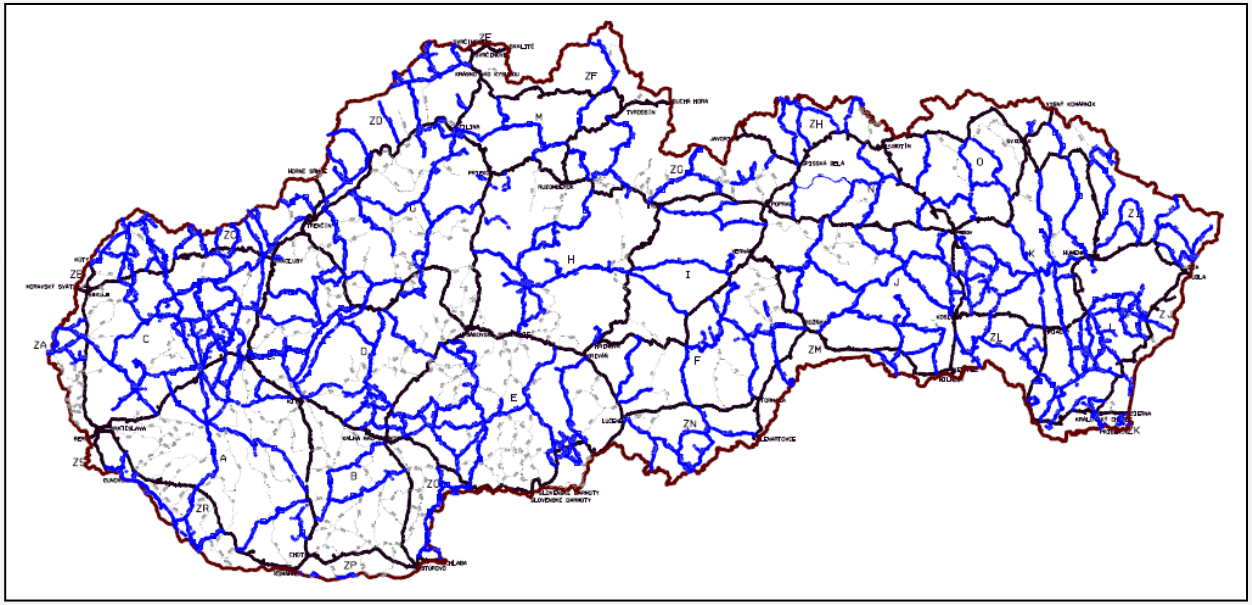
The newest leveling measurements

- Re-measurements of the 1st order ŠNS leveling lines
  - task for 2016
  - plan: 380 km



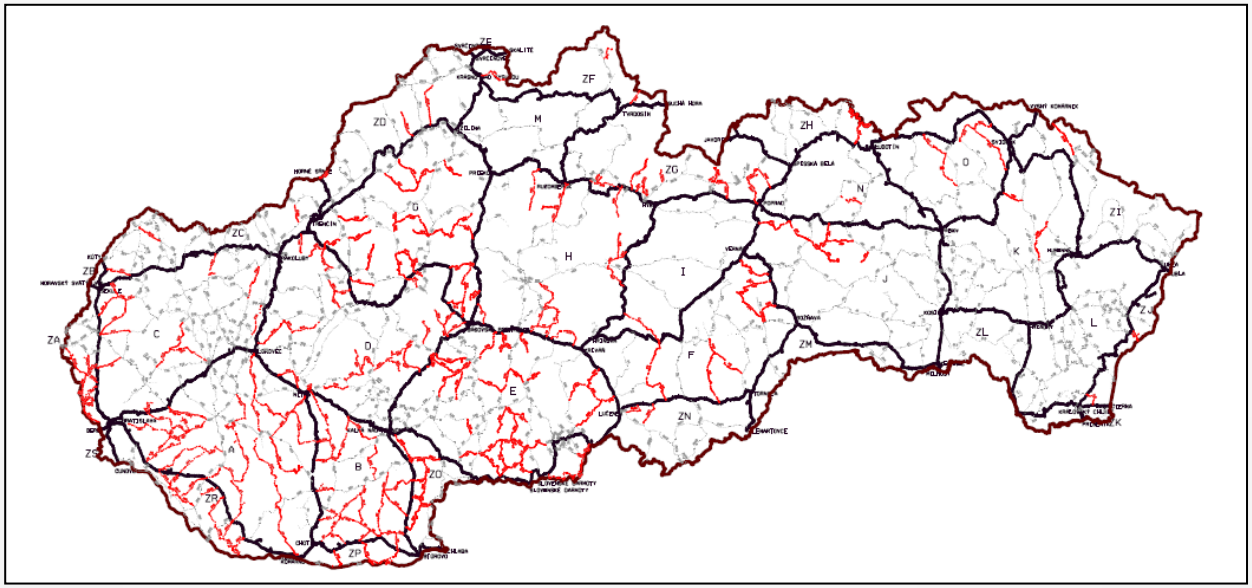
The newest leveling measurements

- 2nd order ŠNS
  - 76% of leveling lines measured between 2003 – 2015
  - Statistics: 667 leveling lines; 7288 km; 18.796 points



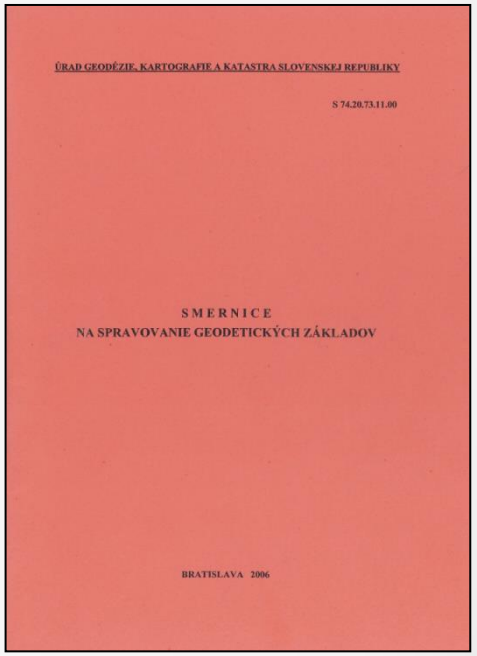
The newest leveling measurements

- 2nd order ŠNS as ČSJNS
  - 24% of leveling lines measured between 1987 – 1996
  - Statistics: 211 leveling lines; 2302 km; 5.935 points



Leveling measurements
Some information from guidelines

- Distances between leveling instrument and staff can be max. 35m long
- Staff reading have to be at least 0,8m above ground
- Used sequences of readings (B=backsight, F=foresight) - BBFF
- Fore and back measurements of a section not allowed at the same day
- Allowed difference between fore observation and back observation of a section between 2 points:
  - for 1st order lines: $1.5 \cdot \sqrt{R}$ [mm]; R = distance in km
  - for 2nd order lines: $2.25 \cdot \sqrt{R}$ [mm]; R = distance in km

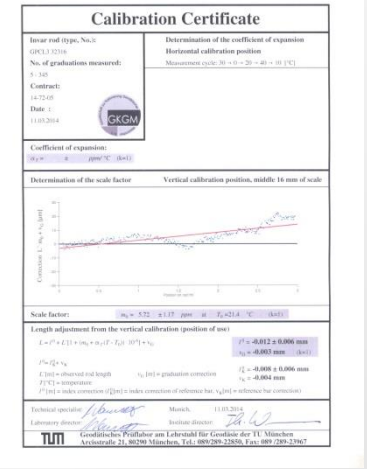


Leveling measurements

Leveling instrument and staff inspection

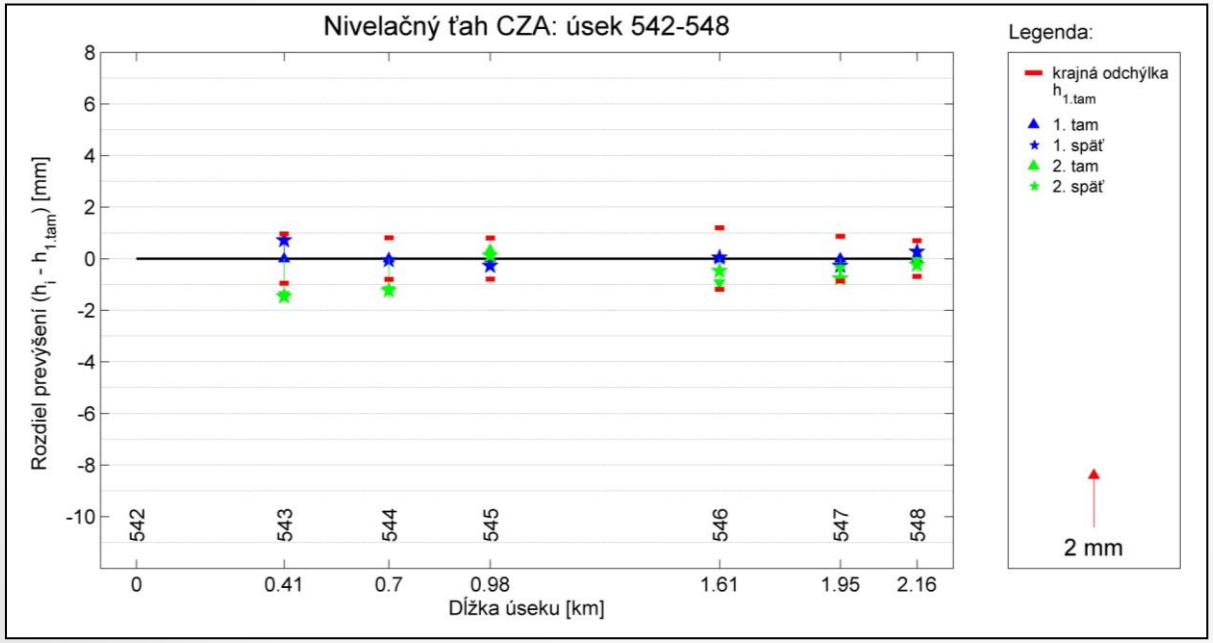
Instrument	Manufacture	Used
DNA03	Leica	2011-2016
NA3000(3)	Wild (Leica)	1995-2010
DiNi 11	Zeiss	1995-2006
Ni002	Zeiss	1987-1995
Ni007	Zeiss	1987-1995

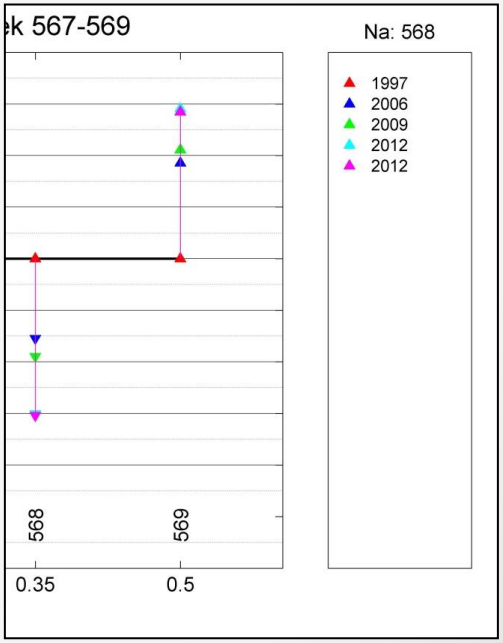
- Calibrations and testing:
  - Leveling rod calibration: every two years at the beginning of the period of measurement
  - Leveling instrument calibration: every two year
  - Instrument/staff testing: Every year at the beginning of the period of measurement on leveling testing round



1st order leveling lines height differences analysis

- Analysis of height differences on 1st order leveling lines composed of comparison of basic epoch with re-measurements and control measurements
  - Standard deviation of repeated leveling was determined
  - Errors and mistakes were eliminated

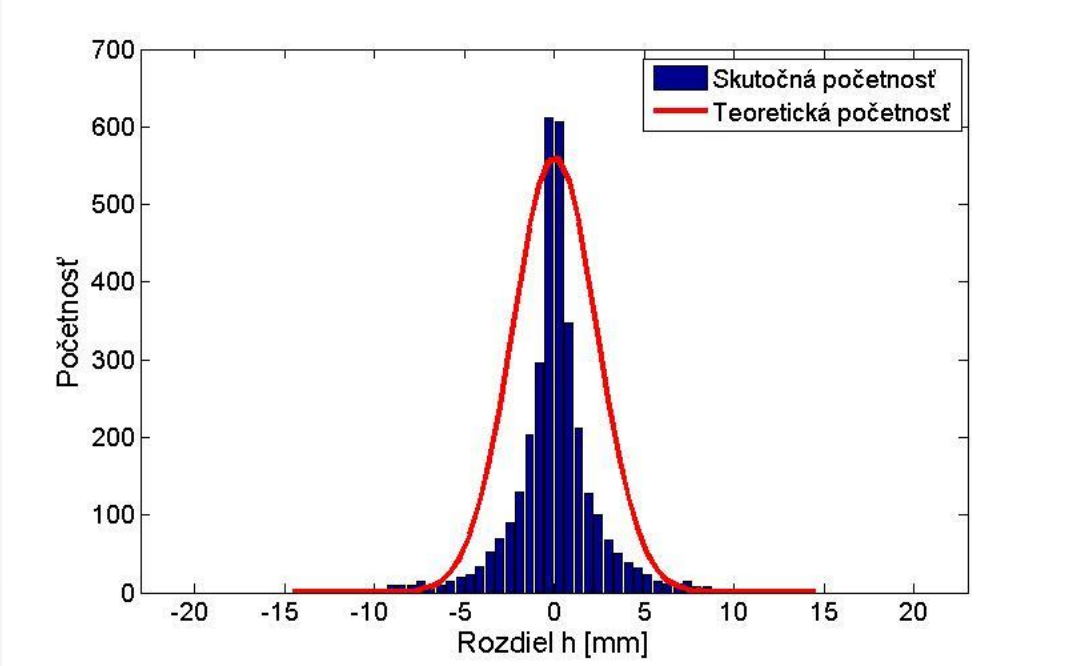




1st order leveling lines height differences analysis

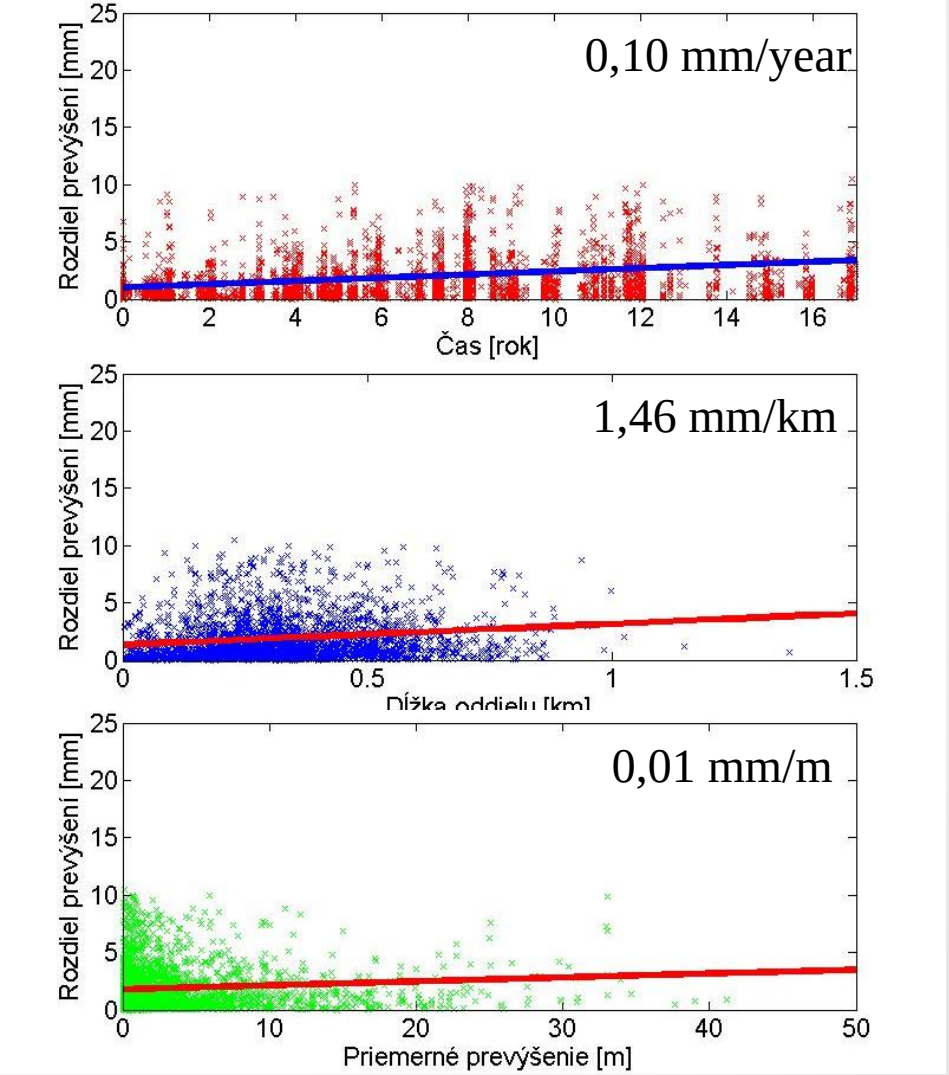
- Result statistics:
  - Height differences: 3292
  - Achieved standard deviation: 2,3 mm
  - Number of eliminated height differences (over 3σ): 173

Quality of repeated leveling confirmed!



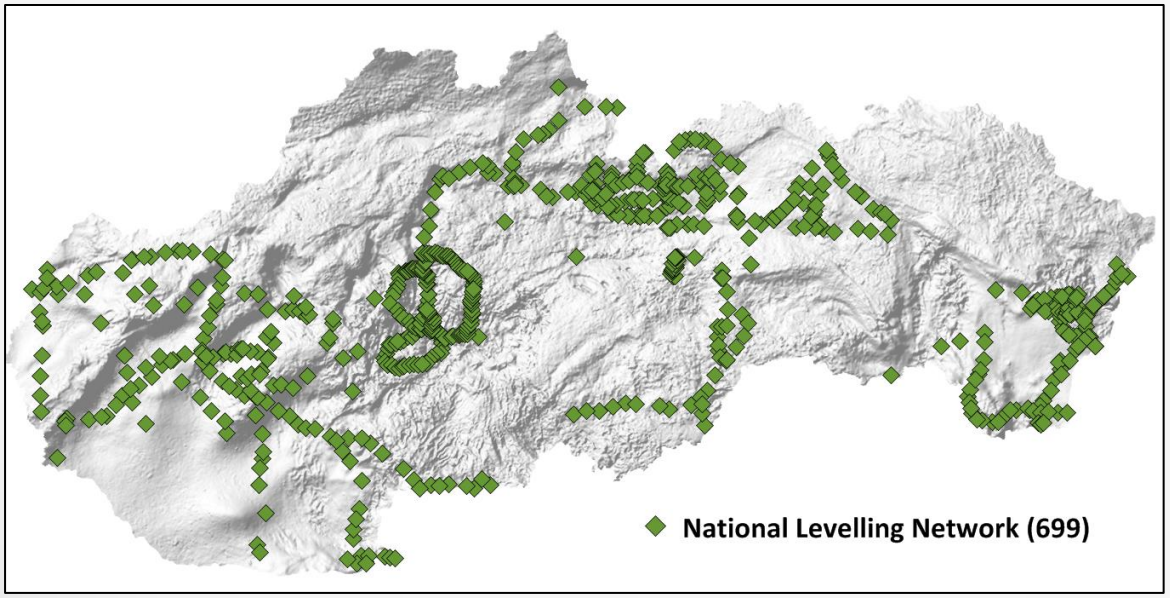
1st order leveling lines height differences analysis

- Height differences analyzed according to dependency on:
  - time span
  - length of section
  - height difference



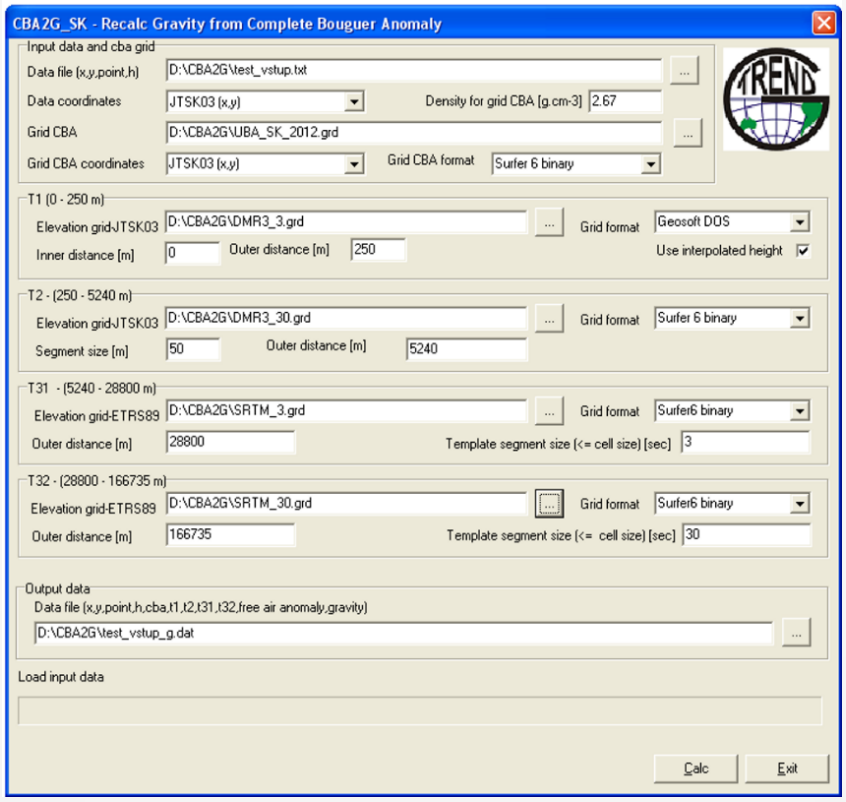
The newest gravity measurements/information

- ŠNS points with direct gravity measurements
  - only 2% of all ŠNS points (5% of 1st order ŠNS points)
  - relative gravimeters LaCoste & Romberg and Scintrex CG5 used
  - Gravity system: S-Gr95



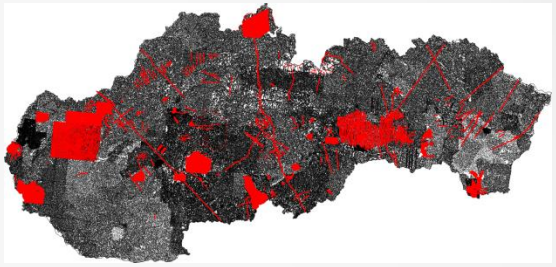
The newest gravity measurements/information

- Points with missing gravity => Decision to use interpolated gravity from CBA2G_SK software (Marusiak et. Al, G-trend company)

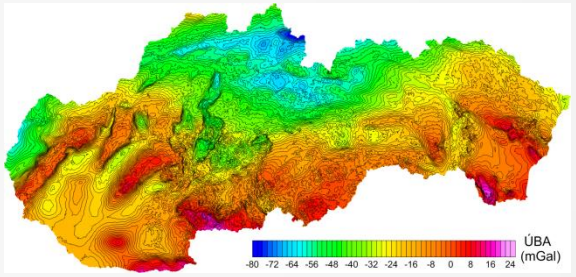


CBA2G_SK software (Marusiak et. al, G-trend)

- Code: C++, Windows 32 bit
- Gravity database: 320 000 points with cleared measurements from 1959-2014



- Geodetic system support: all Slovakian reference geodetic systems

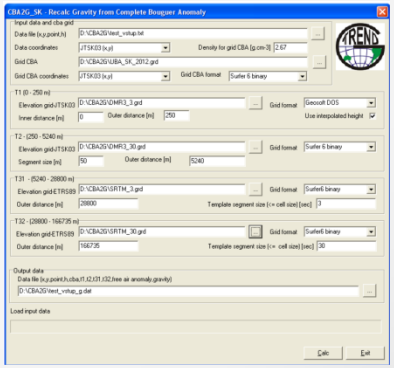


- allow computation of complete Bouguer anomaly from gravity and vice versa:

(1) $\Delta g_{CBA} = g_{mer} - \gamma_0 - \delta g_{vv} + \delta g_{atm} - \delta g_{sf} + T$

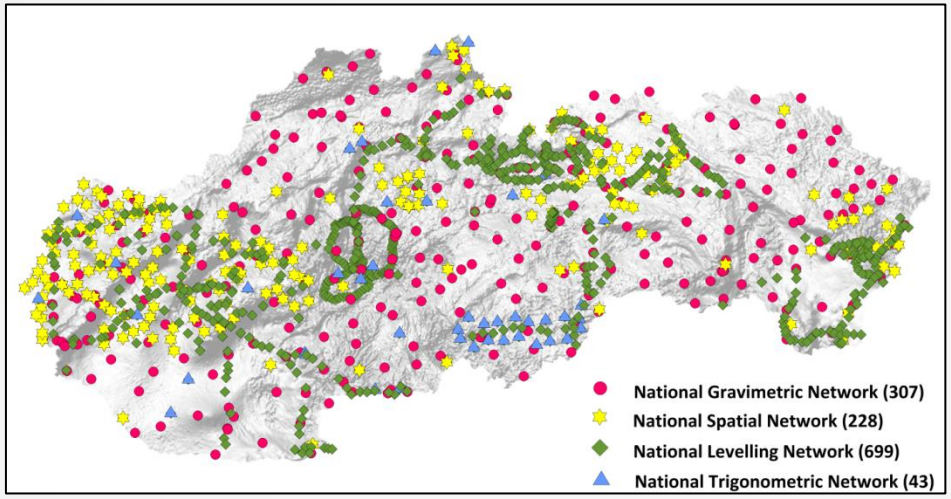
(2) $g_{rek} = \Delta g_{CBA} + \gamma_0 + \delta g_{vv} - \delta g_{atm} + \delta g_{sf} - T$

- DMR used for topo-correction determination:
  - T1 (0 – 250 m) – Slovakian DMR-3 (step 10m)
  - T2 (250 – 5240 m) - Slovakian DMR-3 (step 30m)
  - T31 (5240 – 28800 m) - SRTM-3 (step 3´´)
  - T32 (28800 – 166735 m) - SRTM-30 (step 30´´)

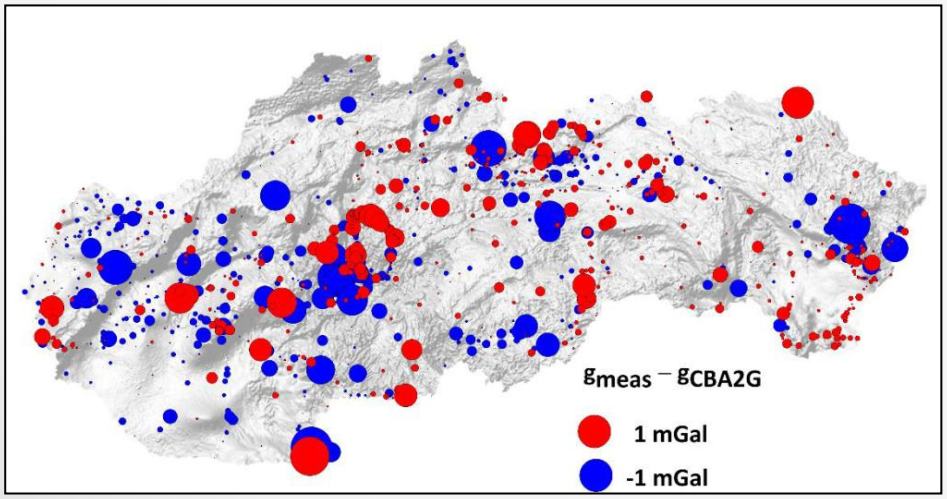


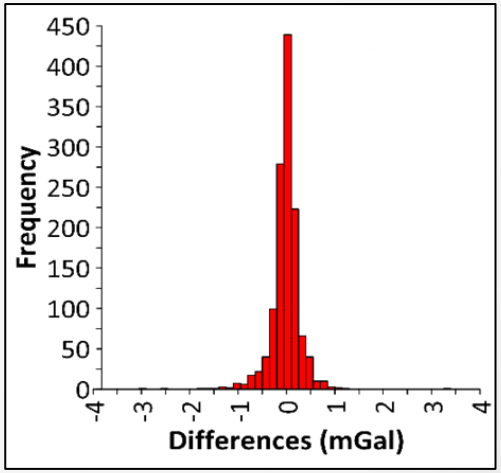
CBA2G_SK software testing

Measured versus interpolated gravity



Characteristic		CBA2G_SK
Minimum	mGal	-5.92
Maximum		10.18
Average		**-0.01**
Standard deviation		**0.46**
Number of values		1277





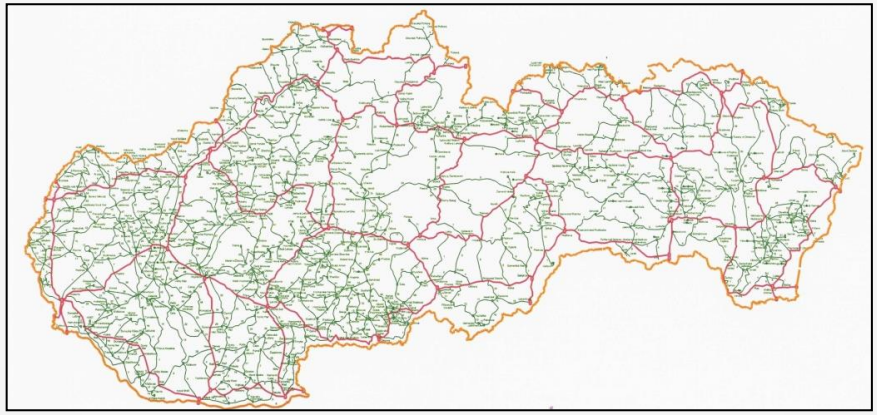
ŠNS points HZ coordinates quality

- HZ coordinates quality of ŠNS vertical points in Slovakian geodetic control database was in **2014**:
  - σ_Y = 14,29 m
  - σ_X = 14,41 m

- In **2015/2016** - **decision to improve this quality to cm level** was set (important for gravity interpolation)
  - leveling marks on buildings, bridges, etc. - coordinates is gotten from vector Cadastral maps and ZB*GIS*© (50%)
  - other points – coordinates is gotten from direct/indirect field measurements (RTK, PPK, GNSS static, RTK+crossing from distances, etc.)
    - 50% - field measurements done till May 2016
    - missing 50% field measurement planed for 2017 (only 1st order)

Next steps (2016/2017)

- **Complete leveling lines reprocessing (1987-2016)** with consideration of :
  - Invar rod scale corrections
  - Invar rod temperature corrections
  - Correction from unequal instrument-staff distances
  - Gravity corrections (for normal heights adjustment)
  - Tidal corrections (in past not considered) – SPOTL software



Next steps (2018)

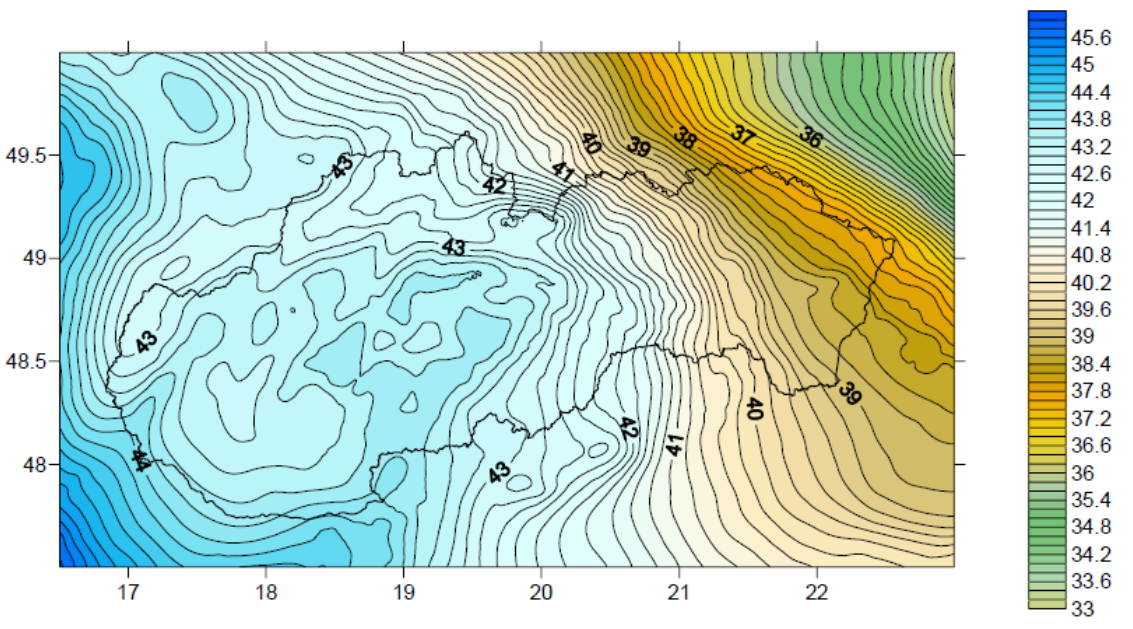
- adjustment:
  - Geopotential numbers adjustment
  - Normal height adjustment + computation of normal height corrections

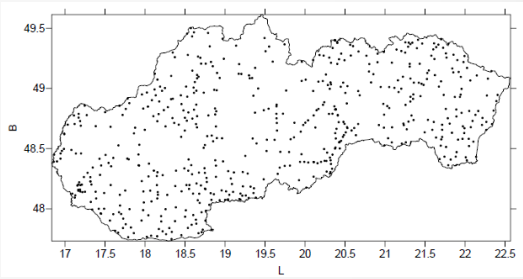
- 2 step adjustment:
  - 1st order separate adjustment,
  - 2nd order adjusted to 1st order heights (covariances considered)

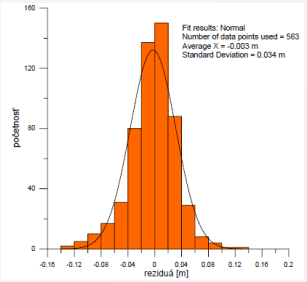
- Type of adjustment:
  - mathematic model and software not selected yet
  - datum point/points not selected yet

Next steps - Quasigeoid

- **DVRM05** = quasigeoid DMSQ03B fitted to ŠNS/ŠPS points
  - DVRM05 quality: from testing (563 points): σ_{DVRM05} **= 34 mm**



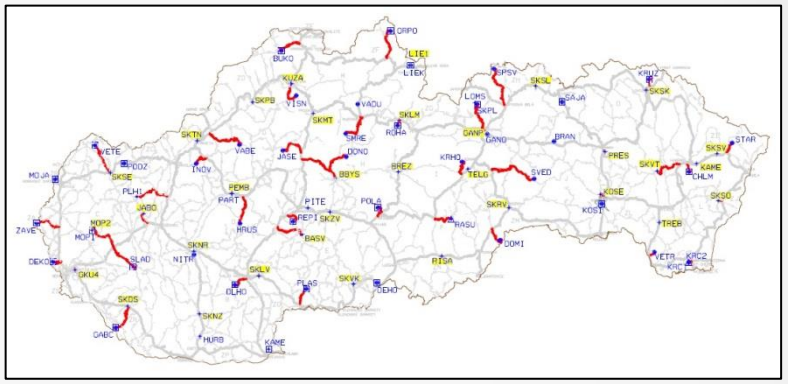




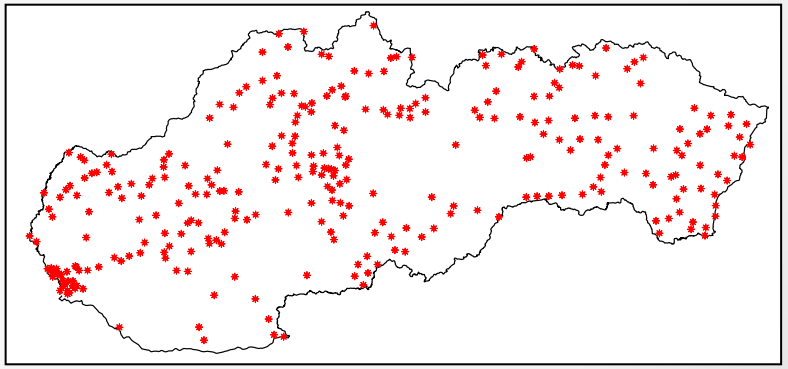
- New precise gravimetric quasigeoid on SUT Bratislava is before completing – we plan to use it

Next steps - New quasigeoid fitting

- Prepared GNSS leveling points for fitting
  - SK*POS*© + SGRN points
  - Equally distributed
  - ETRS89–h quality: σ_ϕ= 2.4 mm, σ_λ = 1.8 mm, σ_h = 3.9 mm
  - H - leveling quality: 1st order points quality



- Prepared GNSS leveling points for testing
  - 670 equally distributed points (ŠPS)
  - 2 x 6 hour GNSS campaign
  - ETRS89–h quality: σ_ϕ = 7.2 mm, σ_λ = 8.3 mm, σ_h = 13.4 mm
  - H - leveling quality: 1st order points quality



Conclusions

- The new realization of vertical reference system in Slovakia is needed
- Both new Bpv frame and new EVRF2007 national realization is planed to compute
- Some steps are not selected/decided yet (e.g. mathematical model of adjustment, datum points, etc.) so cooperation with Slovak university of technology was set
- Inspiration was taken mainly from Germany (BKG concept)
- Owned data (leveling measurements and gravity from CBA2G_SK = 0.5mGal) are very precise so high quality results are awaited

Thank you for your attention

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