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## Basic Gravimetric Network of Republic Macedonia – a New Reality

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# FIG WORKING WEEK 2015

## 17-21 MAY SOFIA BULGARIA

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### INTRODUCTION

**BASIC GRAVIMETRIC NETWORK OF REPUBLIC OF MACEDONIA**  
GRAVIMETRIC REFERENCE SYSTEM ON THE TERRITORY OF MACEDONIA



**Zero Order Gravity Network**  
*Absolute Gravimetric Network*

- Established 2010
- Consists of three points:  
Skopje (AGT01), Ohrid (AGT02),  
Valandovo (AGT03)

**First Order Gravity Network**  
Horizontal Gravimetric Calibration Base  
Microgravity Networks Points

- Procurement from **Agency for Real Estate Cadastre** (project supported by World Bank)
- Gravimetric works: JV Geotechengineering & Zenit Joint Venture between "Geotechengineering" Ltd. (Bulgaria) and "Geofoto Zenit Engineering" Ltd (Macedonia)
- Serbian specialists - **Republic of Serbia Geodetic Authority**

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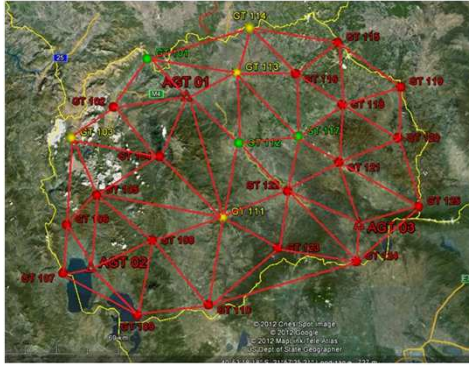
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### First Order Gravimetric Network - main characteristics



- Number of points = 25 (1pt/1070 km<sup>2</sup>)
  - existing from leveling network = 21
  - new established = 4
- Connections (lines) = 68
- Number of closed triangles = 41
- Point positions and heights
  - GNSS measurements - dual frequency GNSS receivers, using MAKPOS system
  - Precise geometric leveling
- Average distance between points = 39 km
  - minimal = 16 km (AGT02 – GT 107)
  - maximal = 85 km (GT124 – GT110)
- Average travel time for connections=2h45min
  - minimal = 1h 25 min (AGT02 – GT 107)
  - maximal = 6h 11 min (AGT01 – GT104)

Total time measurements  
**187 hours**

Total connections length  
**15 600 km**

Total measurement days  
**23 days**

Average daily work  
**680 km/day**

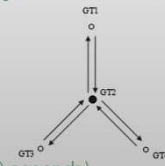


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### First Order Gravimetric Network – gravimetric measurements

- Simultaneous measurements with two gravimeters
  - Scintrex CG3+ (Ser.No. 120140052) and Scintrex CG-5 (Ser. No. 73)
- Registered - air pressure and temperature
  - two barometers of type PHB-318
- Calibration measurements
  - horizontal calibration base AGT01 - AGT02
  - three times over period of gravimetric campaign – before, in the middle and at the end of measurements
- Scheme - Star method or Difference method
  - main closing figures – triangles
- Height of the instruments -accuracy of 1 mm
- Station measurements - 6 cycle measurements (60 seconds)

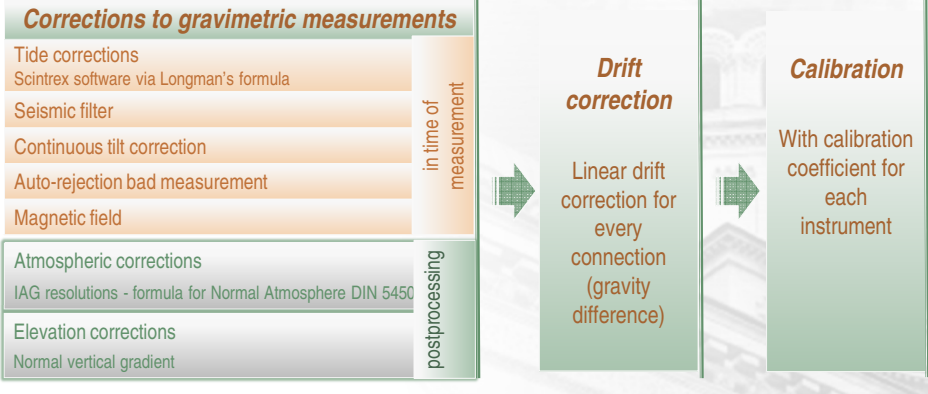




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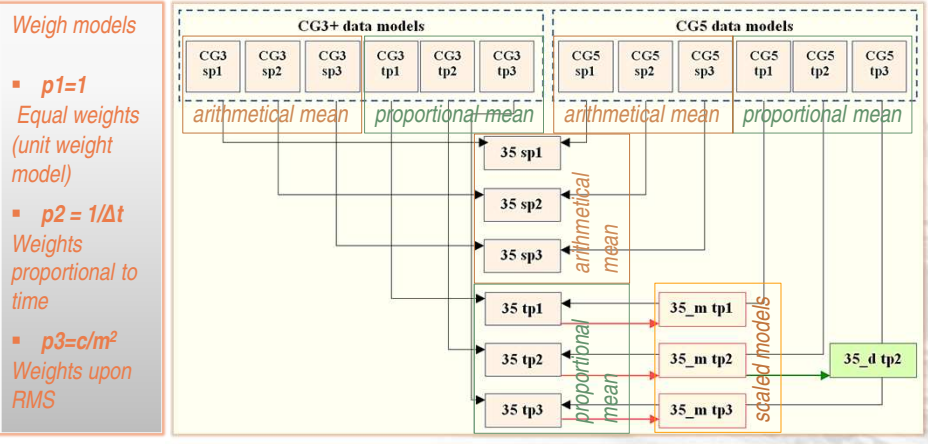
### First Order Gravimetric Network – processing



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### Data models – for estimation and adjustment

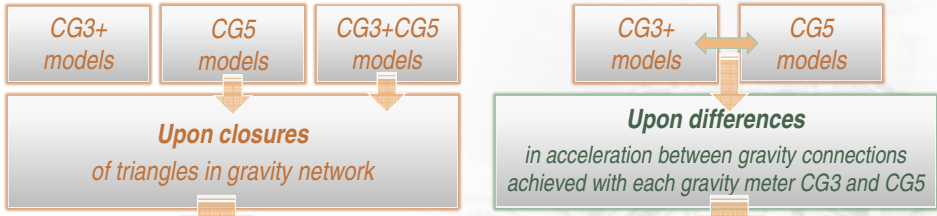




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### Preliminary accuracy estimation



#### STATISTICAL HYPOTHESIS

- **Availability of gross errors**  
confidence level of probability 0.997
- **Availability of systematical errors**  
for non-calibrated and calibrated data; calibrated data gives insignificant values for systematical errors
- **Hypothesis for normal distribution**  
for non-calibrated and calibrated data; results for calibrated data show that hypothesis is not rejected, so data are not in contradiction with hypothesis for normal distribution.



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### Least squares adjustments – free adjustment

PROGRAM GRAVI_P: CG3 and CG5 FREE ADJUSTMENT												
data	CG3						CG5					
model	arithmetical mean			proportional mean			arithmetical mean			proportional mean		
weight	p1	p2	p3	p1	p2	p3	p1	p2	p3	p1	p2	p3
model	cg3_sp1	cg3_sp2	cg3_sp3	cg3_tp1	cg3_tp2	cg3_tp3	cg5_sp1	cg5_sp2	cg5_sp3	cg5_tp1	cg5_tp2	cg5_tp3
m <sup>o</sup> a-priori	12.21	7.31	15.30	8.78	5.16	9.98	11.11	6.97	14.28	11.02	6.92	12.84
mo posteriori	11.74	6.96	14.36	9.59	5.62	10.64	11.98	7.59	16.19	11.98	7.60	14.66
m <sub>max</sub> Δg	8.416	9.452	12.94	6.873	7.634	10.496	8.587	10.302	12.755	8.591	10.307	13.016
Δg(i-k)	120-119	115-119	114-101	120-119	115-119	114-101	120-119	115-119	114-101	120-119	115-119	114-101
v <sub>max</sub> Δg	29.8	28.5	33.0	17.3	21.2	22.4	26.7	25.7	27.7	26.7	25.3	25.8
Δg(i-k)	118-119	115-119	118-119	117-122	114-101	114-101	120-118	120-125	120-118	120-118	120-125	120-118
m <sub>max</sub> Δ	8.86	8.12	10.41	7.24	6.56	8.37	9.04	8.85	10.3	9.05	8.85	10.39
Nr.	107	119	101	107	119	101	107	119	101	107	119	101
Tau test	NO	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Chi square	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES







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**Least squares adjustments – free adjustment of combined models**

Combined models → Combined scaled models → Combined scaled models with Danish method

**FREE ADJUSTMENT OF COMBINED SCALED MODELS:  
BEFORE AND AFTER DANISH METHOD**

weight	FREE ADJUSTMENT OF COMBINED SCALED MODELS			AFTER LAST ITERATION FROM DANISH METHOD		
	p1	p2	p3	p1	p2	p3
$m^w_o$ a-priory	9.32	5.41	10.94	5.92	3.95	8.34
$m_o$ posteriori	9.68	5.68	11.15	5.50	3.60	7.88
$v_{max}\Delta g$	16.1	19.2	17.4	22.4	20.1	21.8
$\Delta g(i-k)$	120-125	120-125	120-125	120-125	120-125	120-125
$m_{max}g$	5.71	5.32	6.83	3.53	4.17	5.06
Nr.	107	119	101	120	115	114



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**Least squares adjustments – free and constrained adjustment**

adjustment	FREE ADJUSTMENT						CONSTRAINED ADJUSTMENT					
	Proportional mean scaled			Proportional mean scaled after last iteration from Danish method			Proportional mean scaled			Proportional mean scaled after last iteration from Danish method		
weight	p1	p2	p3	p1	p2	p3	p1	p2	p3	p1	p2	p3
$m^w_o$ a-priory	9.32	5.41	10.94	5.92	3.95	8.34	9.32	5.41	10.94	5.92	3.95	8.34
$m_o$ posteriori	9.68	5.68	11.15	5.50	3.60	7.88	28.64	16.41	34.73	27.50	15.12	33.74
$v_{max}\Delta g$	16.1	19.2	17.4	22.4	20.1	21.8	46.9	52.4	53.4	48.6	54.8	54.7
$\Delta g(i-k)$	120-125	120-125	120-125	120-125	120-125	120-125	1-111	1-111	1-111	1-111	1-111	1-111
$m_{max}g$	5.71	5.32	6.83	3.53	4.17	5.06	18.35	17.24	21.58	20.2	19.62	23.43
Nr.	107	119	101	120	115	114	119	119	114	115	115	114



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## Least squares adjustments – model p2 free and constrained adjustment

*Combined model with proportional mean data and weight p2 (proportional to time of measurement)*  
--> scaled with weights for each gravimeters --> applied Danish method

**Scaled combined mean proportional model with weight p2 after Danish method**

### Free adjustment

- A-priory RMS = 3.95 microgal
- Posteriori RMS = 3.60 microgal
- Max RMS of g = 4.17 microgal
- RMS ar.mean g = 3.03 microgal

### Constrained adjustment

- Posteriori RMS = 15.12 microgal
- Max RMS of g = 19.62 microgal
- RMS ar.mean g = 13.02 microgal



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## SUMMARY AND CONCLUSIONS

### BASIC GRAVIMETRIC NETWORK OF REPUBLIC OF MACEDONIA

- **Contemporary gravimetric network satisfying present-day standards for accuracy and realization**
- **Realized with use of modern instruments and technologies**
- **With all necessary corrections for precise relative gravimetric measurements**
- **In main stages of processing are made all tests and analyses**
- **Key points in processing are:**
  - control of data in time of measurement;
  - applying of appropriate scheme of gravimetric measurements, which is leading to identical calculation of drift in all loops and securing of direct independence between measurements
- **Appropriate net design and scheme for gravimetric loops - availability to realize good preliminary estimation of accuracy**
- **Two type data models + three type weights = base for detailed analysis of results and localization of possible mistakes in measurements or calculations**
- **Verification for completeness and propriety of models is made with**
  - analyses of residuals and application of Tau-test and Chi-square test
- **Successfully is applied an active robust estimation method – Danish method**



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