Height Reference System Modernization in Turkey : Current Status and Future Plans

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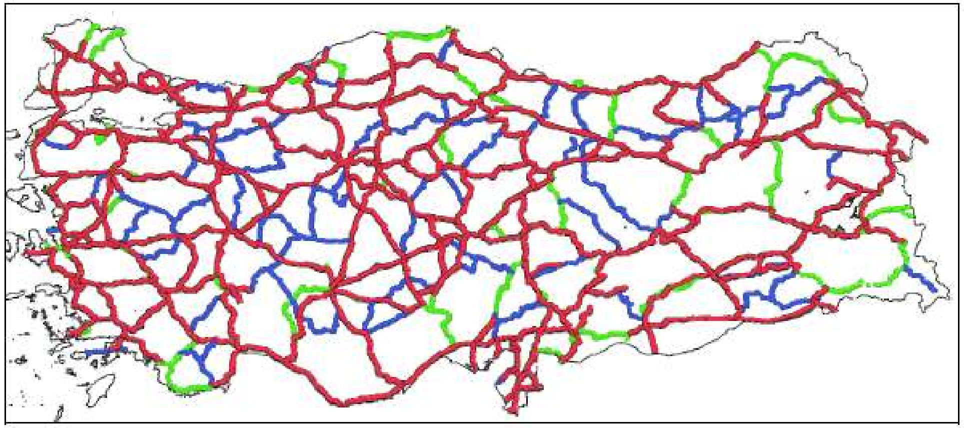
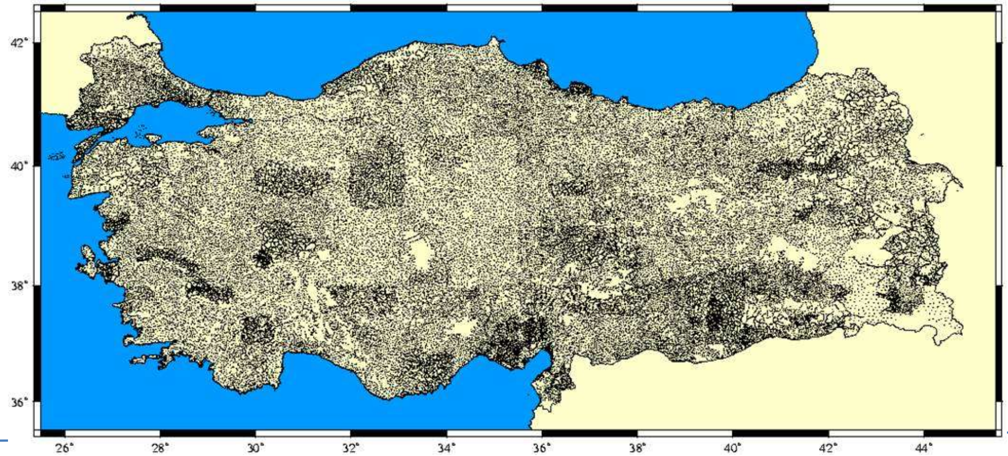
Presentation Overview

- Rationale of Height Reference System Modernization in Turkey
- Turkish Height System Modernization & Gravity Recovery Project (2015-2020) : Aims and Objectives
- Project Work Packages :Current Status and Pleminary Results
- Future Plans

Rationale of Height Reference System Modernization

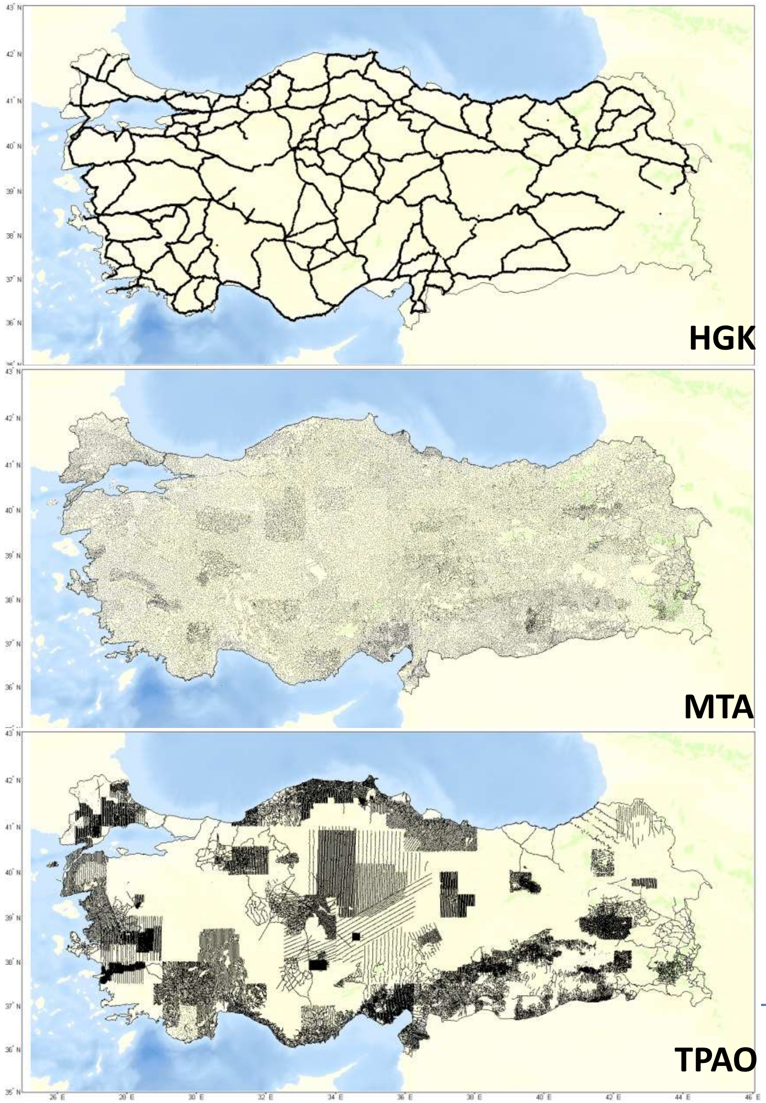
Levelling Network (63% destroyed)





Existing Geoid Model
Accuracy : ± 8 cm

Rationale of Height Reference System Modernization



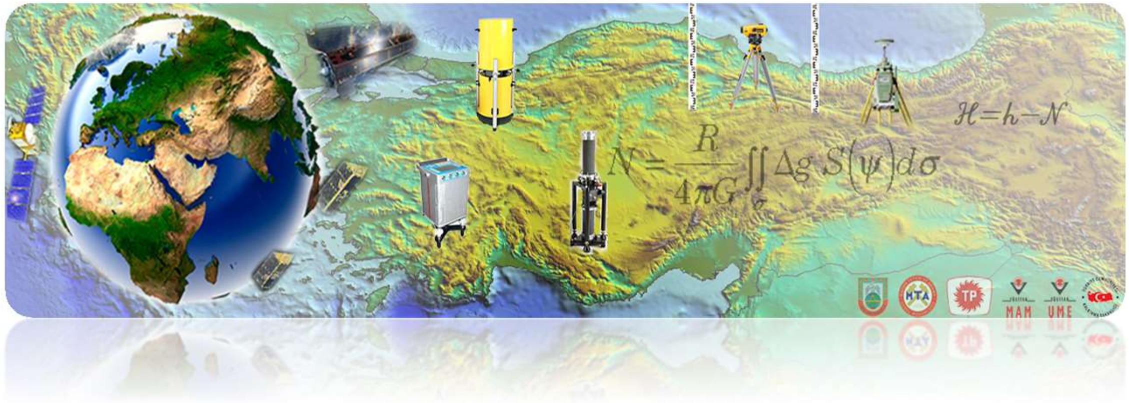
Historical Gravity Data Sets

HGK	MTA	TPAO
21826	64469	202086

21826 + 64469 + 202086

- Gravity reference system ?
- Horizontal coordinate reference system ?
- Vertical coordinate reference ?
- Positioning Method ?
- Gravity observation method ?
- Gravity data processing (tides, drifts etc.) ?
- **Consistency : ???**
- **Accuracy: ???**

Turkish Height System Modernization & Gravity Recovery Project



Turkish Height System Modernization & Gravity Recovery Project is a five-year-long (2015-2020) collaborative project of General Command of Mapping, General Directorate of Mineral Research & Exploration, Turkish Petroleum Agency, TUBITAK Marmara Research Center, and TUBITAK National Metrology Institute supported by Turkish Ministry of Development.

Turkish Height System Modernization & Gravity Recovery Project

Aims :

- To reallize high accuracy and resolution geoiid model (1-3 cm @ 1-3 km) for GNSS heighting
- To recover the gravity data infrastructure

Objectives :

- Turkish Geoid Model – 2020
- Turkish National Gravity Data Center (TR-GRAV)

Turkish Height System Modernization & Gravity Recovery Project

Work Packages (WP):

- 1. Provision of Instruments (2015-2016) **(~Completed)**
- 2. Standardization, training and instrument tests & calibration (2015-2016) **(Completed)**
- 3. Relative Gravimetry (2016-2019)
- 4. Absolute and Airborne Gravimetry (2016-2019)
- 5. GNSS/Motorized Leveling (2016-2019)
- 6. Quality Check and Validation of Historical Gravity Data (2017-2018)
- 7. Establishment of National Gravity Database (2015-2017)
- 8. Gravimetric Geoid Modeling and Testing (2018-2020)
- 9. Transmittion of online geoid prediction through TR-CORS System (2019-2020)
- 10. Reporting and Publishing of Gravimetic Geoid Model (2020)

WP1: Provision of Instruments (2015-2016) (~Completed)

- 10 Scintrex CG-5 Relative Gravimeters
- 10 Topcon GR-5 GNSS Receivers
- 10 Kestrel 2500 Portable Meteorological Sensors
- 10 Laptops
- 1 Micro-g LaCoste A-10 Absolute Gravimeter
- 1 Micro-g LaCoste FG5-X Absolute Gravimeter
- 1 IMAR iNAV RQH-1001 INS (not completed yet)
- 2 VW Amarok
- 4 Renault Clio
- 11000 Relative/Absolute Gravimetry Benchmark
- 200 GNSS/Levelling Benchmark

WP2: Standardization, training and instrument tests & calibration

- Standarts are determined.
- The insturments are tested.
- Practical education is carried out each year.
- Calibration of CG-5 is carried out annually .

WP3: Relative Gravimetry

10 Scintrex CG-5 Autgrav

6459 points out of ~13000 measured in 2016 and 2017

The profile method with the measurement sequence of "A-B-C-D-E-C-B-A"

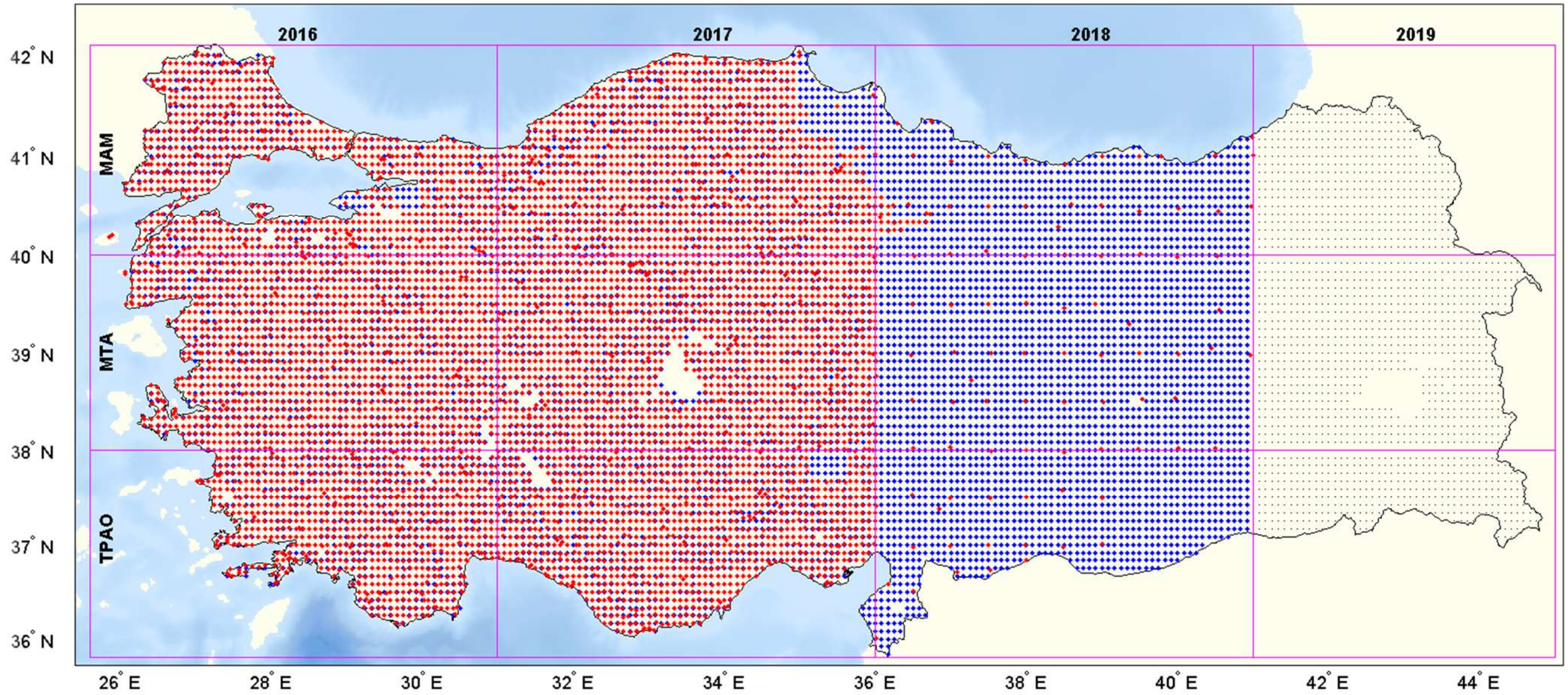
At least 5 readings with 60 seconds reading time

Raw gravity readings are reduced for Solid Earth tide, Ocean Loading, Pressure Changes, Polar Motion, Instrument Height & Drift

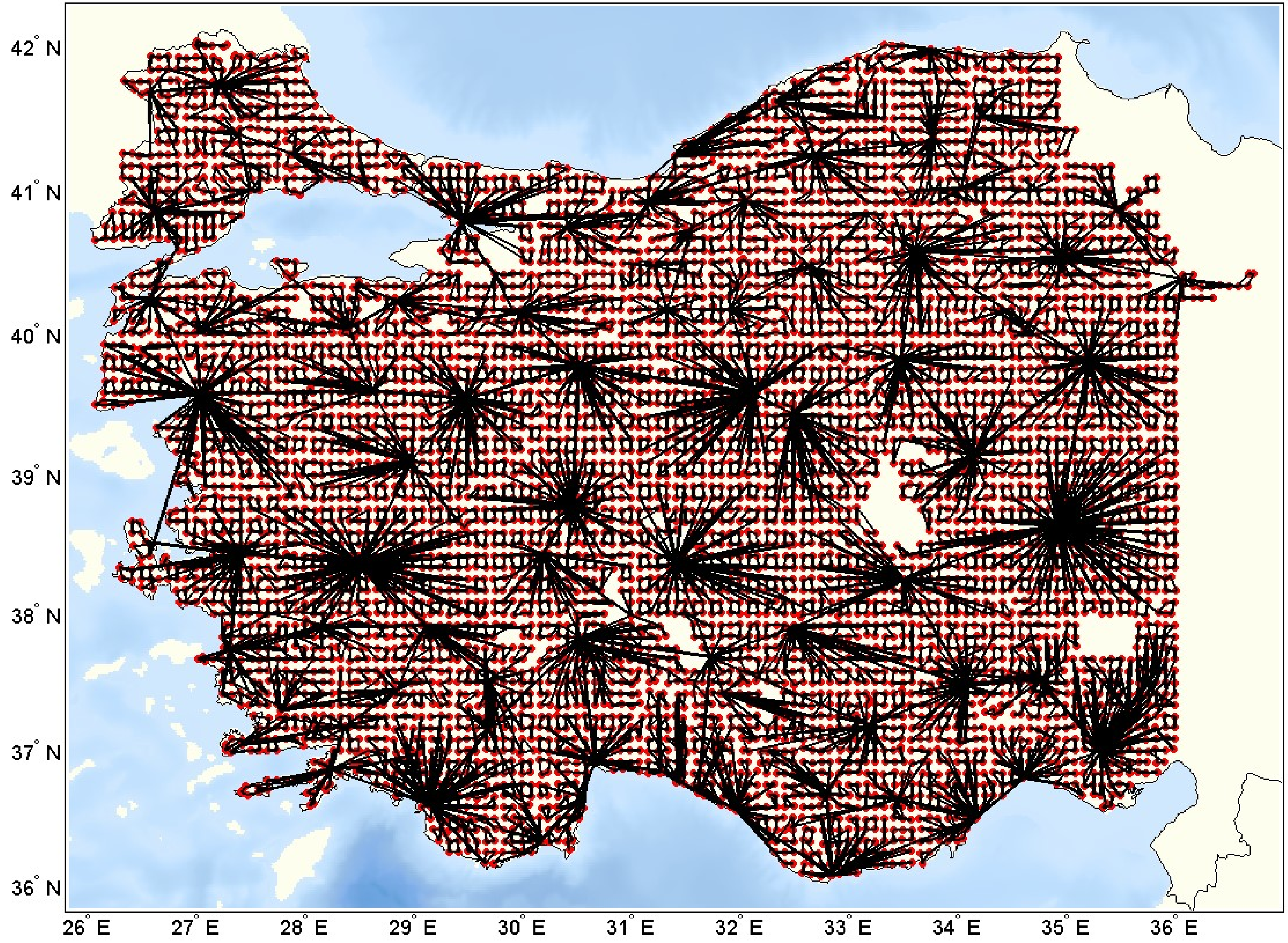
Network adjustment based on weighted constrained least squares

Final adjustment of available observations results in a mean SD of 14 μGal.

Relative gravity measurements 2016-2019



Relative gravity connections 2016-2017



Relative gravity: Data reductions

R_{ham} = GRAV+DC-ETC	Internal drift and tide corrections are removed from the gravity readings	
ΔR_g	New tide correction	$\Delta R_g = -\sum_{i=Ay,Güneş} \delta_2 \frac{GM_i r}{D_i^3}(3\cos^2\Theta_i - 1) + \frac{3}{2}\frac{GM_i r^2}{D_i^4}(5\cos^3\Theta_i - 3\cos\Theta_i) = -\sum_{i=1}^{n}\delta_i A_i(teo)\cos(\omega_i t + \Phi_i(teo) + \Delta\Phi_i)$ — Agnew, D.C.(2007)
ΔR_b	Atmospheric correction	$\Delta R_b = 3\times10^{-4}\left[P_{mbar}^{ölç} - \left(1013.25\times(1-\frac{0.0065\times H_m}{288.15}\right)^{5.2559}\right]_{mGal}$ — IAG 1983 Resolution No.9
ΔR_k	Polar motion correction	$\Delta R_k = \left[1.16\,\omega^2 R\sin 2\varphi\left(\underline{x_P\cos\lambda - y_P\sin\lambda}\right)\times10^5\right]_{mGal}$ — Wahr, J.(1985); IERS Bulletin b
ΔR_o	Ocean loading corrrection	$\Delta R_o = \sum_{k=1}^{11} \underline{f_k} A_k \cos(\chi_k(t) + \underline{u_k} - \phi_k)$ — IERS Conventions 2010; http://holt.oso.chalmers.se/loading/index.htm; M2, S2, N2, K2, K1, O1, P1, Q1, MF, MM, SSA; Model: GOT4.7, EOT11a, …
ΔR_h	Instrument height correction	$\Delta R_h = [0.3086\times\Delta h]_{mGal}$
+		
ΔR_d	Daily drift correction	$\underline{\Delta R} = d_0 + d_1\times\underline{\Delta t} + d_2\times\underline{\Delta t}^2$; $\Delta R_d = \tilde{d}_0 + \tilde{d}_1\times(t_i - t_0) + \tilde{d}_2\times(t_i - t_0)^2$
+		
R_{ind}	**Reduced reading**	
R_{kind}	**Scaled reading**	$R_{kind} = R_{ind}\times k$

Relative gravity network adjustment

$$\Delta R_{kind,i,j} + v_{i,j} = g_j - g_i + \sum_{p=1}^{n} d_p \left(t_j - t_i\right)^p$$

Functional model

$$L_b + V_b = A_b X \qquad X = \begin{bmatrix} X_g \\ X_I \end{bmatrix}$$

Observation equations and unknowns

Rank deficiency = 1

Addition of observation so as to fix the gravity value of at least one point

$$L_g + v_g = A_g X = \begin{bmatrix} I & 0 \end{bmatrix} \begin{bmatrix} X_g \\ X_I \end{bmatrix}$$

Additional observation equation

$$\emptyset = min\left(V_b^T P_b V_b + V_g^T P_g V_g\right)$$

Target function

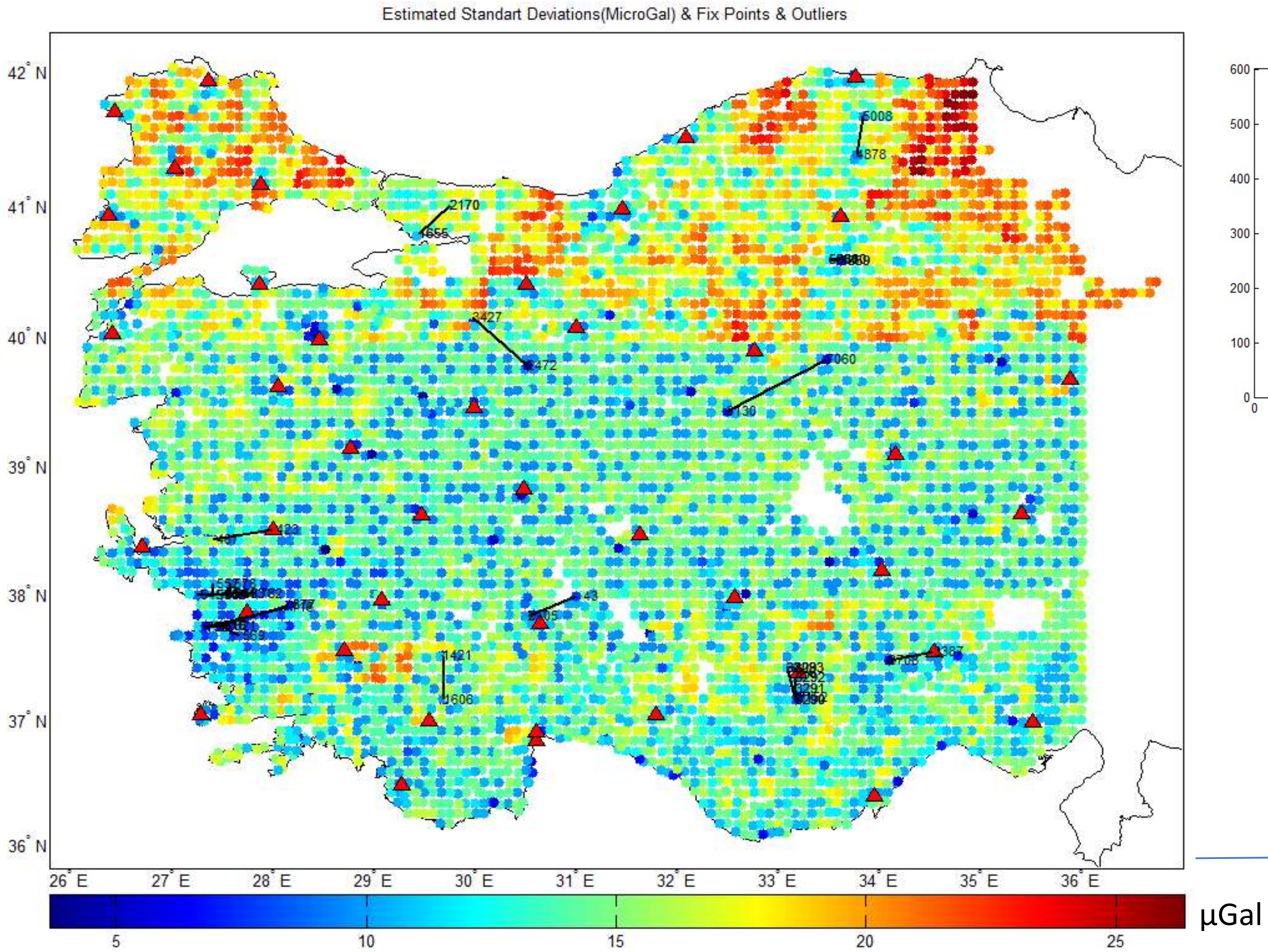
$$\hat{X} = \left(A_b^T P_b A_b + A_g^T P_g A_g\right)^{-1} \left(A_b^T P_b L_b + A_g^T P_g L_g\right)$$

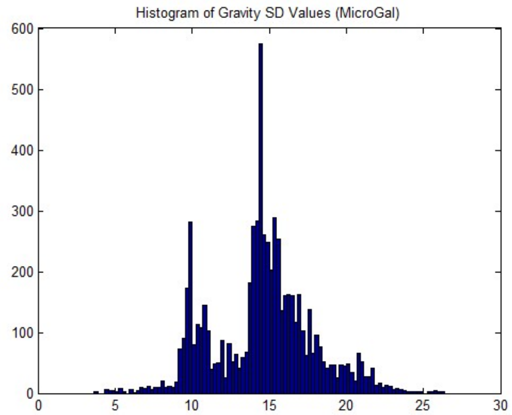
Solution

$$\sum\nolimits_{\hat{X}} = \hat{\sigma}_0^2 \left(A_b^T P_b A_b + A_g^T P_g A_g\right)^{-1}$$

Variance-covariance matrix

Network adjustment : Estimated standart deviations





Max : 26 µGal
Min : 3 µGal
Mean : 14 µGal

WP4: Absolute and Airborne Gravimetry

Micro-g LaCoste A10#044

54 points out of 100 measured in 2016 and 2017

Two set ups in opposite directions (North & south)

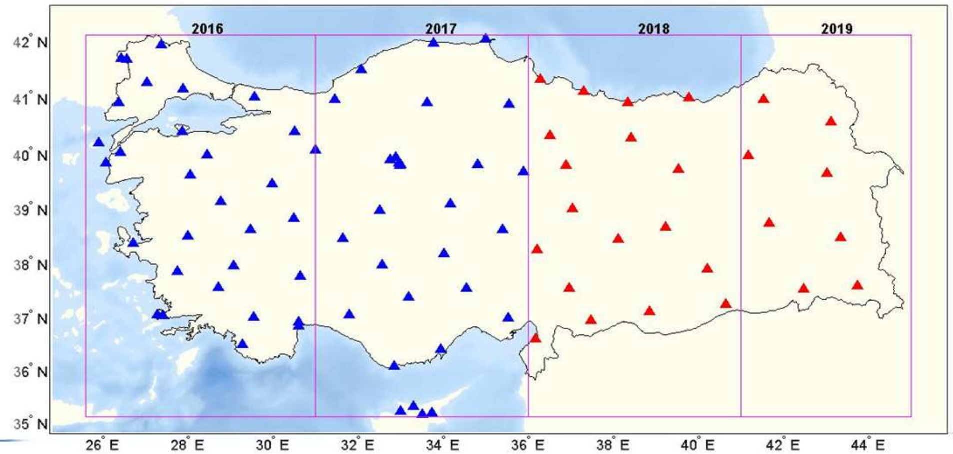
12 set sin each set up

150 drops with 1 second interval

Wzz measurements with CG5

Processsing with g9 software provided by Micro-g LaCoste

The total uncertainties are about 10 μGal



Absolute gravity

$$x_i = x_0 + v_0 \tilde{t_i} + \frac{g_0 \widetilde{t_i^2}}{2} + \frac{\gamma x_0 \widetilde{t_i^2}}{2} + \frac{\gamma v_0 \widetilde{t_i^3}}{6} + \frac{\gamma g_0 \widetilde{t_i^4}}{24}$$

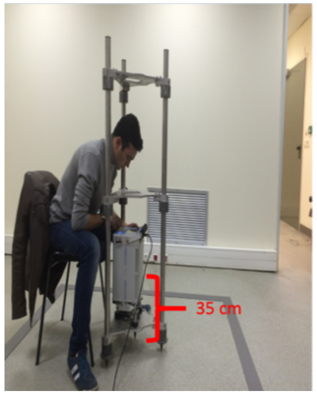
$$\tilde{t_i} = t_i - \frac{x_i - x_0}{c}$$

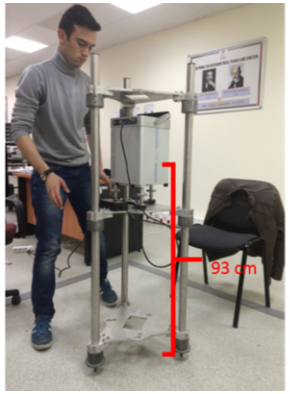
- **A-10 (#044)**
- **12 set north + 12 set south = 24 Set**
- **150 drop/set**
- **4-5 hours/point**

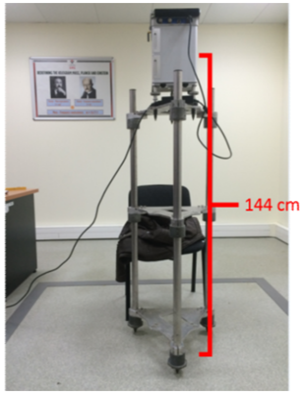
Vertical gravity gradient

$$R_k(h) = ah^2 + bh + c$$

$$W_{zz}(h_i) = ah_i + b$$

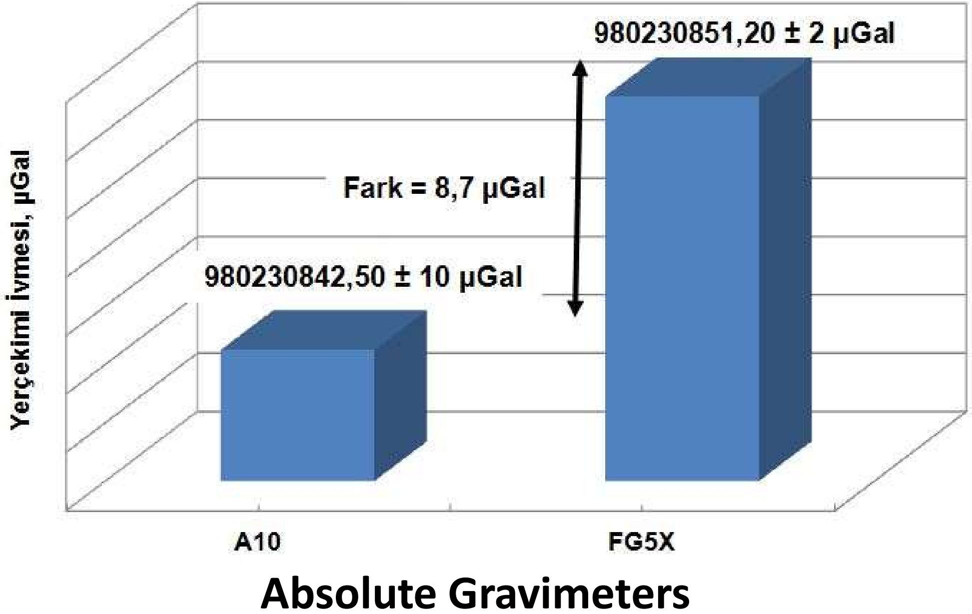






- **Scintrex CG-5 (#40946)**
- **Bottom-Middle-Top-Middle-Bottom-Middle-Top-Bottom-Middle-Top**
- **Quasi-simultaneous with Absolute gravity measurements**

COMPARISON OF A10 WITH FG5X AT TÜBİTAK UME METROLOGY LABORATORY



FG5X of TÜBİTAK-UME attended to
International comparison of absolute gravimeters (ICAG)-2017, Beijing/China , October 2017
IAG, SC 2.1: Gravimetry and Gravity Networks

Airborne Vector Gravimeter (in the procurement)

Vector gravimetry

$$g^i = \ddot{x}^i - f^i$$

Newton's second law of movement in inertial system

$$g^n = \underbrace{\ddot{x}^n}_{\text{GPS}} - \underbrace{C_b^n f^b}_{\text{IMU (Gyro, Acc)}} + \underbrace{(2\Omega_{ie}^n + \Omega_{en}^n)\dot{x}^n}_{\text{GPS}}$$

Newton's second law of movement in local navigation system

Integration → **Kalman Filter, Smoothing**

$$g^n = \gamma^n - \delta g^n$$

Gravity, normal gravity and gravity disturbance in local coordinate system

$$\delta g^n = \ddot{x}^n - C_b^n f^b + (2\Omega_{ie}^n + \Omega_{en}^n)\dot{x}^n - \gamma^n$$

(ψ: Yaw, θ: Pitch, ϕ:Roll)

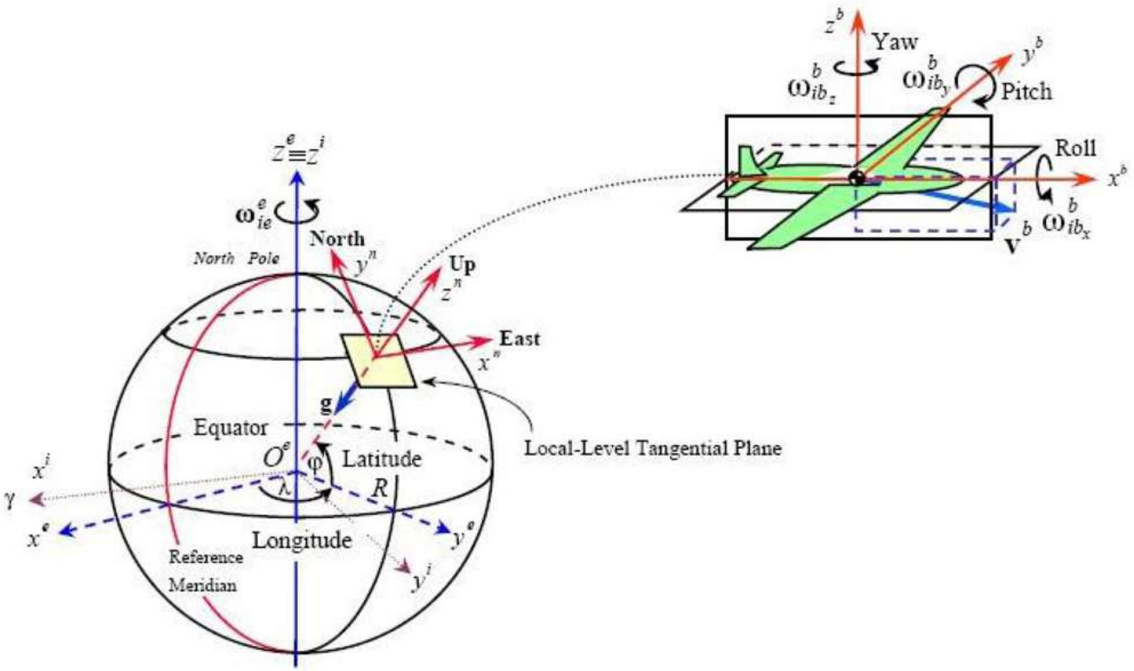
$$C_b^n = R_z(-\psi)R_y(-\theta)R_x(-\phi)$$

(ω_{ie}: Earth rotation rate , φ: geodetic latitude)

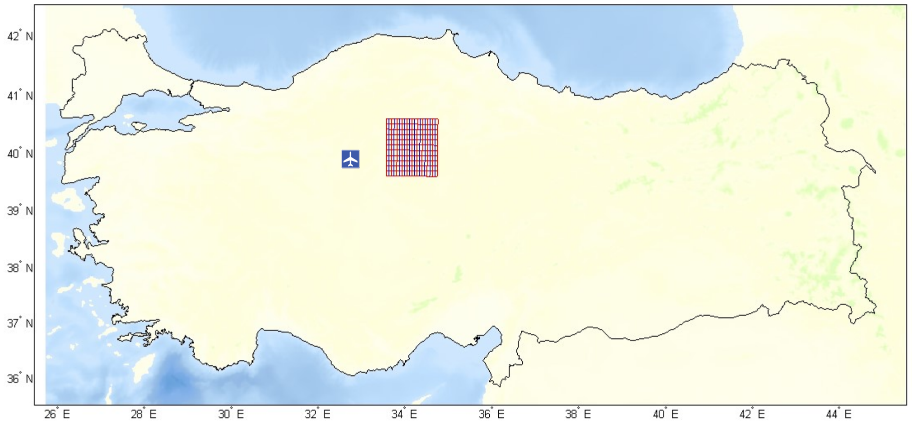
$$\Omega_{ie}^n = \begin{bmatrix} 0 & -\omega_{ie}\sin\varphi & \omega_{ie}\cos\varphi \\ \omega_{ie}\sin\varphi & 0 & 0 \\ \omega_{ie}\cos\varphi & 0 & 0 \end{bmatrix}$$

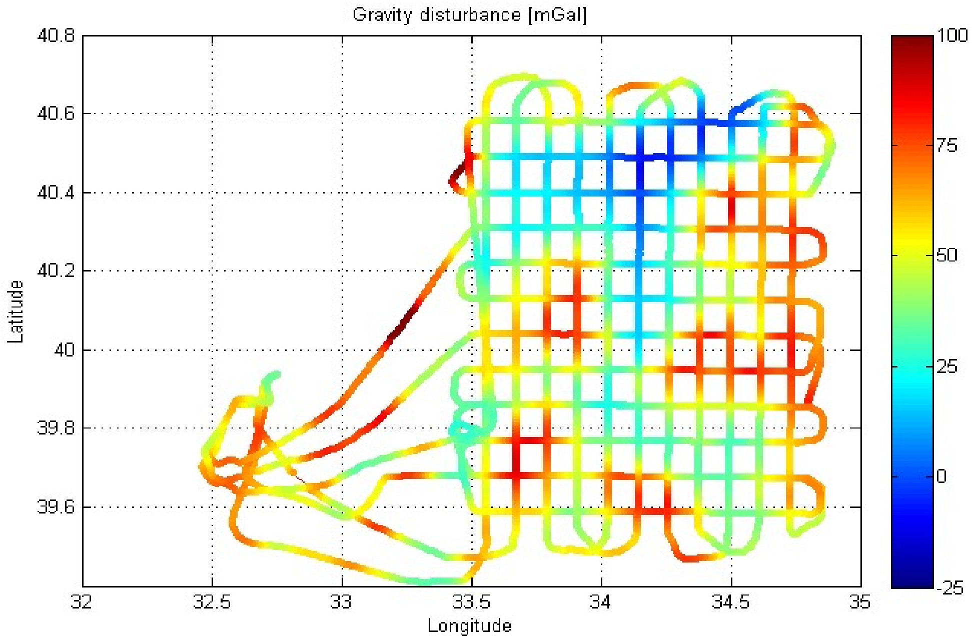
(λ: geodetic longtitude, φ: geodetic latitude)

$$\Omega_{en}^n = \begin{bmatrix} 0 & -\dot{\lambda}\sin\varphi & \dot{\lambda}\cos\varphi \\ \dot{\lambda}\sin\varphi & 0 & \dot{\varphi} \\ \dot{\lambda}\cos\varphi & -\dot{\varphi} & 0 \end{bmatrix}$$



Airborne Gravimeter– Test-1 (Strapdown) in April 2017





RMSE @Cross-over points : 0.77 mGal
RMSE @ Repeated lines : 0.60 mGal

Speed : 100 m/s
Height : 3000 m

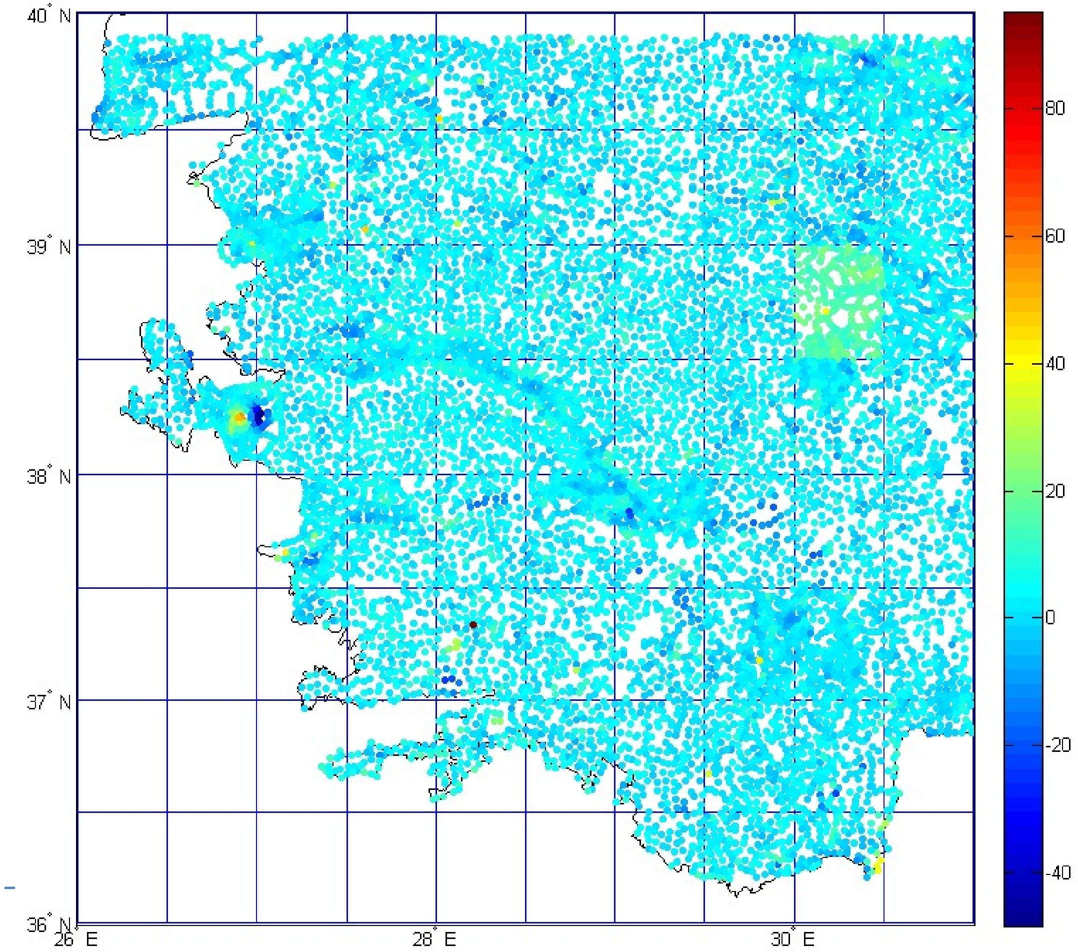
WP5 : GNSS/Motorized Leveling

- **Simultaneous GNSS/levelling measurements**
- **82 km. levelling line in Burdur measured in 2017**
- **Precision Control: 3√k (km)**

2 Motorized levelling teams are constructed within the project.

WP6 : Quality Check and Validation of Historical Gravity Data

Difference = Prediction from new data – Historical MTA Gravity Data



(Remove –Predict - Restore)

$$\Delta g = \Delta g_{FA} - \Delta g_{EGM} - \Delta g_{RTM}$$

$$\Delta g \Rightarrow \Delta g$$

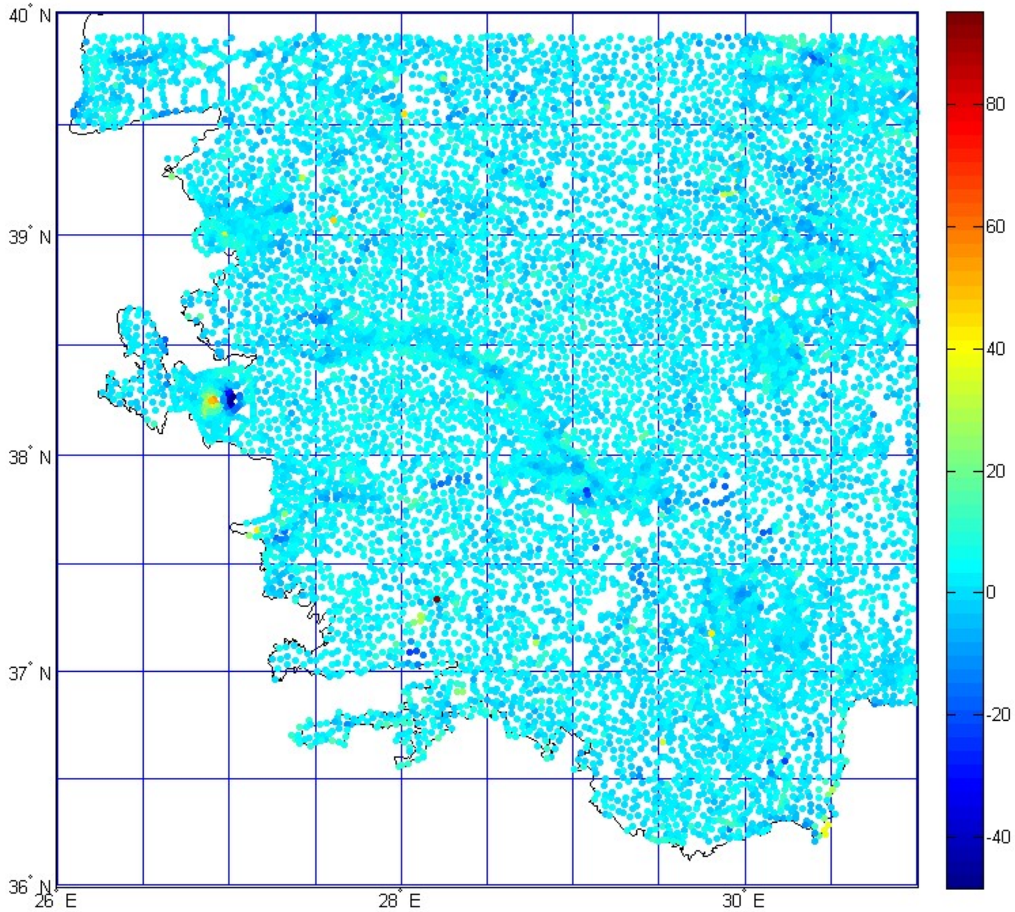
Least Squares Collocation (LSC)

Number of Points	10740
Minimum	-48.3
Maximum	95.2
Mean	2.7
Standart Deviation	± **5.19**

Unit : mGal

After Potsdam datum correction 14 mGal is applied in the related 100 K topographic map (30-30.5 N – 38.5-39 E)

Difference= Prediction – Historical MTA Gravity Data



(Remove –Predict - Restore)

$$\Delta g = \Delta g_{FA} - \Delta g_{EGM} - \Delta g_{RTM}$$

Δg **Δg**

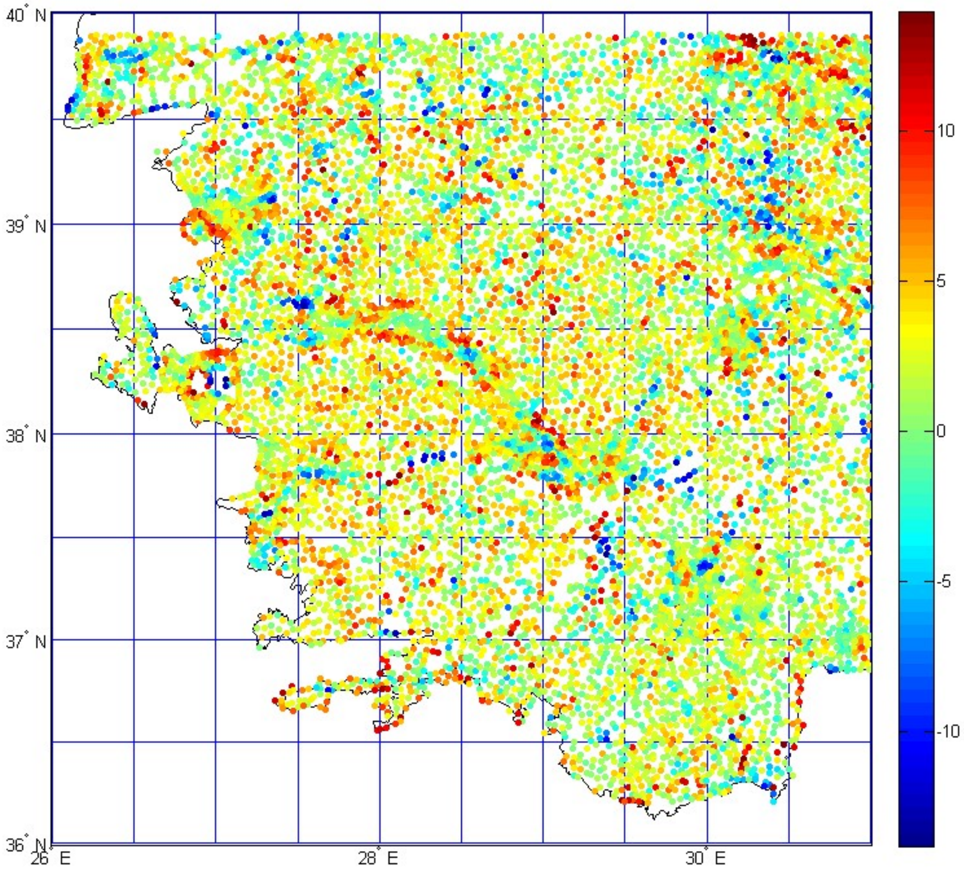
Least Squares Collocation (LSC)

Number of Points	10740
Minimum	-48.3
Maximum	95.2
Mean	2.27
Standart Deviation	± **4.68**

Unit : mGal

After Potsdam datum correction 14 mGal subtractred in the related 100 K topographic map (30-30.5 N – 38.5-39 E) and after the outlier (> 3σ) are removed

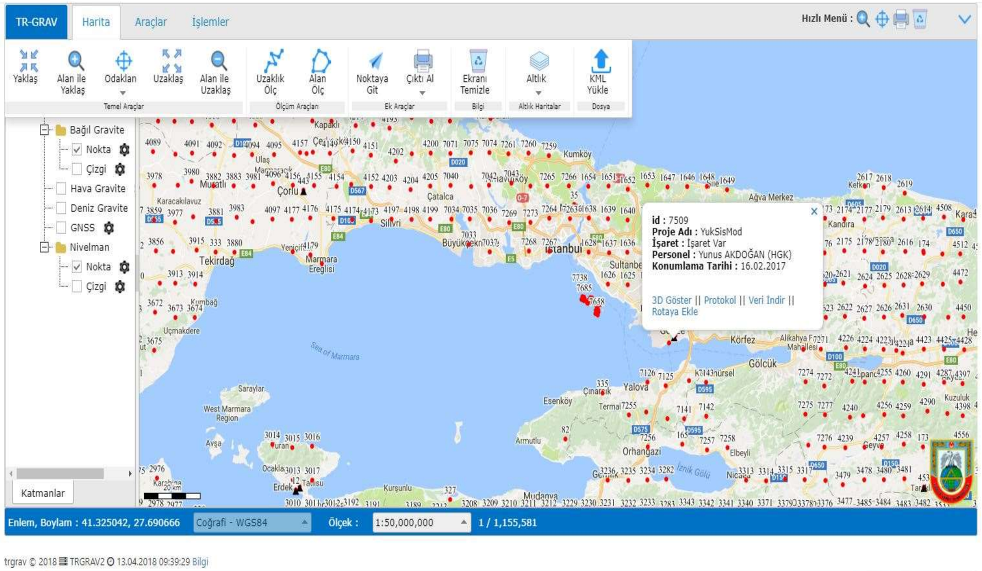
Difference= Prediction – Historical MTA Gravity Data

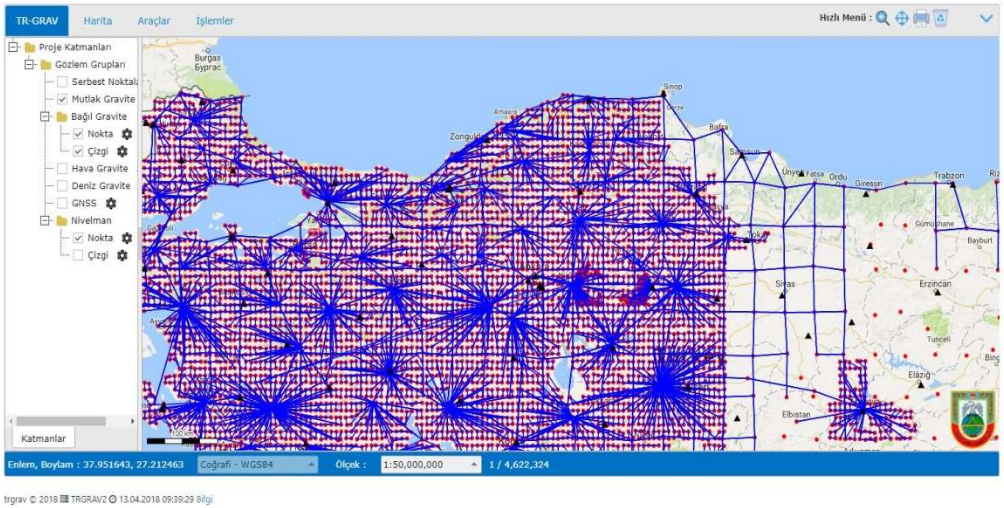


Number of Points	10740
Minimum	-13.8
Maximum	14.0
Mean	2.10
Standart Deviation	± **3.63**

Unit : mGal

WP7 : Establishment of National Gravity Database (TR-GRAV Web Portal)





Authorized users can reach via some authentication processes. Through this portal the users can:

- Define the positions and position metadata of absolute/relative/airborne/shipborne gravimetry, GNSS, levelling, astrogeodetic vertical deflection measurement points, and to list, visualize, edit and delete them.
- Download the point location description sheets in PDF-file generated on the fly.
- Upload, visualize, list, edit and delete data
- Make detailed queries about the projects registered in the database.

WP8 :Gravimetric Geoid Modeling and Testing

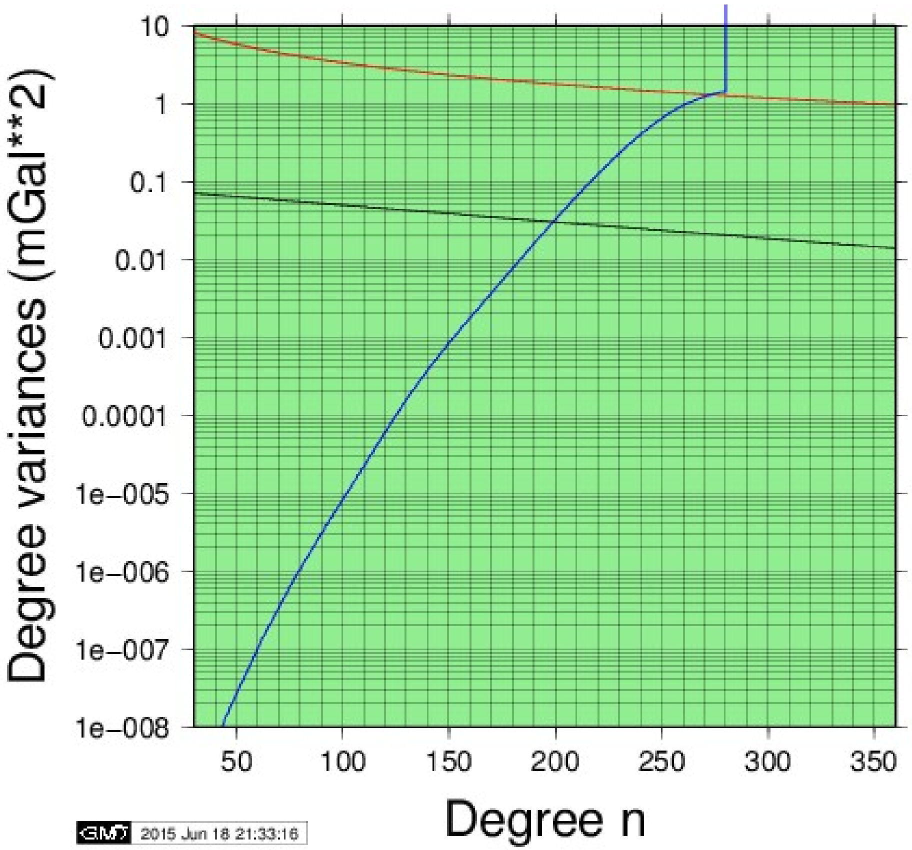
$$N = \frac{R}{4\pi\gamma}\iint_{\sigma_0} S^M(\psi)\Delta g d\sigma + \frac{R}{2\gamma}\sum_{n=2}^{M}(s_n + Q_n^M)\Delta g_n^{EGM} + \delta\zeta_{COMB} + \delta\zeta_{DWC} + \delta\zeta_{ATM}^{COMB} + \delta\zeta_{ELL}$$

$S^M(\psi)$	Modified Stokes' function chosen according to Sjöberg (1991) Least squares modification (stochastic kernel modification)
$\delta\zeta_{COMB}$	Combined topographic effect
$\delta\zeta_{DWC}$	Downward continuation effect (includes analytical continuation to point-level of both the gravity anomalies (Moritz, 1980) and the spherical harmonic expansion (Sjöberg (2003) and Ågren (2004).
$\delta\zeta_{ATM}^{COMB}$	Atmospheric correction (Sjöberg and Navadanchi, 2000)
$\delta\zeta_{ELL}$	is the atmospheric correction (Sjöberg, 2004)

LEAST SQUARES MODIFICATION OF STOKES'S FORMULA WITH ADDITIVE CORRECTIONS
(see Sjöberg 1991, 2003, …)

WP8 :Gravimetric Geoid Modeling and Testing

LEAST SQUARES MODIFICATION OF STOKES'S FORMULA WITH ADDITIVE CORRECTIONS



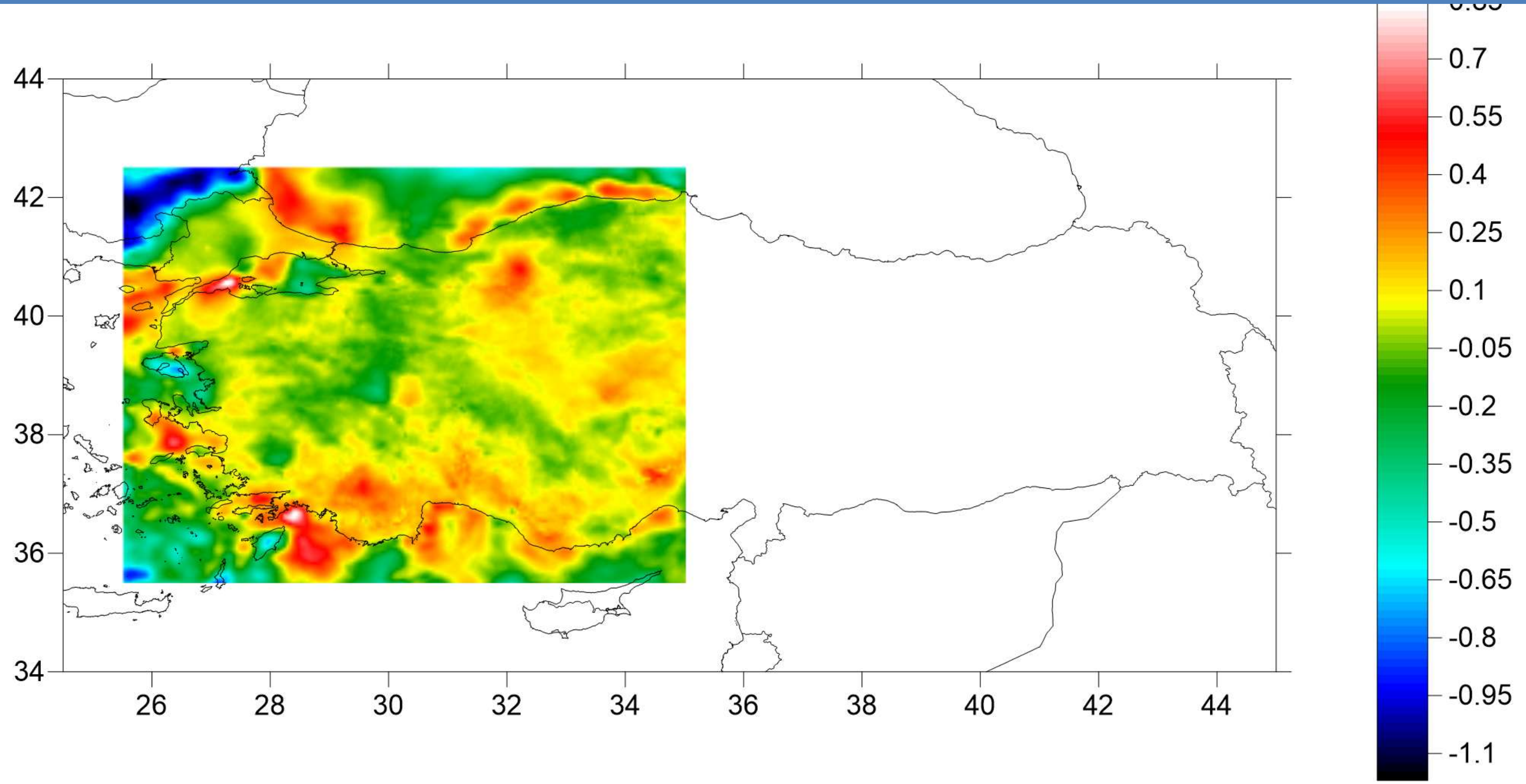
Type of degree Variance	Description
Signal	Tscherning and Rapp (1974).
EGM error	GOCO05S (Mayer-Gürr T. et al. 2015).
Terrestrial gravity error	Reciprocal distance noise part : 1 mGal std The white noise part : 1 mGal std

WP8 :Gravimetric Geoid Modeling and Testing

Comparison with simultaneous GNSS/levelling in 2017 data in Burdur

Statistics (Unit is in meters)	Gravimetric geoid computed within the project	TG-03 Hybrid geoid model (in official use)
Number of points	14	14
Minimum	-0.028	-0.064
Maximum	0.041	0.036
Mean	0.0	0.0
Standart Deviation	**0.021**	**0.028**

Differences between new gravimetric geoid model and TG-03 (Unit: in meters) (mean extracted)



Future Plans

- Testing different geoid determination methods (Least Squares Collocation, Least Squares Modification of Stokes's Formula, FFT, Harmonic Continuation)
- Airborne Software Development : IDGU implementation
- Airborne Gravity Tests at different flight heights
- Airborne gravimetry for geophysical exploration
- Using Airborne Gravimetry System on ships or boats for coastal and marine areas
- Airborne gravity surveys over lakes and mountains.