GRAVITY, GEOID AND HEIGHT SYSTEMS 2016

GOCE-based Comparison and Unification of the Greek & Turkish Height Systems

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Motivation

- Identifying the height datum offset between the Greece & Turkey ,
- after clarifying the contribution of GOCE mission for height datum connection between these two countries,

basically constitute the aim in this study.

**Under this motivation, the GOCE-based geoid models are assessed and compared to local GPS/levelling geoid heights, for both countries as well as for specific regions as the part of the countries, such as the Greek Islands and some local coastal areas in the west of Turkey.*

Motivation

- In the purpose,
  - height offset estimates between the global and local geoids are computed by taking the mean value of the offsets over each specific area under investigation,
  - hence an offset of the local to the global geoid is identified for the interested region…

Should be awared that the accuracy of the vertical datum offset estimates is affected by :

★ *the nature of the ommission-error,*

★ *the commision error of GOCE,*

★ *error content of the GPS and leveling data,*

★ *and the averaging process…*

Strategy

- quality check of GPS/levelig data,
- spectral assessment of GGMs,

- assessment of GGMs at the GPS/leveling benchmarks (applying spectral enhacement method),
- determining best GGM with optimum d/o,

- calculating the local geoidal potential ($\widehat{W}_o^{LVD}$),
- determining the geopotential difference ($\widehat{\delta W}_o^{LVD}$) relative to a reference geopotential value (W_o^{CVD})

- *hence defining a connection between LVD of Greece, Greek Islands and Turkey*

Strategy

- **Datum height differences** (ΔN) with enhanced part of the GGM geoid signal :

$$\Delta N_{enh.} = N_{enh.}^{GPS/lev} - \left[N^{i} \left|_{2}^{l_1} + N^{EGM08} \right|_{l_1+1}^{2160} \right] - N_{RTE} - N_o$$

EGM2008 global model, ultra-high resolution, used to compensate the non-included part of the signal in the content of GOCE-based GGM…

using 3″ DTM data

the zero-degree term

Regarding to tide-systme and reference ellipsoid:

- ★ *$H^{ort.}$ – > converted from «mean tide» to «tide free» system,*
- ★ *GGM coefficients are «tide free»,*
- ★ *the reference ellipsoid is GRS80 in computations …*

Strategy

- <u>Local Geoidal Potential</u> ($\widehat{W}_o^{LVD}$), base on the basic physical model with Helmert ortho. heights:

ellipsoidal height

Orthometric height

Geoid height by GGM

$$\widehat{W}_o^{LVD} = W_o^{CVD} - \frac{\sum_i^n (h_i - H_i - N_i)\,\bar{g}_i}{n}$$

local geoidal potential

potential of the geoid realized by the GGM

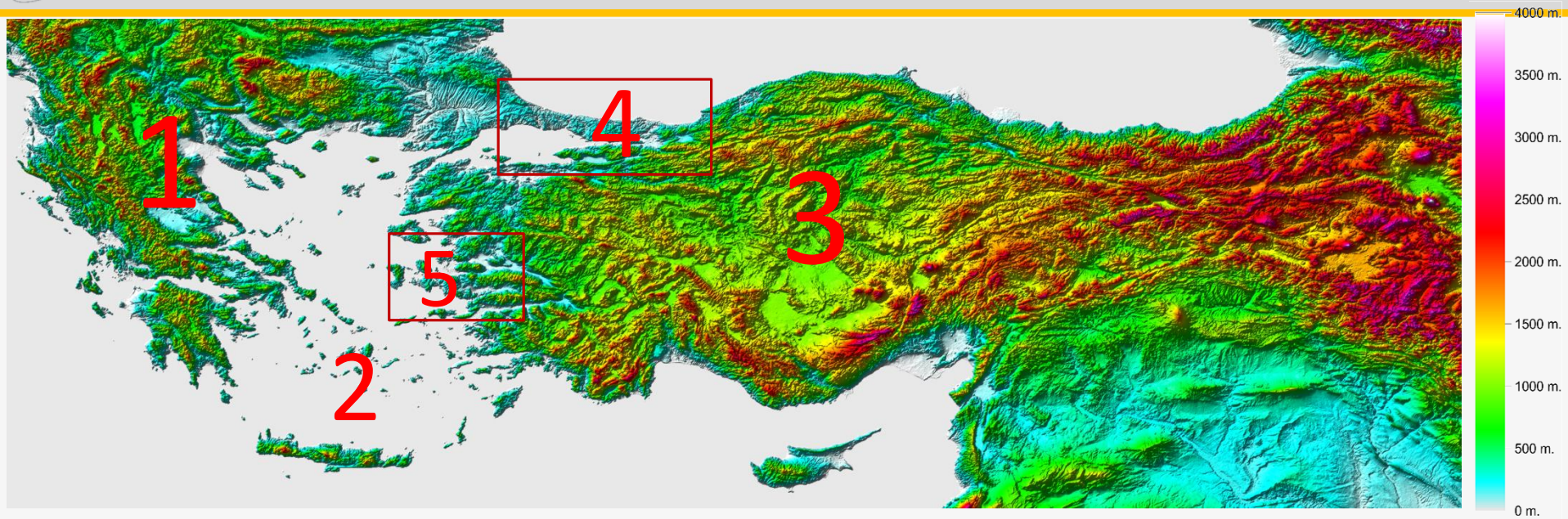
number of BMs used in computations

mean gravity value along the plumb-line

$$(h_i - H_i - N_i)\bar{g}_i = \Delta C_i^{CVD/LVD} \leftarrow \bar{g}_i = g_i + 0.0424H_i$$

$$g_i = \gamma_i - \frac{\partial T}{\partial r} \qquad \gamma = \gamma_e \left[\frac{1 + k\,sin^2\,\varphi}{\sqrt{1 - e^2\,sin^2\,\varphi}}\right]$$

Study Area & Data



The study covers the area between the 34°N- 43°N latitudes and 19°E- 45°E longitudes.

In terms of the data distribution (GPS/leveling BMs), the investigation area is categorized into five as:

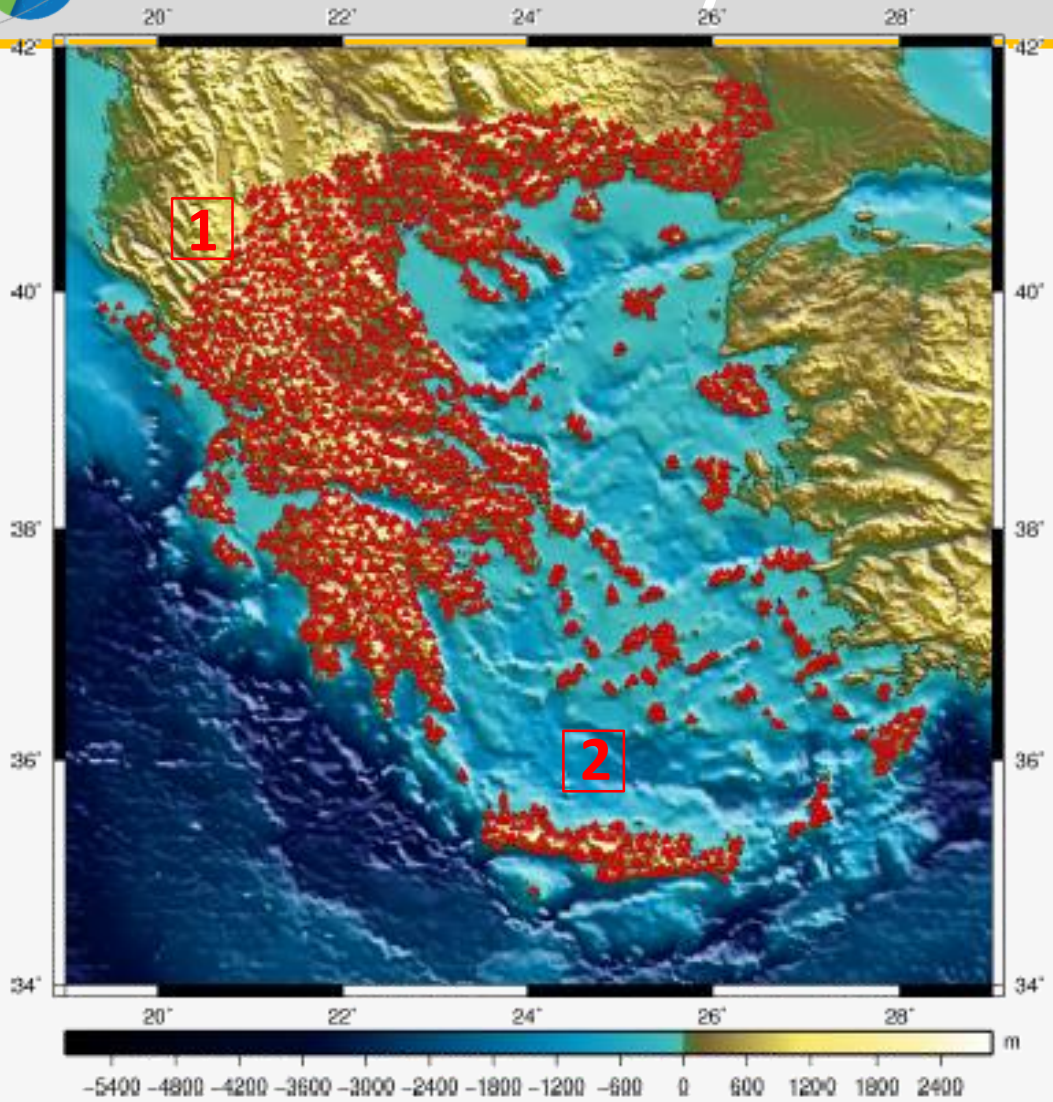
(1) Greece, **(2)** Greek Islands (Aegean Sea), **(3)** Turkey, **(4)** Marmara (a GPS densification network with leveling of 81 BMs), **(5)** İzmir (of 301 BMs)

Study Area & Data

	GREECE (main-land)	TURKEY
Vertical Datum Definition	HVD86	TUDKA99A
Tide-gauge (zero-point)	Piraeus (mean sea level using observations between 1933-1978)	Antalya (mean sea level using observations between 1936-1971)
height system	Helmert Orth. Heights	Helmert Orth. Heights
vertical control base on	Vertical Control Network	Vertical Control Network
Coordinate Datum	ITRF00 (2007.236)	ITRF96
regional geoid (current release)	GreekGeoid2010 (~ 4 cm accuracy)	Turkey Geoid 2003 (TG03) (~ 8 cm accuracy)

Table : Summary information on geodetic infrastructure in Greece and Turkey

Study Area & Data

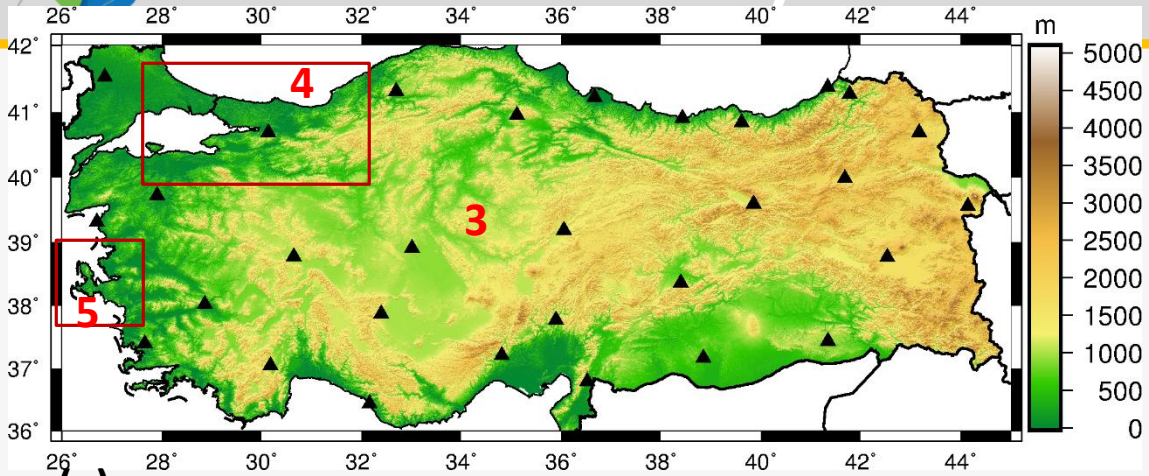


Data Sets #1 & #2 :

- Border GPS network points with third order leveling heights,
- the topography changes from 0 m to 2400 m
- the density of the BMs is 1 BMs per 10 km
- There are almost 70 İslands apart from the Greece mainland that each island has its own height system, relying on MSL.

Figure : 1542 GPS/leveling BMs in Greece (main-land) and 797 BMs in Greek islands

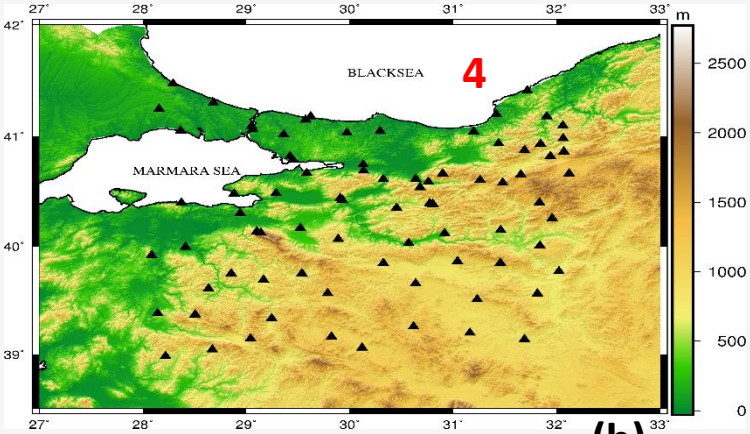
Study Area & Data



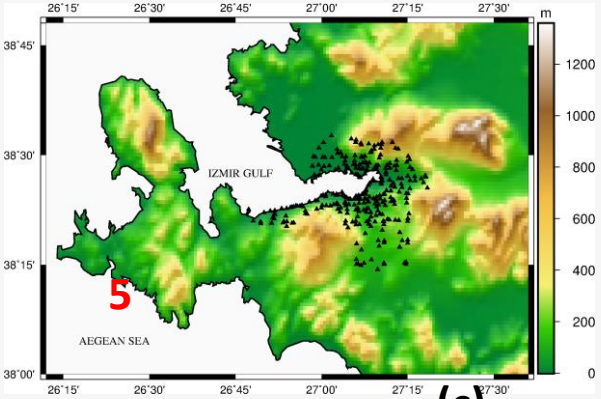
(a)

Data Set #3 :

- 30 BMs over the entire country,
- B order GPS network BMs with 3rd order leveling heights,
- 1 BM per 250 km,
- The topography changes from sea level to 4500 m



(b)



(c)

Data Set #5 :

- 301 BMs in West of country, C order GPS network BMs with 4th order leveling heights,
- 1 BM per 8 km,
- The topography changes bt. 0 m-1200 m

Data Set #4 :

- 81 BMs in north west of country, B order GPS network BMs with 3rd order leveling heights, 1 BM per 80 km, The topography changes from sea level to 2500 m

Figure : (a) 30 GPS/leveling BMs in Turkey, (b) 81 BMs in North-West local area, (c) 301 BMs in West local area of Turkey.

Validation of GGMs

- GO-DIR-R5, GO-TIM-R5, GOCO05S in addition to ultra-high resolution EGM2008 model are validated…

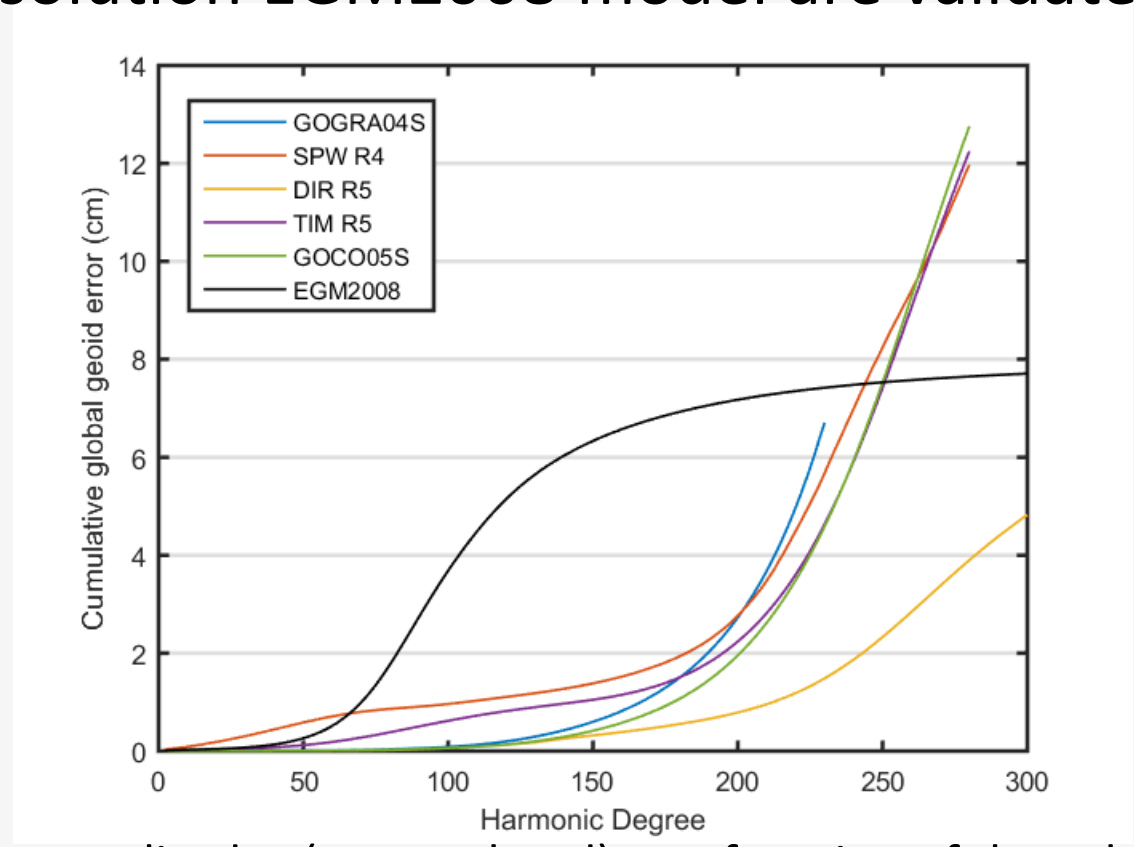
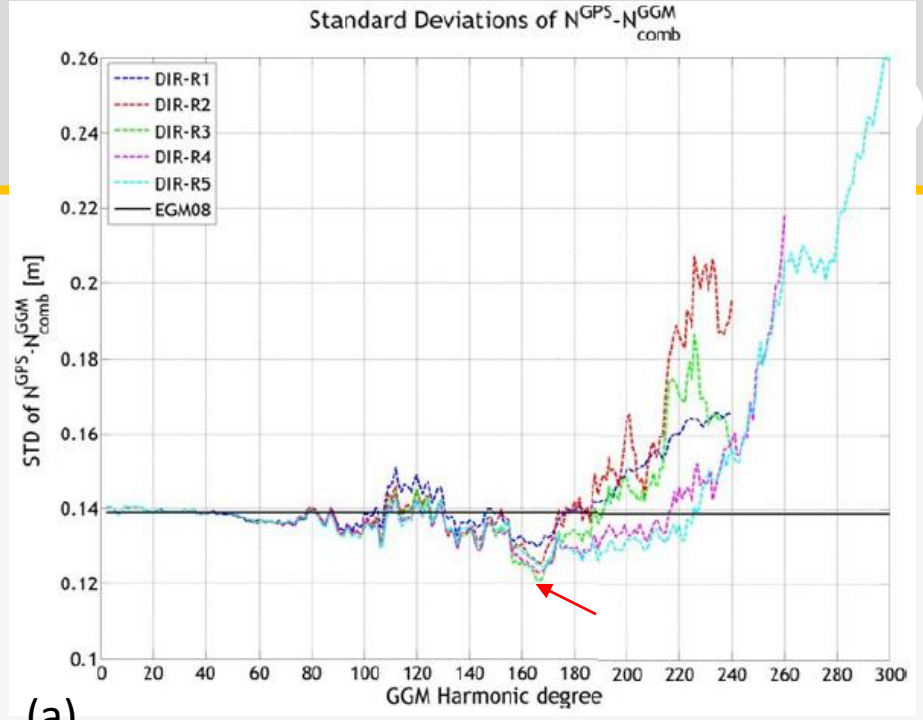
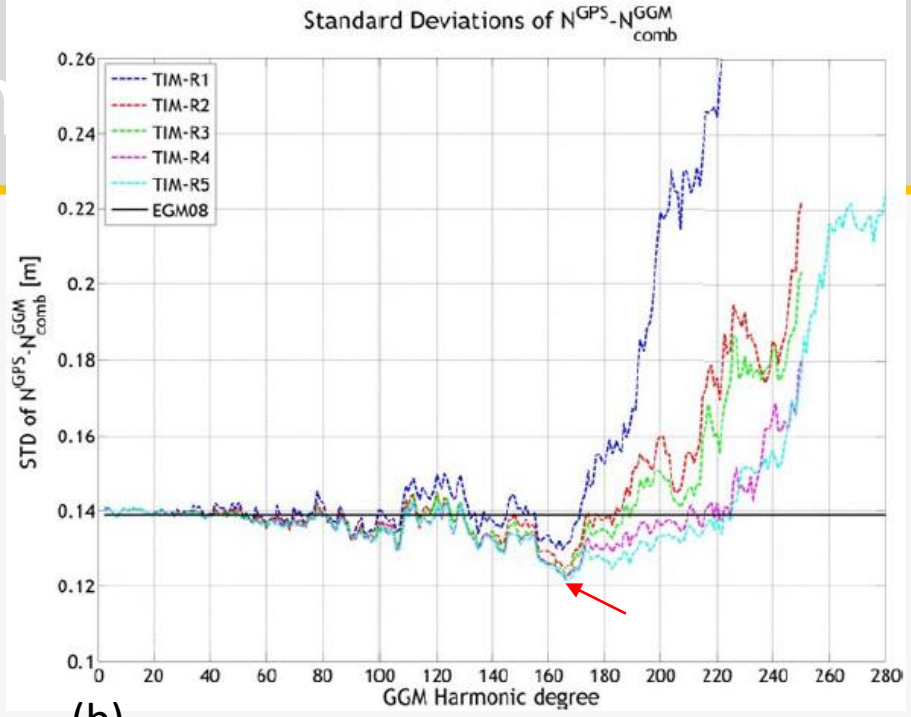


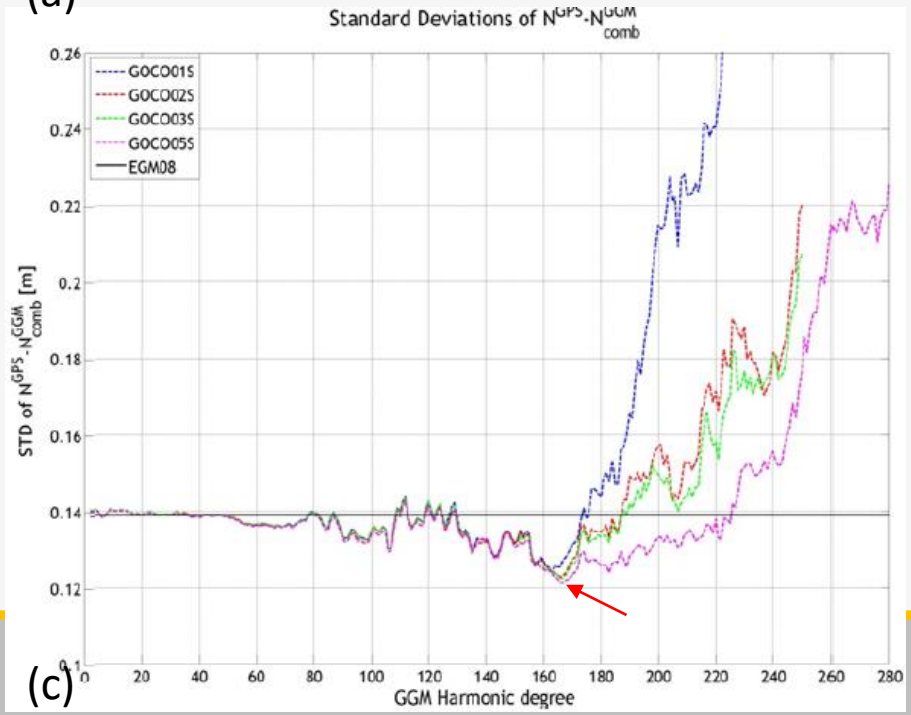
Figure : Error amplitudes (accumulated) as a function of the spherical harmonic degrees (l) in terms of geoid heights



(a)



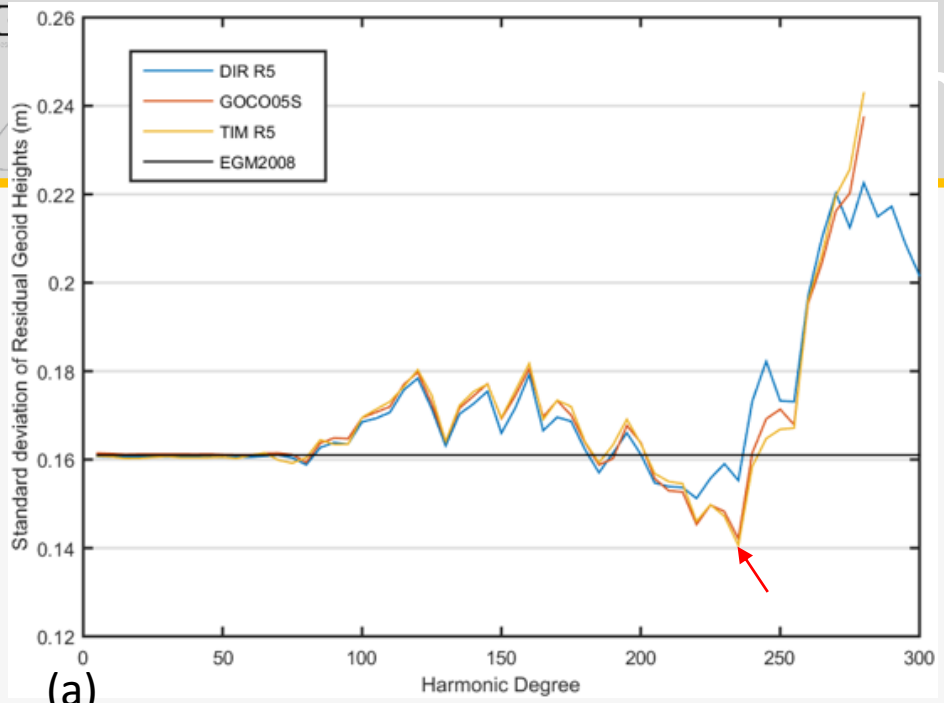
(b)

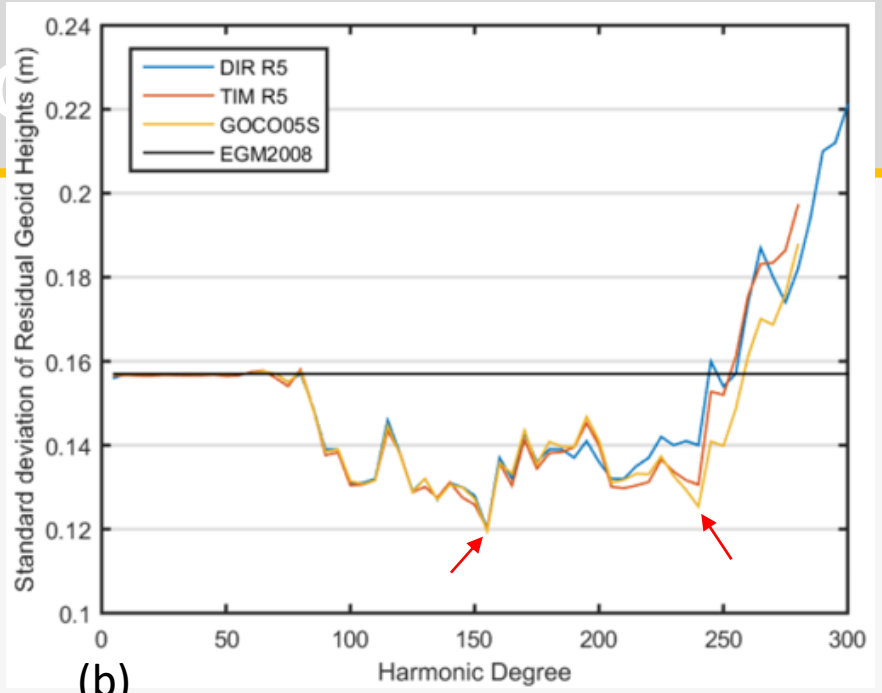


(c)

Figure : Validation of DIR Rx, TIM Rx and GOCO0xS models **at 1542 BMs on Greece mainland:**

the std. deviation of the geoid undulation residuals ($N_{GPS/lev.} - N_{GGM}^{enh.}$) with sequentially increasing d/o of GGMs.





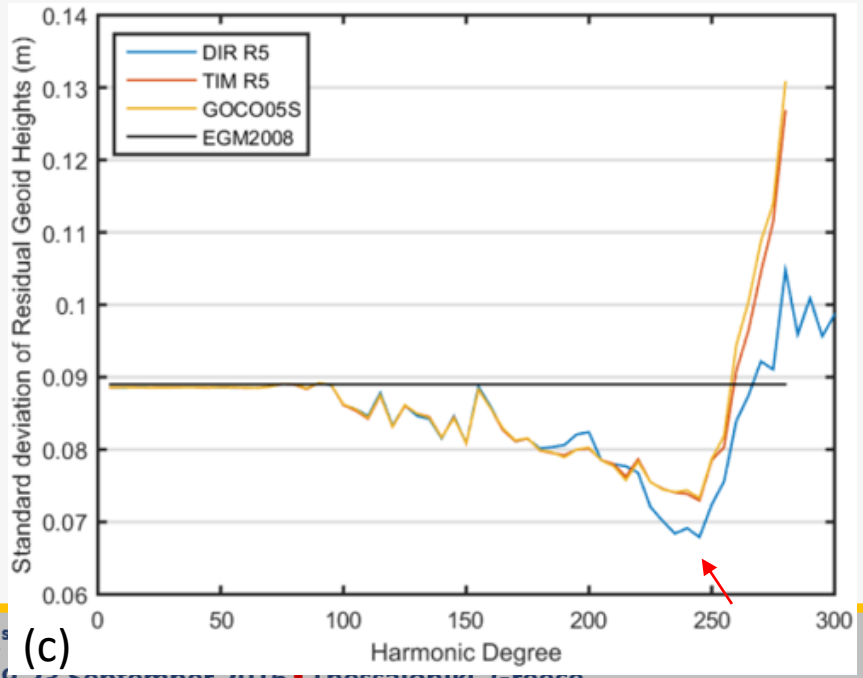


Figure : Validation of DIR R5, TIM R5 and GOCO005S models in Turkey:

(a) 30 BMs over the entire country (#3),

(b) 81 BMs in north-west local area (#4),

(c) 301 BMs in local area west of TR (#5)

the std. deviation of the geoid undulation residuals ($N_{GPS/lev.} - N_{GGM}^{enh.}$) with sequentially increasing d/o of GGMs.

GGM 1542 BMs	GREECE MAINLAND (34°N-42°N & 19°E-27°E)					
	Worst degree	Std. Deviation	Best degree	Std. deviation	Max. degree	Std. Deviation
DIR R5	298	26.1	169	12.4	300	25.9
TIM R5	280	22.6	166	12.2	280	22.6
GOCO05S	280	22.6	166	12.1	280	22.6

GGM 30 BMs	TURKEY (36°N-42°N & 26°E-45°E)					
	Worst degree	Std. Deviation	Best degree	Std. deviation	Max. degree	Std. Deviation
DIR R5	300	20.1	220	15.1	300	20.1
TIM R5	280	24.1	235	14.1	280	24.1
GOCO05S	280	23.9	235	14.2	280	23.9

Table : Std. Deviations of geoid height residuals, obtained through the optimum and maximum degrees of the models, at GPS/leveling BMs in Greek mainland and Turkey.

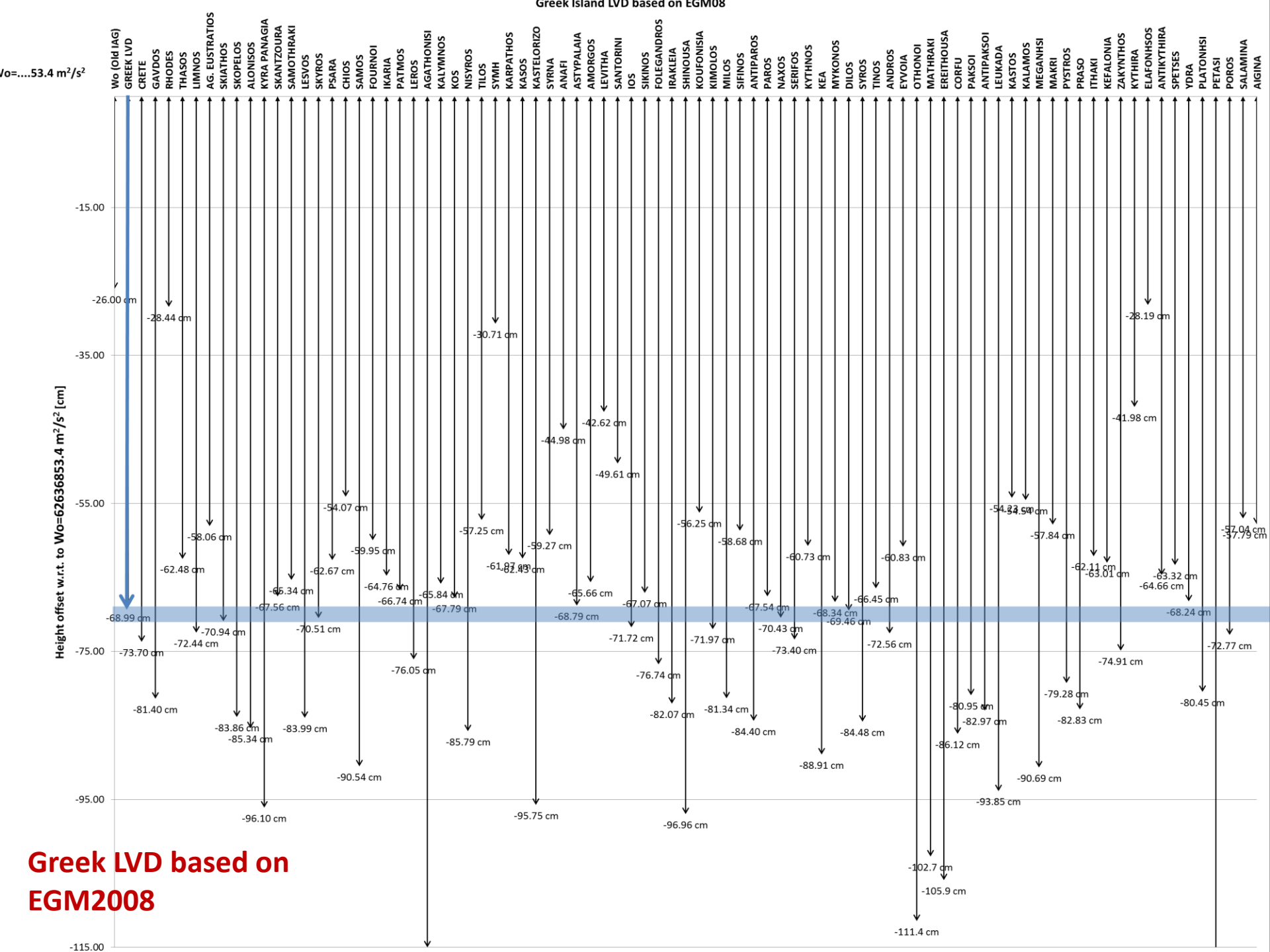
GGM 81 BMs	TURKEY - NORTH WEST (38°N-42°N & 28°E-32°E)					
	Worst degree	Std. Deviation	Best degree	Std. deviation	Max. degree	Std. Deviation
DIR R5	300	22.1	155	12.0	300	22.1
TIM R5	280	19.7	155	12.0	280	19.7
GOCO05S	280	18.8	155	12.0	280	18.8

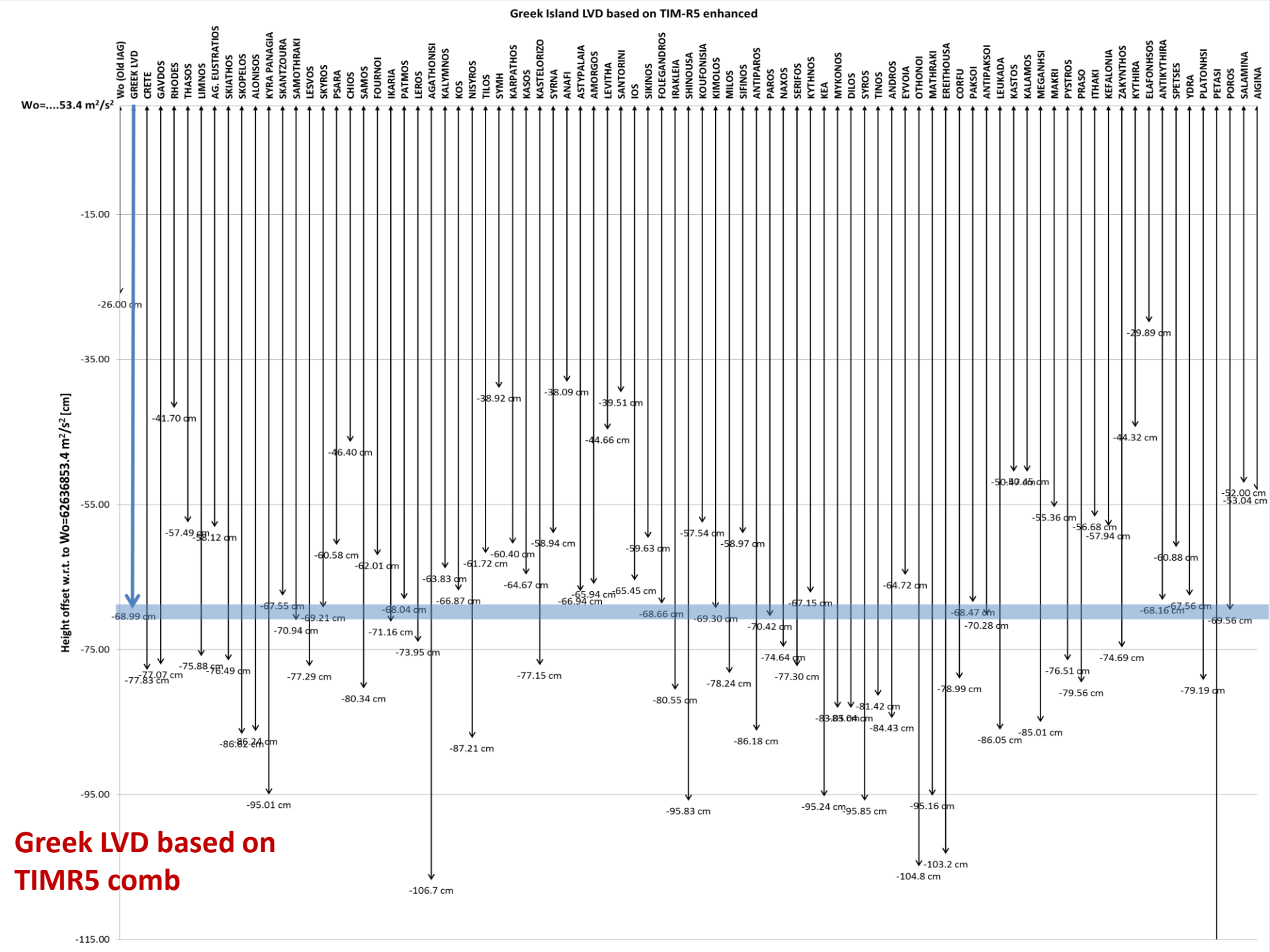
GGM 301 BMs	TURKEY – WEST (38°15′N-38°45′N & 26°45′E-27°15′E)					
	Worst degree	Std. Deviation	Best degree	Std. deviation	Max. degree	Std. Deviation
DIR R5	280	10.5	245	6.8	300	33.0
TIM R5	280	12.7	245	7.3	280	12.7
GOCO05S	280	13.1	245	7.3	280	13.1

Table : Std. Deviations of geoid height residuals, obtained through the optimum and maximum degrees of the models, at GPS/leveling BMs in Turkey for north-west and west local areas.

$\widehat{W}_o^{LVD}$ Determination

- The estimation of the mean offset is used to provide a direct link between the Greek and Turkish LVDs with the IAG conventional value 62636854.3 m^2/s^2 that is proposed as a W_o for a global WHS,
- The determination is carried out based on the available ellipsoidal, Helmert orthometric and geoid heights over the networks of BMs throughout the Greece main-land, Greek Islands (Aegean Sea), Turkey and two local areas with dense data in West of Turkey...


Greek Island LVD based on EGM08
Wo=....53.4 m²/s²
Wo (Old IAG)
GREEK LVD
CRETE
GAVDOS
RHODES
THASOS
LIMNOS
AG. EUSTRATIOS
SKIATHOS
SKOPELOS
ALONISOS
KYRA PANAGIA
SKANTZOURA
SAMOTHRAKI
LESVOS
SKYROS
PSARA
CHIOS
SAMOS
FOURNOI
IKARIA
PATMOS
LEROS
AGATHONISI
KALYMNOS
KOS
NISYROS
TILOS
SYMH
KARPATHOS
KASOS
KASTELORIZO
SYRNA
ANAFI
ASTYPALAIA
AMORGOS
LEVITHA
SANTORINI
IOS
SIKINOS
FOLEGANDROS
IRAKLEIA
SHINOUSA
KOUFONISIA
KIMOLOS
MILOS
SIFINOS
ANTIPAROS
PAROS
NAXOS
SERIFOS
KYTHNOS
KEA
MYKONOS
DILOS
SYROS
TINOS
ANDROS
EYVOIA
OTHONOI
MATHRAKI
EREITHOUSA
CORFU
PAKSOI
ANTIPAKSOI
LEUKADA
KASTOS
KALAMOS
MEGANHSI
MAKRI
PYSTROS
PRASO
ITHAKI
KEFALONIA
ZAKYNTHOS
KYTHIRA
ELAFONHSOS
ANTIKYTHIRA
SPETSES
YDRA
PLATONHSI
PETASI
POROS
SALAMINA
AIGINA
Height offset w.r.t. to Wo=62636853.4 m²/s² [cm]
-15.00
-35.00
-55.00
-75.00
-95.00
-115.00
-26.00 cm
-28.44 cm
-62.48 cm
-58.06 cm
-72.44 cm
-70.94 cm
-83.86 cm
-85.34 cm
-96.10 cm
-65.34 cm
-67.56 cm
-83.99 cm
-70.51 cm
-62.67 cm
-54.07 cm
-90.54 cm
-59.95 cm
-64.76 cm
-66.74 cm
-76.05 cm
-65.84 cm
-67.79 cm
-30.71 cm
-57.25 cm
-85.79 cm
-61.97 cm
-62.43 cm
-59.27 cm
-95.75 cm
-44.98 cm
-42.62 cm
-49.61 cm
-65.66 cm
-68.79 cm
-67.07 cm
-71.72 cm
-76.74 cm
-82.07 cm
-96.96 cm
-56.25 cm
-71.97 cm
-58.68 cm
-81.34 cm
-84.40 cm
-67.54 cm
-70.43 cm
-73.40 cm
-60.73 cm
-88.91 cm
-68.34 cm
-69.46 cm
-84.48 cm
-60.83 cm
-66.45 cm
-72.56 cm
-102.7 cm
-105.9 cm
-111.4 cm
-86.12 cm
-80.95 cm
-82.97 cm
-93.85 cm
-54.33 cm
-54.50 cm
-90.69 cm
-57.84 cm
-79.28 cm
-82.83 cm
-62.11 cm
-63.01 cm
-74.91 cm
-28.19 cm
-41.98 cm
-63.32 cm
-64.66 cm
-68.24 cm
-80.45 cm
-57.04 cm
-57.79 cm
-72.77 cm
Greek LVD based on EGM2008


Greek Island LVD based on TIM-R5 enhanced
Wo=....53.4 m²/s²
Height offset w.r.t. to Wo=62636853.4 m²/s² [cm]
-15.00
-26.00 cm
-35.00
-55.00
-68.99 cm
-75.00
-95.00
-115.00
Wo (Old IAG)
GREEK LVD
CRETE
GAVDOS
RHODES
THASOS
LIMNOS
AG. EUSTRATIOS
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SKOPELOS
ALONISOS
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SPETSES
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PLATONHSI
PETASI
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SALAMINA
AIGINA
-41.70 cm
-46.40 cm
-38.92 cm
-38.09 cm
-39.51 cm
-44.66 cm
-29.89 cm
-44.32 cm
-52.00 cm
-53.04 cm
-57.49 cm
-58.12 cm
-60.58 cm
-62.01 cm
-60.40 cm
-61.72 cm
-58.94 cm
-63.83 cm
-64.67 cm
-66.87 cm
-65.94 cm
-66.94 cm
-65.45 cm
-59.63 cm
-57.54 cm
-58.97 cm
-64.72 cm
-67.55 cm
-69.21 cm
-70.94 cm
-68.04 cm
-71.16 cm
-73.95 cm
-68.66 cm
-69.30 cm
-70.42 cm
-74.64 cm
-67.15 cm
-68.47 cm
-70.28 cm
-55.36 cm
-56.68 cm
-57.94 cm
-68.16 cm
-67.56 cm
-69.56 cm
-60.88 cm
-74.69 cm
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-79.56 cm
-77.07 cm
-77.83 cm
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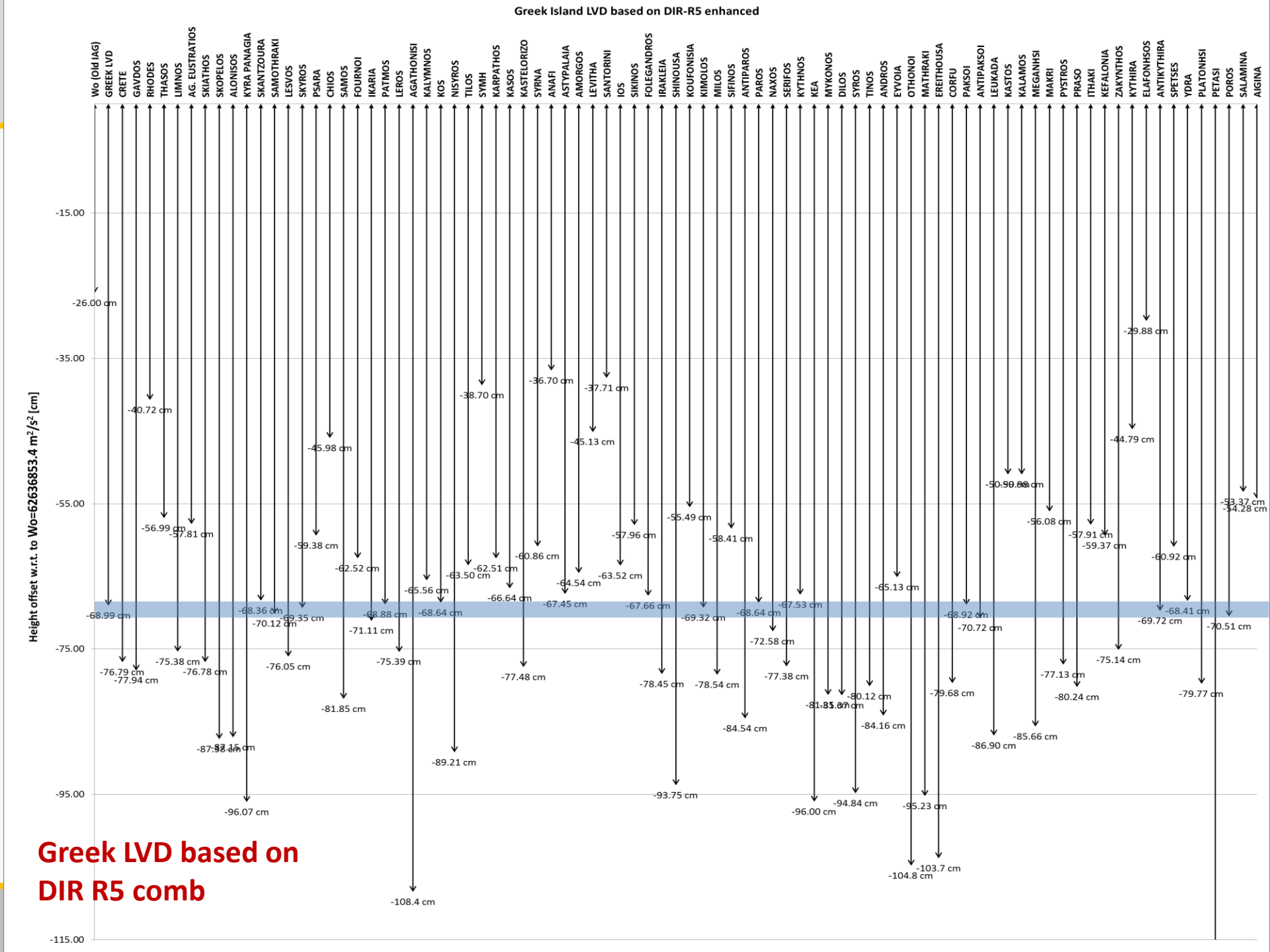
-80.55 cm
-81.42 cm
-84.43 cm
-86.18 cm
-86.05 cm
-85.01 cm
-86.24 cm
-86.82 cm
-87.21 cm
-95.01 cm
-95.83 cm
-95.24 cm
-95.85 cm
-95.16 cm
-103.2 cm
-104.8 cm
-106.7 cm
Greek LVD based on
TIMR5 comb


Greek Island LVD based on DIR-R5 enhanced
Height offset w.r.t. to Wo=62636853.4 m²/s² [cm]
-15.00
-35.00
-55.00
-75.00
-95.00
-115.00
Wo (Old IAG)
GREEK LVD
CRETE
GAVDOS
RHODES
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KYTHIRA
ELAFONHSOS
ANTIKYTHIRA
SPETSES
YDRA
PLATONHSI
PETASI
POROS
SALAMINA
AIGINA
-26.00 cm
-40.72 cm
-56.99 cm
-57.81 cm
-45.98 cm
-59.38 cm
-62.52 cm
-38.70 cm
-63.50 cm
-65.56 cm
-36.70 cm
-60.86 cm
-64.54 cm
-37.71 cm
-45.13 cm
-63.52 cm
-57.96 cm
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-55.49 cm
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-54.28 cm
-70.51 cm
-68.99 cm
-68.36 cm
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-68.88 cm
-71.11 cm
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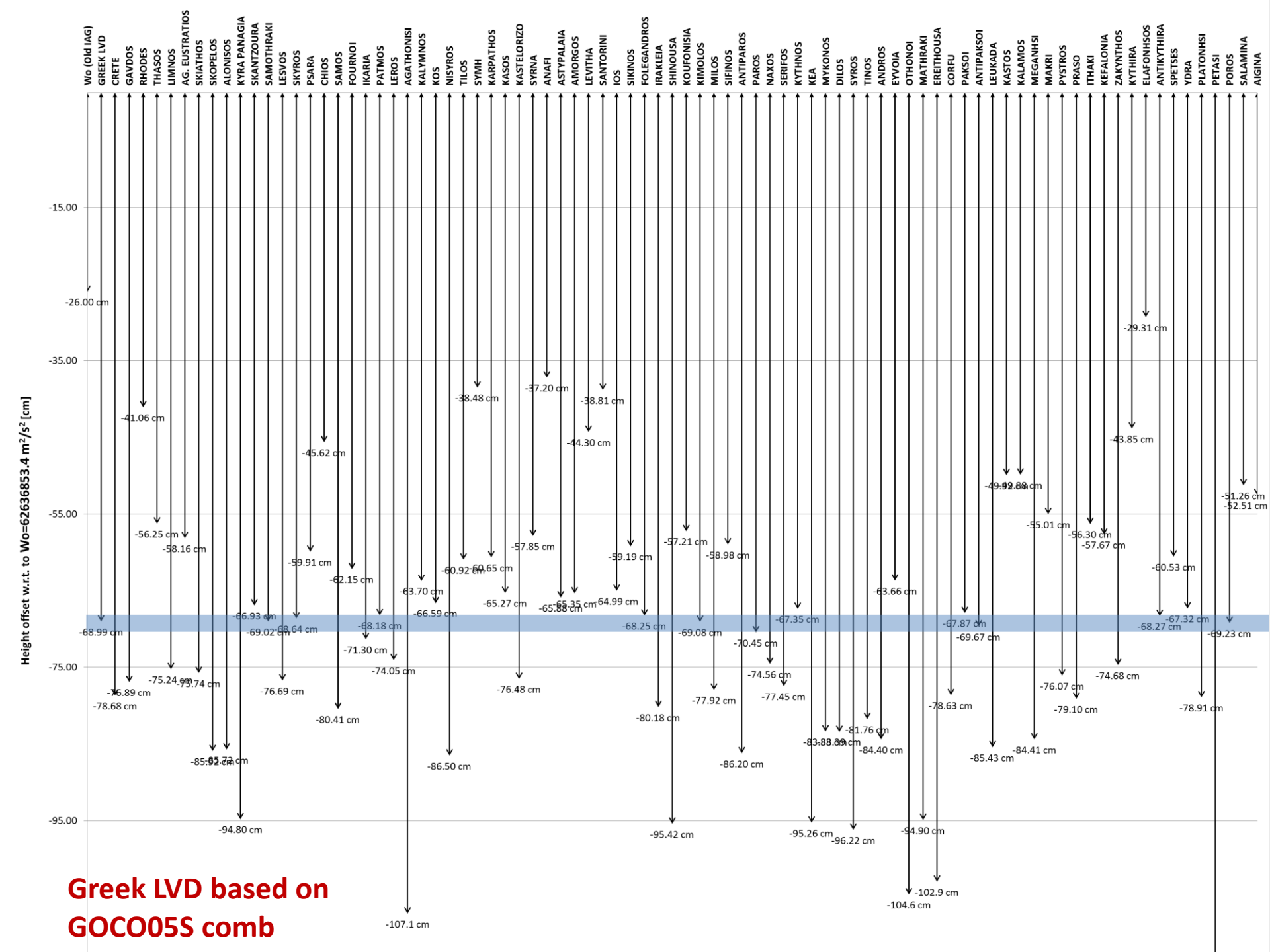
-76.05 cm
-81.85 cm
-75.39 cm
-108.4 cm
-89.21 cm
-77.48 cm
-78.45 cm
-78.54 cm
-84.54 cm
-77.38 cm
-96.00 cm
-94.84 cm
-80.12 cm
-84.16 cm
-93.75 cm
-95.23 cm
-104.8 cm
-103.7 cm
-79.68 cm
-86.90 cm
-85.66 cm
-77.13 cm
-80.24 cm
-75.14 cm
-79.77 cm
Greek LVD based on
DIR R5 comb


Wo (Old IAG)
GREEK LVD
CRETE
GAVDOS
RHODES
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AG. EUSTRATIOS
SKIATHOS
SKOPELOS
ALONISOS
KYRA PANAGIA
SKANTZOURA
SAMOTHRAKI
LESVOS
SKYROS
PSARA
CHIOS
SAMOS
FOURNOI
IKARIA
PATMOS
LEROS
AGATHONISI
KALYMNOS
KOS
NISYROS
TILOS
SYMH
KARPATHOS
KASOS
KASTELORIZO
SYRNA
ANAFI
ASTYPALAIA
AMORGOS
LEVITHA
SANTORINI
IOS
SIKINOS
FOLEGANDROS
IRAKLEIA
SHINOUSA
KOUFONISIA
KIMOLOS
MILOS
SIFINOS
ANTIPAROS
PAROS
NAXOS
SERIFOS
KYTHNOS
KEA
MYKONOS
DILOS
SYROS
TINOS
ANDROS
EYVOIA
OTHONOI
MATHRAKI
EREITHOUSA
CORFU
PAKSOI
ANTIPAKSOI
LEUKADA
KASTOS
KALAMOS
MEGANHSI
MAKRI
PYSTROS
PRASO
ITHAKI
KEFALONIA
ZAKYNTHOS
KYTHIRA
ELAFONHSOS
ANTIKYTHIRA
SPETSES
YDRA
PLATONHSI
PETASI
POROS
SALAMINA
AIGINA
Height offset w.r.t. to Wo=62636853.4 m²/s² [cm]
-15.00
-26.00 cm
-35.00
-55.00
-75.00
-95.00
-41.06 cm
-56.25 cm
-58.16 cm
-45.62 cm
-59.91 cm
-62.15 cm
-38.48 cm
-60.92 cm
-60.65 cm
-63.70 cm
-65.27 cm
-66.59 cm
-37.20 cm
-57.85 cm
-65.88 cm
-65.35 cm
-38.81 cm
-44.30 cm
-64.99 cm
-59.19 cm
-57.21 cm
-58.98 cm
-63.66 cm
-29.31 cm
-43.85 cm
-49.92 cm
-51.26 cm
-52.51 cm
-55.01 cm
-56.30 cm
-57.67 cm
-60.53 cm
-67.32 cm
-68.27 cm
-68.99 cm
-66.93 cm
-69.02 cm
-68.64 cm
-68.18 cm
-71.30 cm
-74.05 cm
-68.25 cm
-69.08 cm
-70.45 cm
-74.56 cm
-77.45 cm
-67.35 cm
-67.87 cm
-69.67 cm
-69.23 cm
-75.24 cm
-75.74 cm
-76.89 cm
-78.68 cm
-76.69 cm
-80.41 cm
-74.68 cm
-76.07 cm
-79.10 cm
-78.91 cm
-85.92 cm
-85.72 cm
-94.80 cm
-86.50 cm
-76.48 cm
-80.18 cm
-77.92 cm
-86.20 cm
-78.63 cm
-85.43 cm
-84.41 cm
-83.88 cm
-81.76 cm
-84.40 cm
-95.42 cm
-95.26 cm
-96.22 cm
-94.90 cm
-102.9 cm
-104.6 cm
-107.1 cm
Greek LVD based on
GOCO05S comb

GGM Study Area	Geoid Height Residuals $(N_{GPS/lev.} - N_{model}^{enhenced})$ cm					Gravity Potential base on $W_o^{CVD} = 62636854.30\ m^2/s^2$	
TIM R5 $(\|_{l=0}^{n_{opt}} + \|_{n_{opt}+1}^{2190})$	min	max	mean	std.	rms.	$\widehat{W}_o^{LVD}$ (m^2/s^2)	$\delta\widehat{W}_o^{LVD}$ (cm)
#3 (30 BMs)	-10.7	49.7	9.5	14.1	17.0	62636852.4716	18.6
#4 (81 BMs)	-36.3	31.4	4.6	12.0	12.9	62636852.9453	13.8
#5 (301 BMs)	0.7	56.8	21.5	7.3	22.7	62636851.2937	30.6
DIR R5 $(\|_{l=0}^{n_{opt}} + \|_{n_{opt}+1}^{2190})$	min	max	mean	std.	rms.	$\widehat{W}_o^{LVD}$ (m^2/s^2)	$\delta\widehat{W}_o^{LVD}$ (cm)
#3 (30 BMs)	-13.4	58.6	9.9	15.6	18.5	62636852.4287	19.1
#4 (81 BMs)	-36.1	31.7	4.5	12.0	12.9	62636852.9550	13.7
#5 (301 BMs)	-3.1	48.8	15.6	6.9	17.1	62636851.8663	24.5
GOCO05S $(\|_{l=0}^{n_{opt}} + \|_{n_{opt}+1}^{2190})$	min	max	mean	std.	rms.	$\widehat{W}_o^{LVD}$ (m^2/s^2)	$\delta\widehat{W}_o^{LVD}$ (cm)
#3 (30 BMs)	-8.8	51.9	9.7	14.2	17.2	62636852.4509	18.9
#4 (81 BMs)	-36.2	31.2	4.4	11.9	12.7	62636852.9664	13.6
#5 (301 BMs)	-0.9	55.8	19.6	7.4	21.0	62636851.4763	28.8
EGM-08 (2190)	min	max	mean	std.	rms	$\widehat{W}_o^{LVD}$ (m^2/s^2)	$\delta\widehat{W}_o^{LVD}$ (cm)
#3 (30 BMs)	-28.1	61.6	7.5	15.5	17.2	62636852.6056	17.3
#4 (81 BMs)	-43.3	51.1	5.9	15.9	16.9	62636852.8248	15.0
#5 (301 BMs)	-22.3	40.1	0.7	8.8	8.9	62636853.3254	10.0

Table : Zero-level potential calculations using enhanced geopotential models with the optimum degrees.

Conclusions & Discussion

- The results show that the GOCE data has contribution to improvement of GGMs in medium frequency bands (btw. d/o 100-250), both in Greece and Turkey,
- Spectral enhancement method provides a practical solution to compensate the omission error in validations,
- The topographic character, distribution of GPS/leveling data and size of the area have role in assessments of GGM performance (e.g. Izmir vs all Turkey)

Conclusions & Discussion

- The recent releases of GO-DIR, TIM and GOCO-S models has much improved performance in Greece and Turkey,
- The accuracy of GGMs is around 12-14 cm with optimum d/o and 20-25 cm with maximum d/o, both in Greece and Turkey (in terms of std.dev. of geoidal height residuals),
- The performance assessments of GGMs are essential to determine the height system offset of the country using best GGM and it's optimum d/o…

Conclusions & Discussion

- Regarding the $\widehat{W}_o^{LVD}$ computations,
  - Greece (mainland) is approximately 60 cm higher than the reference surface specified by the geoidal potential of 62636854.3 m^2/s^2,
  - The situation at the islands varies greatly, with each island or isle practically realizing its own LVD, which is not connected to that of the zero-level geopotential value at Piraeus harbor,
  - The height offsets of the datum in Islands vary between 40 cm and 1 m over the reference surface,

Conclusions & Discussion

- Regarding the $\widehat{W}_o^{LVD}$ computations (cont.)
  - Turkey LVD is closer to the newly adopted global W_o by IAG, and approximately 20 cm lower than the reference surface,
  - In the border line significant biases exist, as for instance between Chios and Izmir, being at the 76 cm level.
- The presented results here are preliminary and further studies on precise determination of relative height system offset btw. Geece and Turkey are planned…

GGHS

1st Joint Commission 2 and IGFS Meeting
International Symposium on
Gravity, Geoid and Height Systems 2016

September 19-23, 2016
Thessaloniki, Greece

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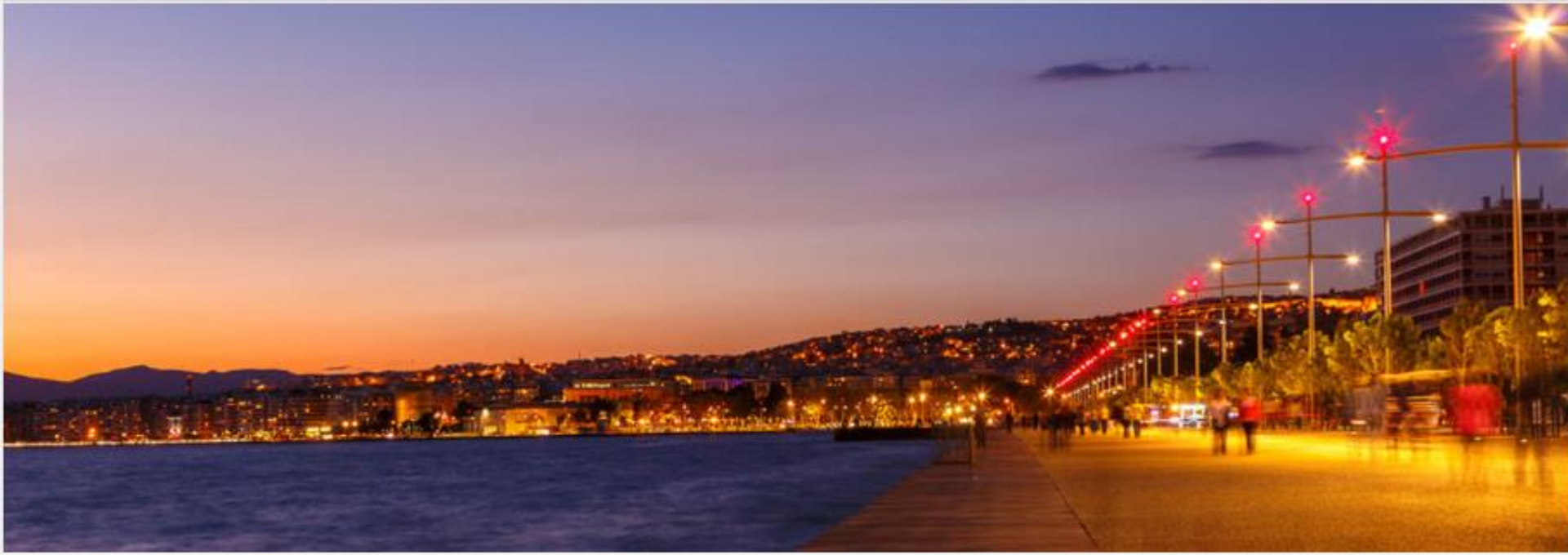

Thank you for your attention…