Validation of GOCE/GRACE satellite only and combined global geopotential models over Greece, in the frame of the GOCESeaComb Project

Department of Geodesy and Surveying
Aristotle University of Thessaloniki

I.N. Tziavos, G.S. Vergos, V.N. Grigoriadis, E.A. Tzanou and D.A. Natsiopoulos

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OUTLINE

- Spectral evaluation of GOCE/GRACE-based GGMs over Greece
- Evaluation of combined GOCE/GRACE-based GGMs over Greece using gravity anomalies
- Evaluation of combined GOCE/GRACE-based GGMs over Greece using deflections of the vertical
- Evaluation of GOCE/GRACE-based and combined GGMs over Greece using GPS/leveling data
- Evaluation of combined GOCE/GRACE-based GGMs over Greece obtained from a wavelet decomposition and reconstruction procedure using GPS/leveling data

AVAILABLE DATA (1/2)

1) GOCE/GRACE GGMs

- TIM *(R1, R2, R3, R4)*
- SPW *(R1, R2)*
- DIR *(R1, R2, R3, R4)*
- GOCO *(R1, R2, R3)*
- EIGEN-*S/C *(51C, 6S, 6C, 6C2)*
- DGM1S
- ITG-GRACE2010S

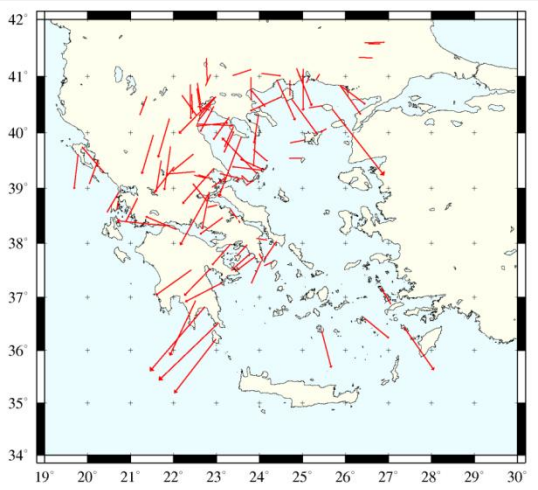
2) EGM08 (used as reference)

3) Gravity anomalies

294777 free-air anomalies

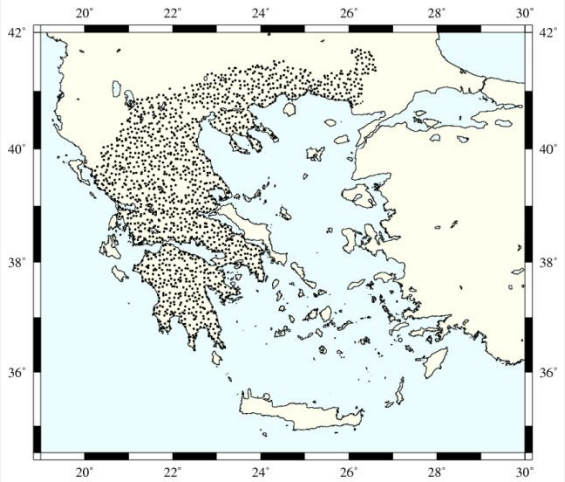
4) 99 deflections of the vertical

(Tziavos 1984; Müller et al 2007; Somieski 2008)



5) GPS/Leveling data

1542 GPS/Leveling BMs



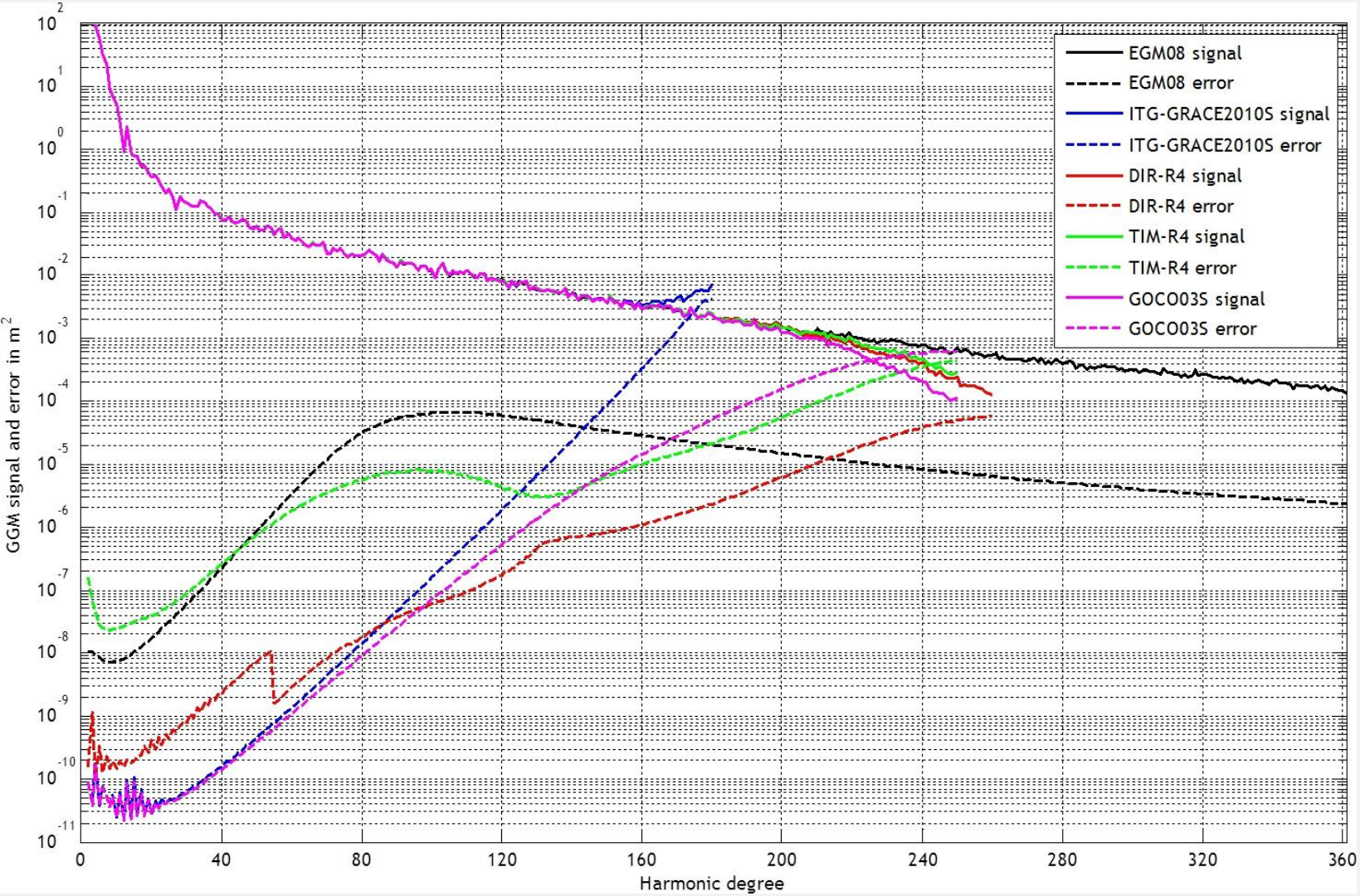
Data/Parameters used

- Mean Tide to Tide Free conversion for orthometric heights
- GGM Zero Tide to Tide Free when necessary
- All computations in GRS80
- N_o relative to the IERS W_o of 62636856.0 m^2/s^2

Examined values

- GGM spectra and error spectra
- SNR and GAIN (w.r.t. EGM08) for each GGM
- Geoid degree and error degree variances (& cumulatively)
- GGM difference degree variance relative to EGM08
- Signal and error PSD w.r.t. Kaula's rule and EGM08

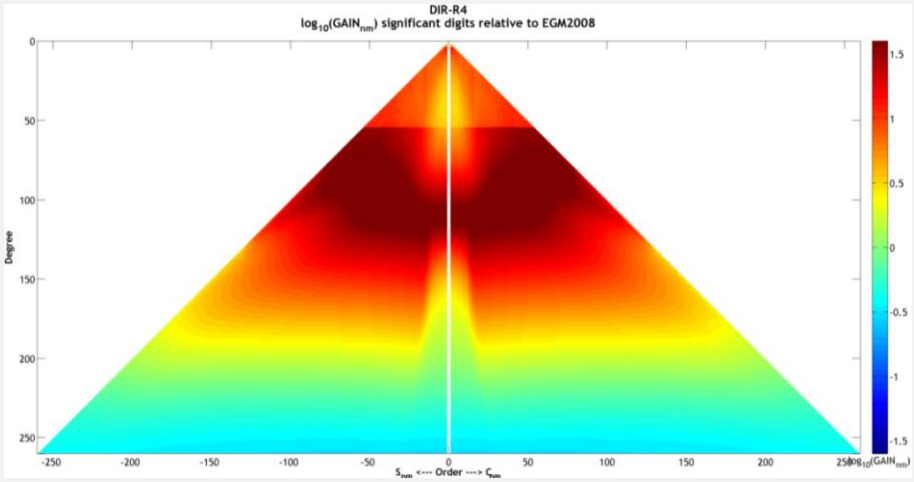
SPECTRAL EVALUATION



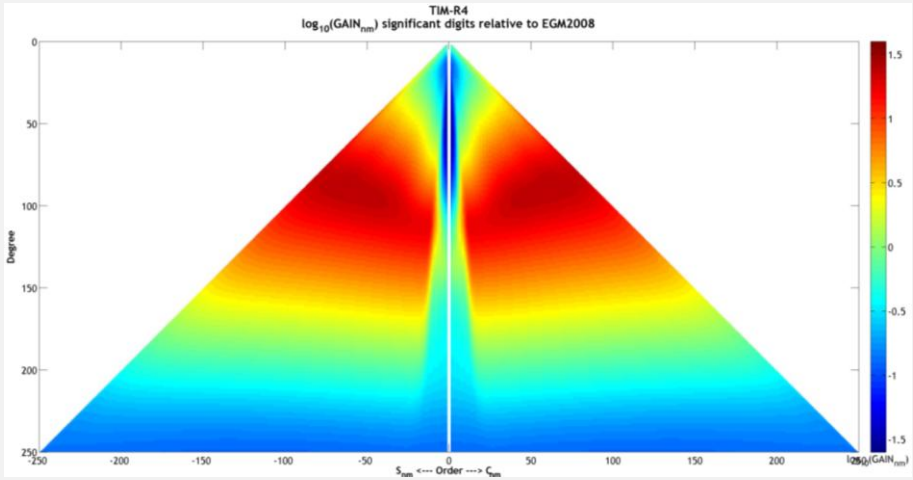
DIR-R4, TIM-R4, GOCO03S, ITG-GRACE degree and error degree variances

- **Improved GGM errors up to d/o 220-240**

SPECTRAL EVALUATION



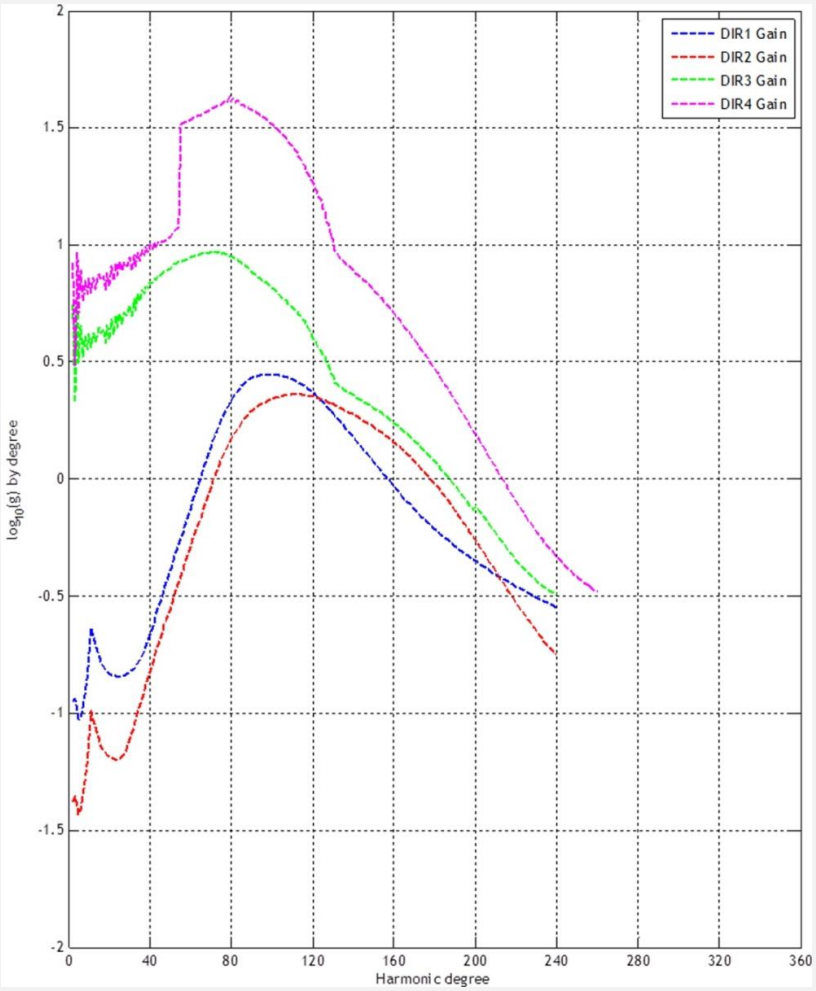
DIR-R4 gain

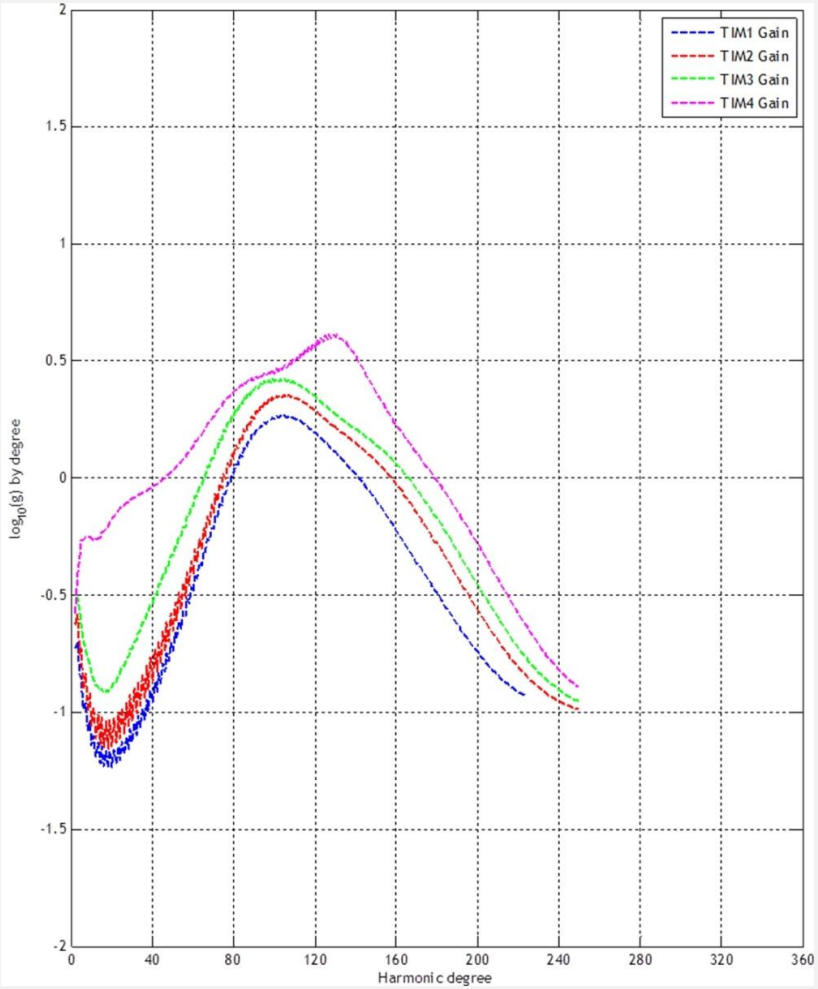


TIM-R4 gain

- **DIR-R4 and TIM-R4 2D gain shows significant improvement w.r.t. EGM08 in the zonal and near-zonal harmonics and to all above d/o 190**

SPECTRAL EVALUATION





- **DIR-R4 degree variances smaller than EGM08 up to d/o 213 and TIM-R4 up to d/o 180. DIR-R4 and TIM-R4 cumulative geoid errors of 4.4 and 11.3 cm to their n_{max}**

Limitations

- **Most of the gravity anomalies included in our database were used in the development of EGM08 - the exact number is unknown**

- **Validation is biased, since EGM08 and gravity anomalies are highly correlated**

Validation

$$\Delta g_{red} = \Delta g - \Delta g^{\mathrm{GOCE}}\Big|_{2}^{n} - \Delta g^{\mathrm{EGM08}}\Big|_{n+1}^{2159}$$

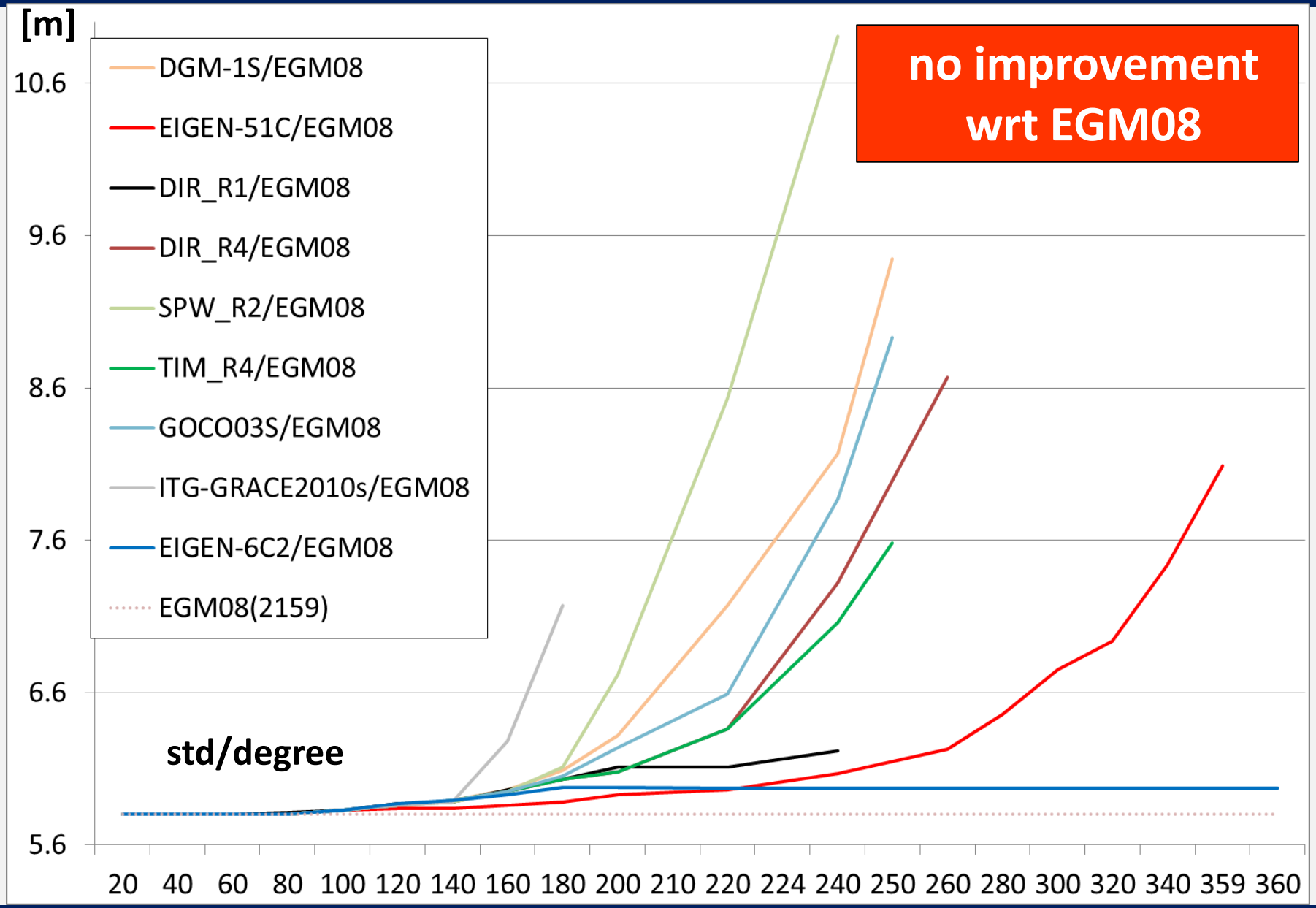
$$\Delta g_{res} = \Delta g - \Delta g^{\mathrm{GOCE}}\Big|_{2}^{n} - \Delta g^{\mathrm{EGM08}}\Big|_{n+1}^{1834} - \Delta g_{\mathrm{RTM}}$$

$(n \leq n_{max}\ \&\ n_{i+1} = n_i + 20)$

Results

- **No concurrent improvement both in std and mean value were observed**

VALIDATION WITH GRAVITY DATA



VALIDATION WITH DoV

	EGM08	DIR-R4			TIM-R3		TIM-R4		GOCO3S			ITG-GRACE 2010S
Δξ	2159	180	240	180	200	240	240	250	180	200	240	160
mean	-0.34	-0.33	-0.25	-0.33	-0.31	**-0.29**	-0.24	-0.23	-0.34	-0.31	**-0.30**	-0.34
std	2.18	2.13	2.15	2.14	2.10	**2.12**	2.13	2.14	2.14	2.10	**2.12**	2.14
range	10.65	10.89	10.56	10.92	10.66	10.39	10.16	10.01	10.96	10.71	10.32	11.14
Δη	*[Units: arcsec]*											
mean	0.58	0.58	0.52	0.57	0.58	**0.53**	0.55	0.55	0.57	0.57	**0.52**	0.54
std	2.28	2.28	2.26	2.28	2.27	**2.25**	2.22	2.19	2.28	2.27	**2.24**	2.28
range	10.37	10.54	10.58	10.33	10.11	9.79	10.68	10.88	10.40	10.17	9.92	10.66

$$\Delta\xi = \xi - \xi^{\mathrm{GOCE}}\Big|_{2}^{n} - \xi^{\mathrm{EGM08}}\Big|_{n+1}^{2159}$$

$$\Delta\eta = \eta - \eta^{\mathrm{GOCE}}\Big|_{2}^{n} - \eta^{\mathrm{EGM08}}\Big|_{n+1}^{2159}$$

$(n \leq n_{max})$

$(n_{i+1}=n_i+20)$

Selection criteria: lowest mean & std for both ξ, η

Methodology

- **GGM differences to their n_{max}**

$$\Delta N = N^{GPS/Lev} - N^{i}_{n_{max}} - N_o$$

$$N^{i}_{GGM},\ i = DIR/TIM/SPW/GOCO/EIGEN-R1,R2,R3,R4$$

- **Combined GGM differences to n_{max}=216,000**

$$\Delta N = N^{GPS/Lev} - N^{i}\Big|_{2}^{n_1} - N^{EGM2008}\Big|_{n_1+1}^{2160} - N^{RTM} - N_o$$

$N^{i}\Big|_{2}^{n_1}$ **evaluation of GOCE/GRACE GGMs every 1 degree**

N^{RTM} **from a 3″ DTM over Greece**

Differences of GMs(nmax) with GPS/levelling [m]

	max	min	mean	rms	std
N(grav)	0.119	-1.033	-0.392	0.416	0.140
EGM08 *(2160)*	0.168	-0.810	-0.374	0.400	0.141
EIGEN-6C2 (1949)	0.193	-0.929	-0.388	0.411	0.137
EIGEN-6C2 (1420)	0.316	-0.874	-0.389	0.417	0.149
EIGEN-6C (1420)	0.357	-0.867	-0.394	0.425	0.161
EIGEN-51C *(359)*	1.341	-1.242	-0.309	0.507	0.403
EGM08 *(250)*	1.218	-1.746	-0.343	0.584	0.472
EIGEN-6C (250)	1.246	-1.689	-0.361	0.599	0.478
EIGEN-6C2 (250)	1.202	-1.639	-0.356	0.593	0.475
EIGEN-6S (240)	1.400	-1.837	-0.358	0.625	0.512
DGM-1S *(250)*	1.506	-1.576	-0.363	0.630	0.515

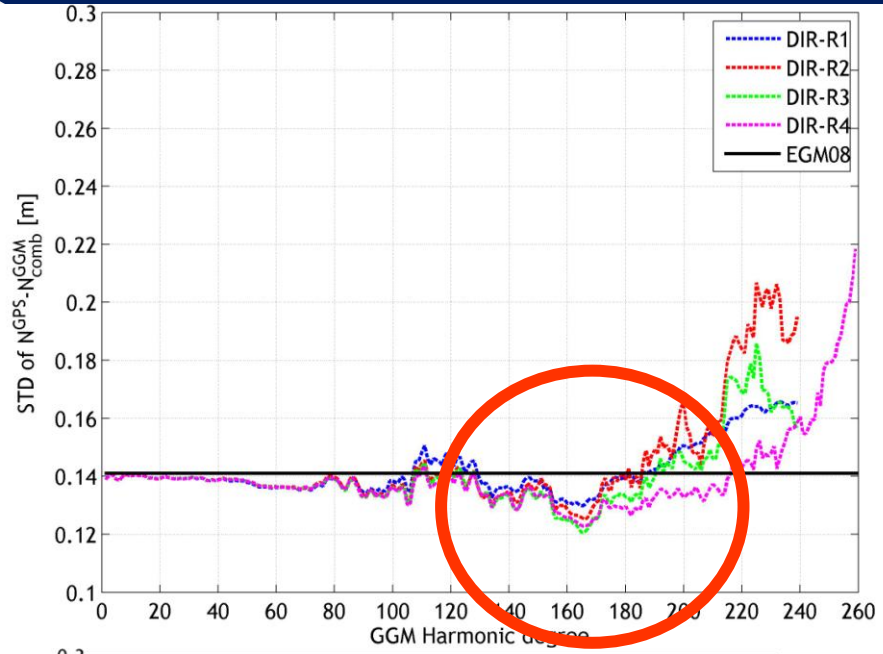
Differences of GMs(nmax) with GPS/levelling [m]

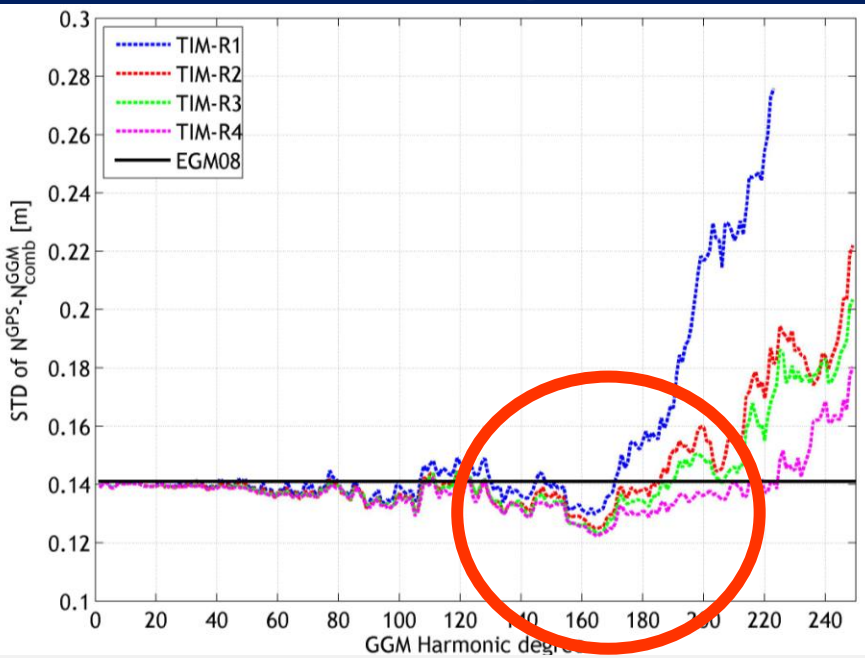
	max	min	mean	rms	std
DIR-R1 *(240)*	1.488	-1.801	-0.344	0.613	0.507
DIR-R2 *(220)*	1.603	-1.650	-0.347	0.613	0.505
DIR-R3 *(240)*	1.406	-1.703	-0.352	0.597	0.482
DIR-R4 *(260)*	1.379	-1.607	-0.361	0.597	0.476
TIM-R1 *(224)*	1.607	-1.948	-0.348	0.646	0.544
TIM-R2 *(250)*	1.505	-1.659	-0.360	0.618	0.502
TIM-R3 *(250)*	1.386	-1.804	-0.356	0.609	0.494
TIM-R4 *(250)*	1.260	-1.628	-0.352	0.598	0.484
EGM08 *(250)*	1.218	-1.746	-0.343	0.584	0.472
EIGEN-6C2 (250)	1.202	-1.639	-0.356	0.593	0.475

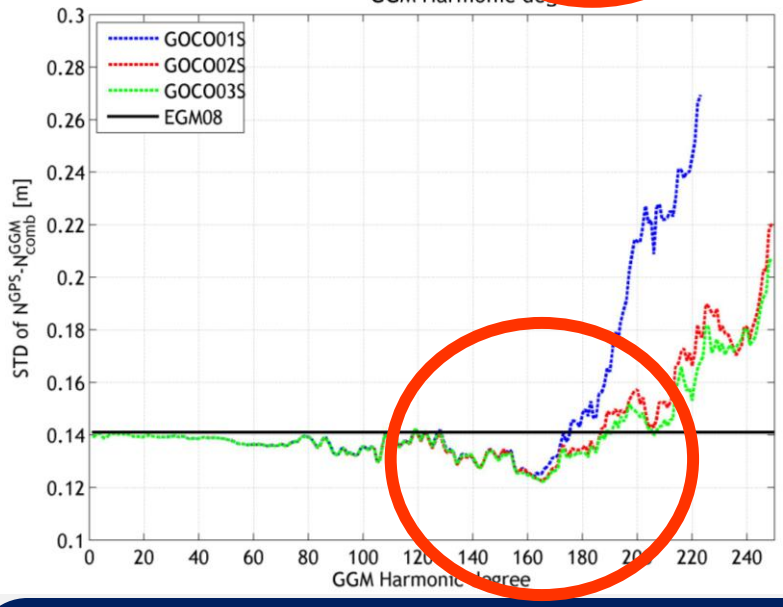
Differences of GMs(nmax) with GPS/levelling [m]

	max	min	mean	rms	std
GOCO01S *(224)*	1.580	-1.969	-0.340	0.644	0.547
GOCO02S *(250)*	1.483	-1.687	-0.358	0.616	0.501
GOCO03S *(250)*	1.415	-1.795	-0.353	0.609	0.496
ITG-GRACE10S *(180)*	1.747	-2.183	-0.299	0.752	0.690
EGM08 *(250)*	1.218	-1.746	-0.343	0.584	0.472
EIGEN-6C2 (250)	1.202	-1.639	-0.356	0.593	0.475

VALIDATION WITH GPS/LEVELING

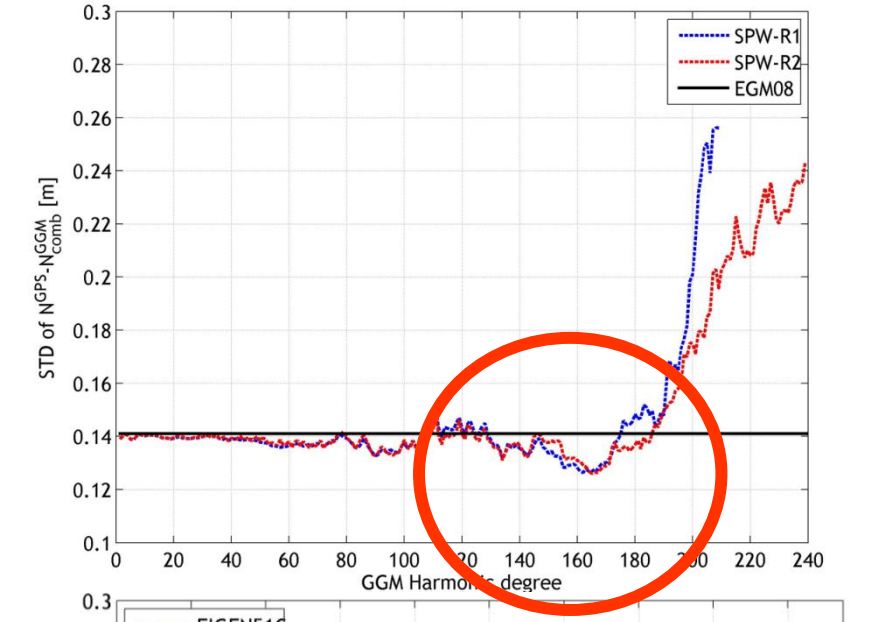




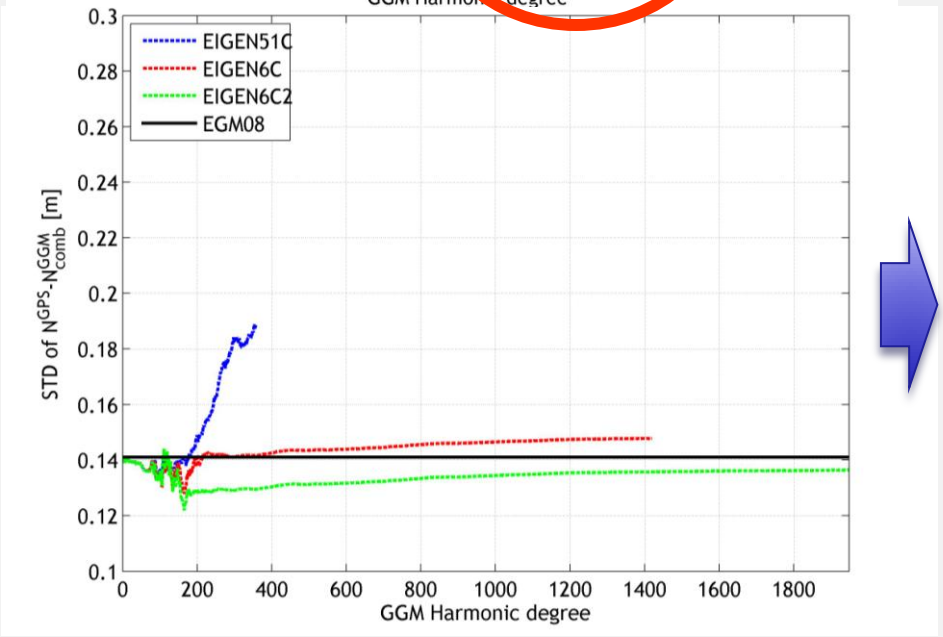


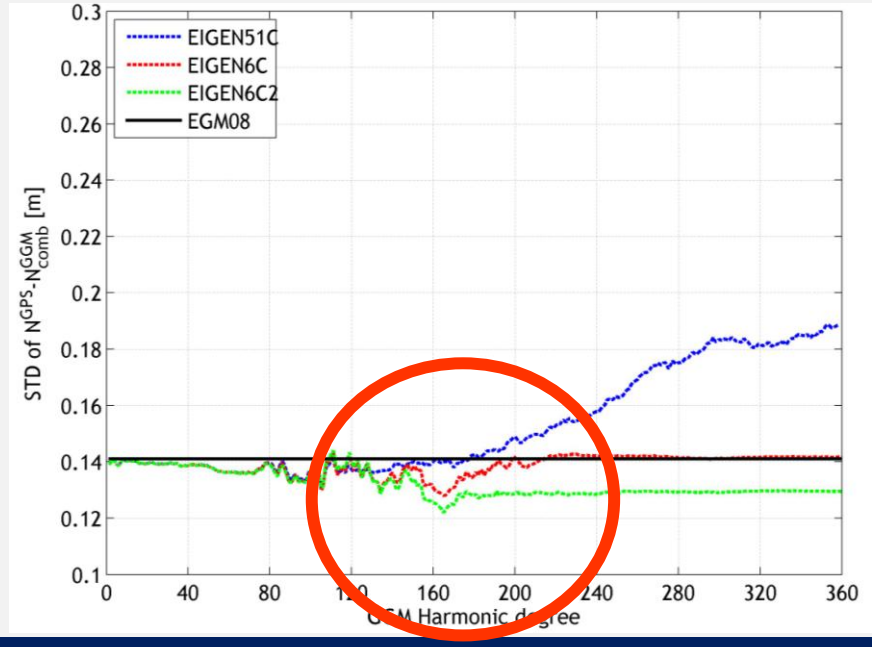
Std of N_{GPS}-N_{comb}

VALIDATION WITH GPS/LEVELING

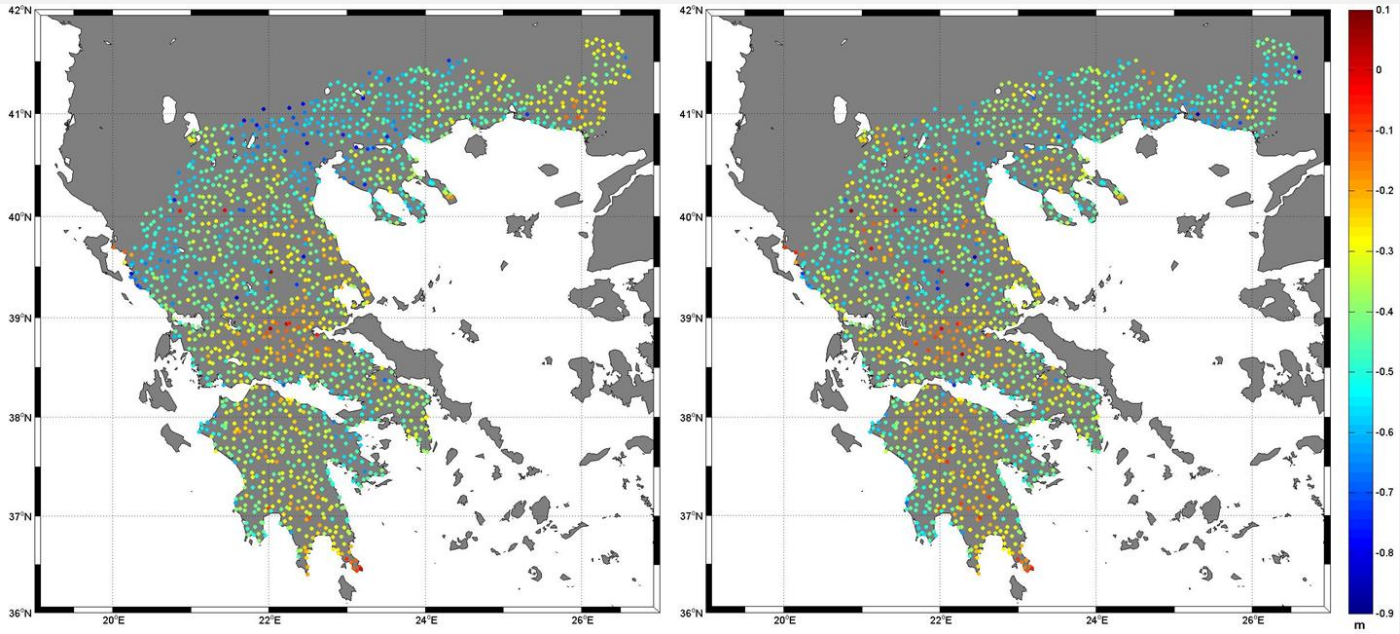


Std of N_{GPS}-N_{comb}



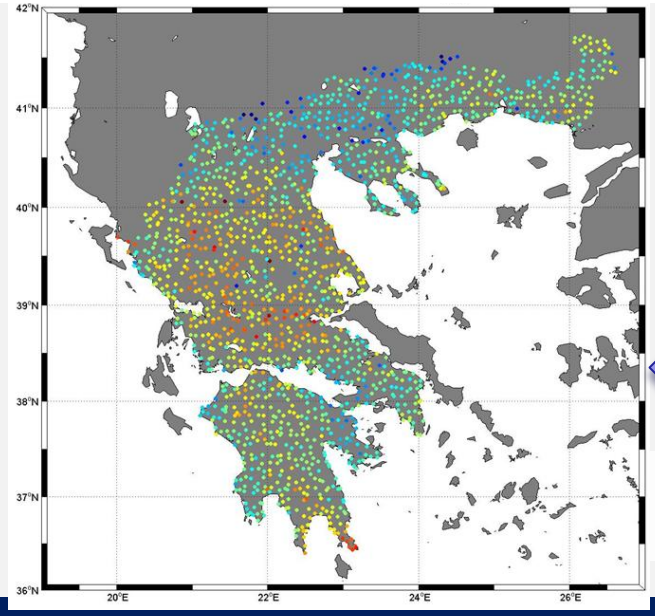


VALIDATION WITH GPS/LEVELING



N_{GPS}-N_{EGM08}

N_{GPS}-$N_{EIGEN6C2}$



N_{GPS}-N_{grav}

WL DECOMPOSITION & RECONSTRUCTION

Available data

Gridded geoid Heights from ICGEM (2arcmin resolution)

- TIM *(R1, R2, R3, R4)*
- DIR *(R1, R2, R3, R4)*
- GOCO *(R1, R2, R3)*
- EGM08

Wavelet analysis

Db10 wavelet *smooth & suitable for potential field data*

13 Decomposition Levels

level	resolution	level	resolution	level	resolution	level	resolution
1	3.7-7.3	4	29.3-58.6	7	234.4-468.9	10	1875.5-3750.9
2	7.3-14.7	5	58.6-117.2	8	468.9-937.7	11	3750.9-7501.8
3	14.7-29.3	6	117.2-234.4	9	937.7-1875.5	12	7501.8-15003.7
Resolution in km						13	15003.7-30007.3

WL DECOMPOSITION & RECONSTRUCTION

Methodology

A

Levels 1-6		Levels 7-13
EGM08	+	GOCE-based model

B

Levels 1-6		Levels 7-8		Levels 9-13
EGM08	+	GOCE-based model	+	EGM08

- All computations were carried out using MATLAB

Output

22 new combined models (11 from each methodology)

Validation

- **Geoid heights were obtained from the 22 new combined models (grids) using bilinear interpolation**

- **The validation was conducted using the following equation:**

$$\Delta N = N^{GPS/Lev} - N_{combined\_model} - N_o$$

Statistics are presented in two groups according to the two methodologies (A,B) – next two slides

WL DECOMPOSITION & RECONSTRUCTION

Model (L7-L13)	max [m]	min [m]	mean [m]	rms [m]	std [m]
DIR-R1	0.094	-0.937	-0.405	0.428	±0.139
DIR-R2	0.087	-0.954	-0.411	0.434	±0.140
DIR-R3	0.092	-0.935	-0.406	0.429	±0.138
DIR-R4	0.069	-0.927	-0.409	0.431	±0.134
TIM-R1	0.111	-0.935	-0.405	0.429	±0.142
TIM-R2	0.079	-0.941	-0.413	0.435	±0.136
TIM-R3	0.080	-0.938	-0.410	0.432	±0.135
TIM-R4	0.061	-0.930	-0.416	0.437	±0.133
GOCO01S	0.105	-0.930	-0.402	0.425	±0.139
GOCO02S	0.081	-0.940	-0.409	0.431	±0.136
GOCO03S	0.084	-0.931	-0.408	0.430	±0.136
EGM08	0.074	-0.907	-0.408	0.430	±0.135

WL DECOMPOSITION & RECONSTRUCTION

Model (L7-L8)	max [m]	min [m]	mean [m]	rms [m]	std [m]
DIR-R1	0.100	-0.926	-0.400	0.423	±0.138
DIR-R2	0.098	-0.950	-0.400	0.424	±0.142
DIR-R3	0.115	-0.909	-0.385	0.409	±0.138
DIR-R4	0.070	-0.921	-0.407	0.428	±0.133
TIM-R1	0.143	-0.923	-0.379	0.406	±0.146
TIM-R2	0.083	-0.957	-0.408	0.432	±0.140
TIM-R3	0.084	-0.941	-0.404	0.427	±0.137
TIM-R4	0.071	-0.905	-0.404	0.425	±0.131
GOCO01S	0.134	-0.924	-0.380	0.406	±0.144
GOCO02S	0.086	-0.959	-0.406	0.430	±0.141
GOCO03S	0.093	-0.932	-0.400	0.423	±0.137
EGM08	0.074	-0.907	-0.408	0.430	±0.135

CONCLUSIONS

For the Hellenic area:

- **No improvement was observed in the validation against gravity anomalies when using the combined GGMs.**
- **Slight improvement of the order of 10^{-2} arcsec was found in the validation against deflections of the vertical for the combined models of DIR-R4, TIM-R3, TIM-R4, GOCO03S and ITG-GRACE2010S.**
- **Significant improvement of approx. 2 cm was achieved with the combined models in the validation against GPS/leveling data and when using the R4 GOCE-based models up to approx. degrees 210-220.**
- **The validation against combination models produced using a Wavelet decomposition and reconstruction procedure and by using GOCE-based models for levels 7-8 showed a slight improvement of some millimeters.**

ACKNOWLEDGEMENT

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