GGEO 2008 Symposium

Evaluation of EGM08 using GPS and leveling heights in Greece

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Objective(s)

Evaluation of EGM08 in Greece using data from the recent HEPOS/GPS observation campaign

- GGM testing and accuracy assessment of GPS/geoid-based leveling **over the entire Hellenic mainland** (for the first time)
- Contribution to the Joint IGFS/IAG(comm. 2) WG "Evaluation of Global Earth Gravity Models"
- Quality analysis of the Hellenic vertical datum (HVD)

HEPOS

HEllenic **PO**sitioning **S**ystem

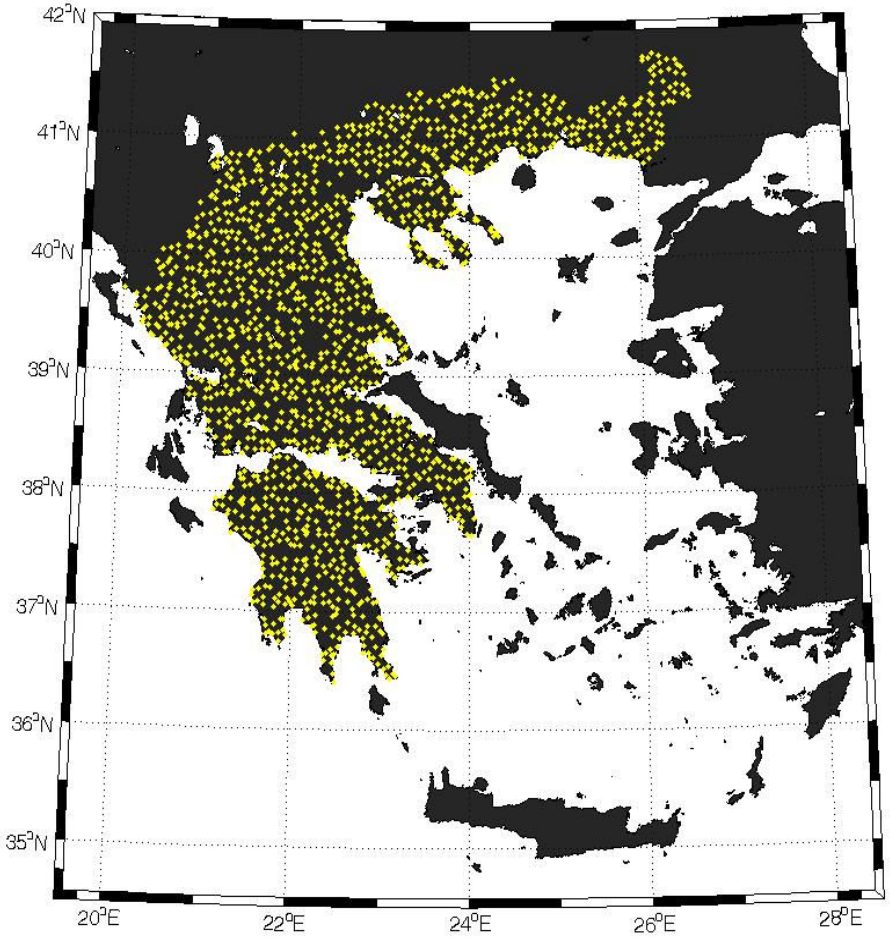
A modern GPS-based positioning service for mapping, surveying, cadastral and other geodetic apps in Greece

- Network of 98 permanent GPS reference stations
  (Trimble NetRS receivers w/ Zephyr geodetic antennas)
- Support for real-time and post-processing positioning applications
  (DGPS, RTK, VRS, FKP, MAC)
- Realization of a new ETRF-based 3D reference frame
  for the Hellenic region
- Part of the Operational Program “Information Society”, co-funded by the EU Regional Development Fund (EDRF) and the Hellenic State
- Responsible agency: Ktimatologio S.A.

National GPS campaign

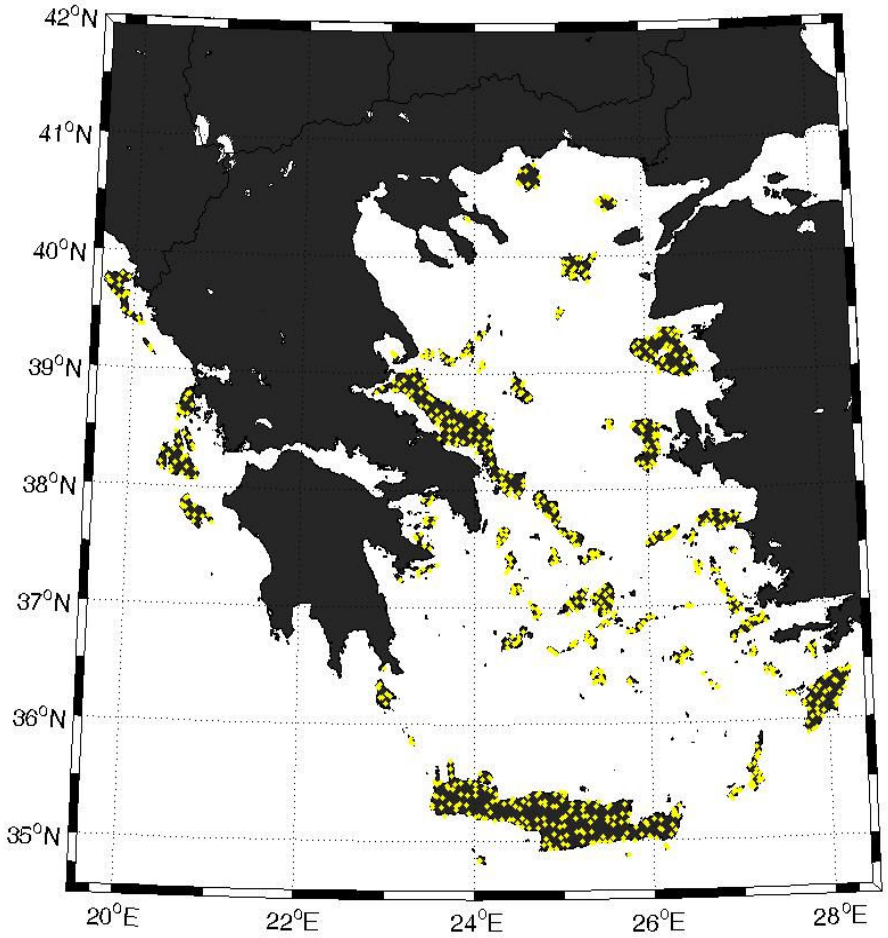
- Establish CTMs between the HEPOS reference frame and the Hellenic geodetic reference frame of 1987
- **2470 points** (part of the Hellenic triangulation geodetic network)
- Time period: March 2007 – September 2007
- 12 dual-frequency Trimble 5700/5800 GPS receivers
- 15-sec data sampling rate, elevation cut-off angle 15°
- 33 reference stations (24 hrs), 2437 rover stations (1-3 hrs), multiple baseline solutions (< 40 km) using EUREF/EPN ties and IGS precise orbits
- Accuracy (1σ level): **1-4 cm (horizontal)** and **2-5 cm (vertical)**

Greek GPS/leveling BMs



- **1542 points** (mainland)
- X, Y, Z (ITRF00, t=2007.236)
  from HEPOS/GPS campaign
- Helmert-type ortho heights
  from Hellenic Military Geographic Service
- Stations with identified blunders or other suspected problems have been removed

Greek GPS/leveling BMs



- **802 points** (islands)
- X, Y, Z (ITRF00, t=2007.236)
  from HEPOS/GPS campaign
- Helmert-type ortho heights
  from Hellenic Military Geographic Service
- To be used in forthcoming studies for the assessment of vertical datum inconsistencies among the Greek islands and the mainland region

‘Combined’ GGMs

$$\{\overline{C}_{nm}, \overline{S}_{nm}\}_{n \geq 2}$$

Models	n_{max}	Data	Reference
EGM08	2190	S(GRACE), G, A	Pavlis et al. (2008)
EIGEN-GL04C	360	S(GRACE, Lageos), G, A	Förste et al. (2006)
EIGEN-CG03C*	360	S(CHAMP, GRACE), G, A	Förste et al. (2005)
EIGEN-CG01C*	360	S(CHAMP, GRACE), G, A	Reigber et al. (2006)
GGM02C	200	S(GRACE), G, A	Tapley et al. (2005)
EGM96	360	S(EGM96S), G, A	Lemoine et al. (1998)

(*) include first-degree SHCs

Computation of N^{GGM}

Geoid heights computed at GPS/Lev BMs, as follows:

$$N = \zeta + \frac{\Delta g^{FA} - 0.1119H}{\bar{\gamma}} H + N_o$$

height anomaly ζ

free-air gravity anomaly Δg^{FA}

} SHS, $\{\bar{C}_{nm}, \bar{S}_{nm}\}\ n \geq 2$

GRS80 normal gravity field

Zero-Tide system

zero-degree term $$N_o = \frac{GM - GM_o}{R\gamma} - \frac{W_o - U_o}{\gamma}$$

$W_o = 62636856.00\ \mathrm{m^2 s^{-2}}$ (IERS 2003)

$GM = 398600.4415 \times 10^9\ \mathrm{m^3 s^{-2}}$

GRS80 normal field parameters (GM_o, U_o, R, γ)

} N_o = -0.442 m

Computation of N^{GPS}

Geoid heights computed at GPS/Lev BMs, as follows:

$$N^{GPS} = h - H$$

wrt ITRF2000

- Reference ellipsoid for GPS heights: **GRS80**
- **No low-pass filtering** has been applied to the N^{GPS} heights
  (i.e. GGM omission errors will be reflected in our evaluation results)
- Accuracy of H (or even δH) is not realistically known
- Unknown W_o value associated with the HVD
- Accuracy of h ranges between **2 – 5 cm** (1σ level)

Statistics for h, H, N

Heights	Max	Min	μ	σ
h	2562.753	24.950	545.676	442.418
H	2518.889	0.088	510.084	442.077
$N^{GPS} = h - H$	43.864	19.481	35.592	5.758
N (EGM08)	44.374	19.663	**35.968**	5.800
N (EIGEN-GL04C)	44.104	19.303	**35.874**	5.878
N (EIGEN-CG03C)	44.049	19.257	**35.861**	5.867
N (EIGEN-CG01C)	44.108	19.663	**35.823**	5.873
N (GGM02C)	44.034	19.771	**35.905**	5.780
N (EGM96)	44.007	19.687	**36.037**	5.753

* values in m

The full spectral range of each GGM is used

Note: EGM08 geoid shows a mean offset of 6 – 15 cm relative to other GGMs

Pointwise evaluation

Raw residuals $h_i - H_i - N_i = v_i$

Residuals after bias fit $h_i - H_i - N_i = \boldsymbol{\mu} + v_i$

Residuals after bias/tilt fit

$$h_i - H_i - N_i = \boldsymbol{\mu} + \mathbf{a}(\varphi_i - \varphi_o) + \mathbf{b}(\lambda_i - \lambda_o)\cos\varphi_i + v_i$$

Residuals after '3D-shift/scale' fit

$$h_i - H_i - N_i = \boldsymbol{\mu} + \mathbf{a}\cos\varphi_i\cos\lambda_i + \mathbf{b}\cos\varphi_i\sin\lambda_i + \mathbf{c}\sin\varphi_i + v_i$$

* No VCE-based analysis was applied due to lack of a reliable CV matrix for the orthometric heights ($\boldsymbol{C}_H$)

Statistics of h-H-N

After bias fit

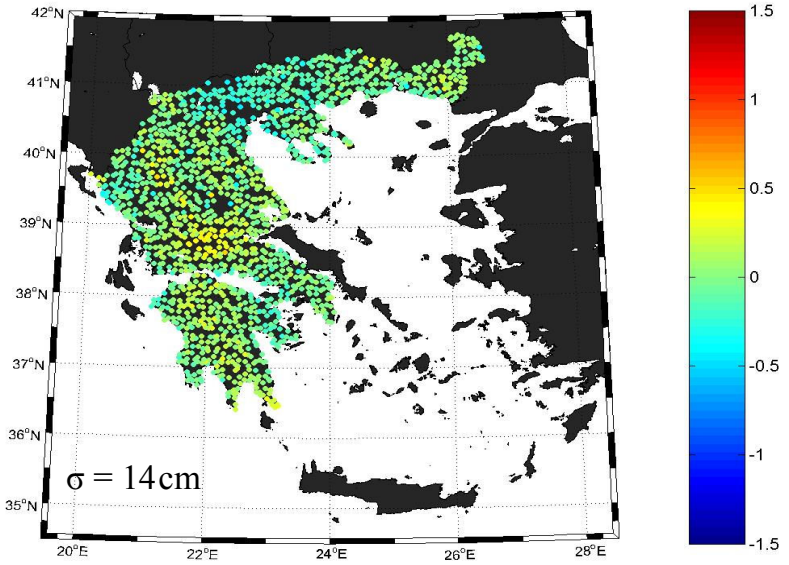
Models	Max	Min	σ	Bias
EGM08 (n_{max}=2190)	**0.542**	**-0.437**	**0.142**	-0.377
EGM08 (n_{max}=360)	1.476	-1.287	0.370	-0.334
EIGEN-GL04C (n_{max}=360)	1.773	-1.174	0.453	-0.283
EIGEN-CG03C (n_{max}=360)	1.484	-1.173	0.453	-0.270
EIGEN-CG01C (n_{max}=360)	1.571	-1.135	0.492	-0.231
GGM02C (n_{max}=200)	2.112	-1.472	0.551	-0.313
EGM96 (n_{max}=360)	1.577	-1.063	0.423	-0.446

* values in m

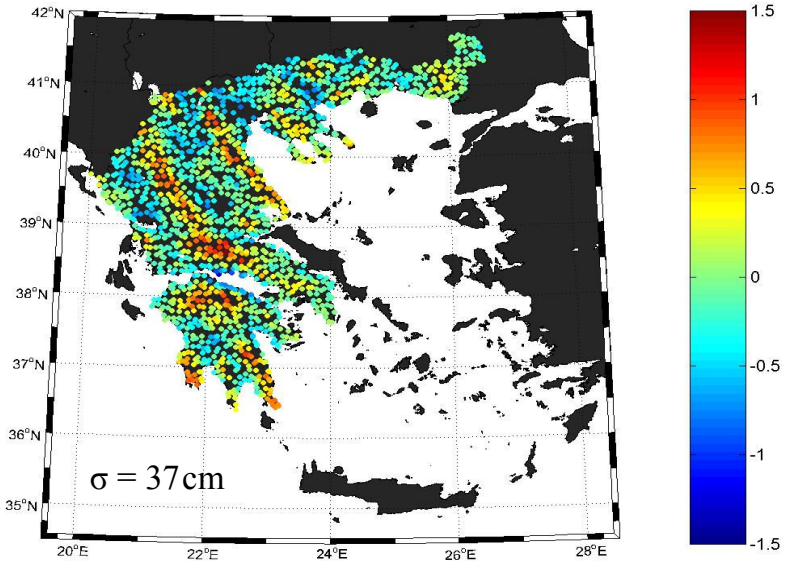
Improvement by a factor of > 3 over all existing combined GGMs!

Scatter plots for h-H-N

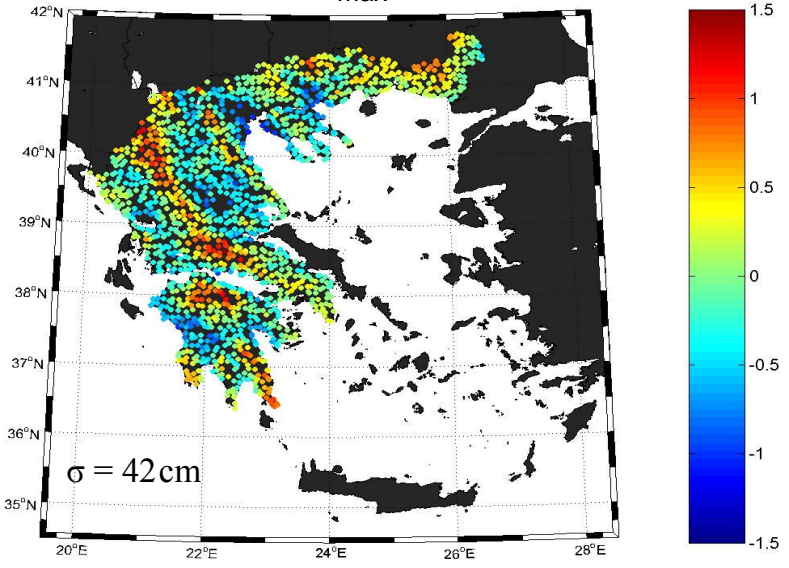
EGM08 (n_{max}=2190)



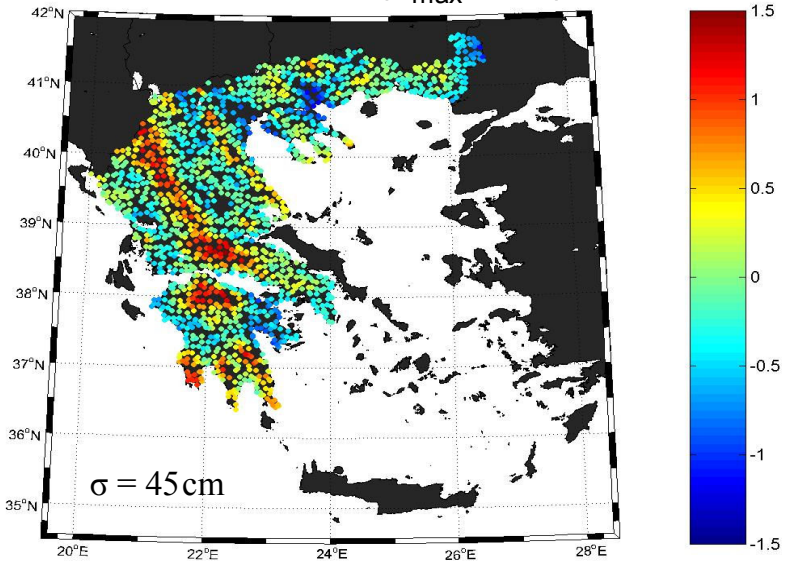
EGM08 (n_{max}=360)



EGM96 (n_{max}=360)

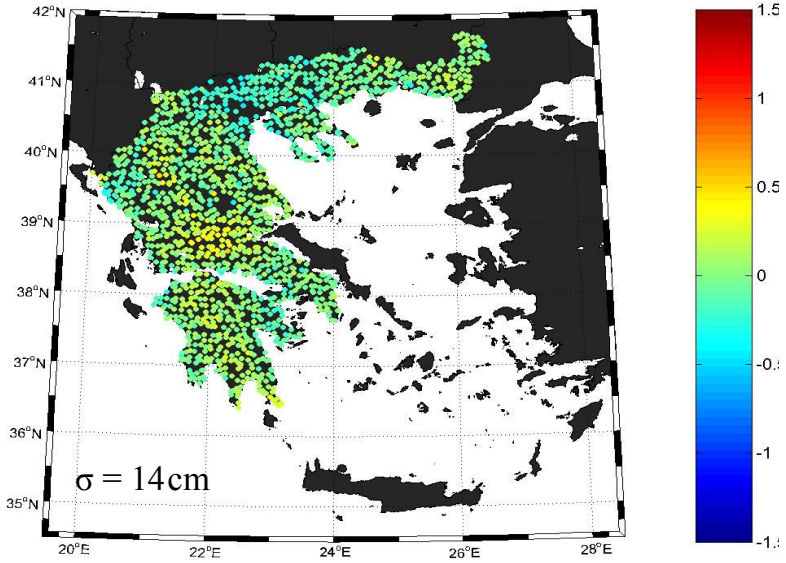


EIGEN-GL04C (n_{max}=360)

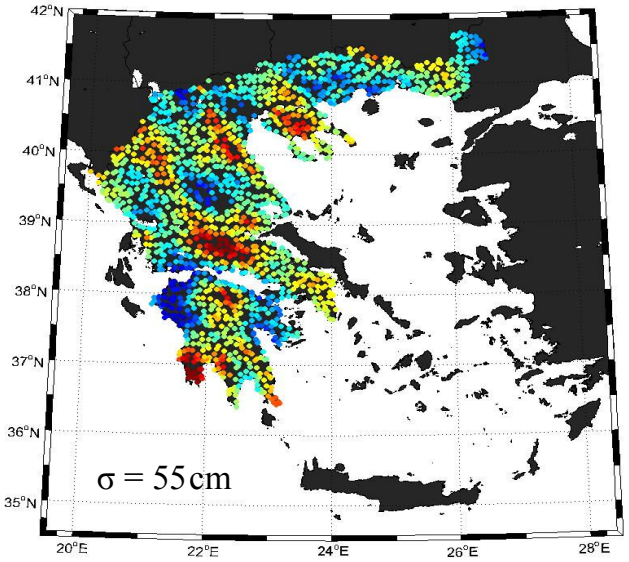


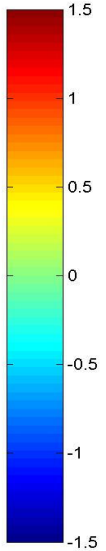
Scatter plots for h-H-N

EGM08 (n_{max}=2190)

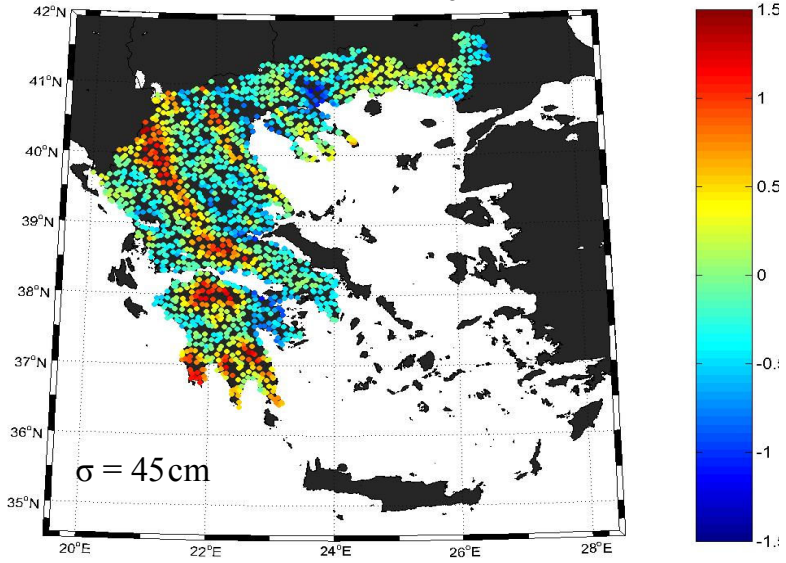


GGM02C (n_{max}=200)

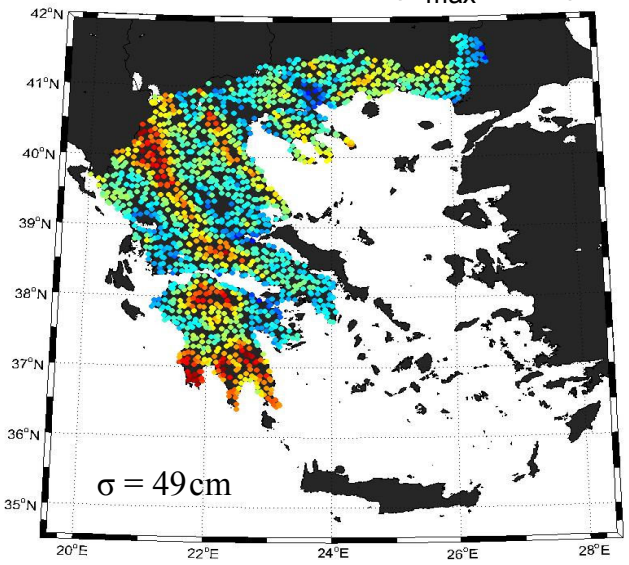


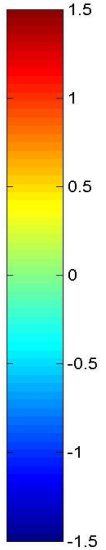


EIGEN-CG03C (n_{max}=360)



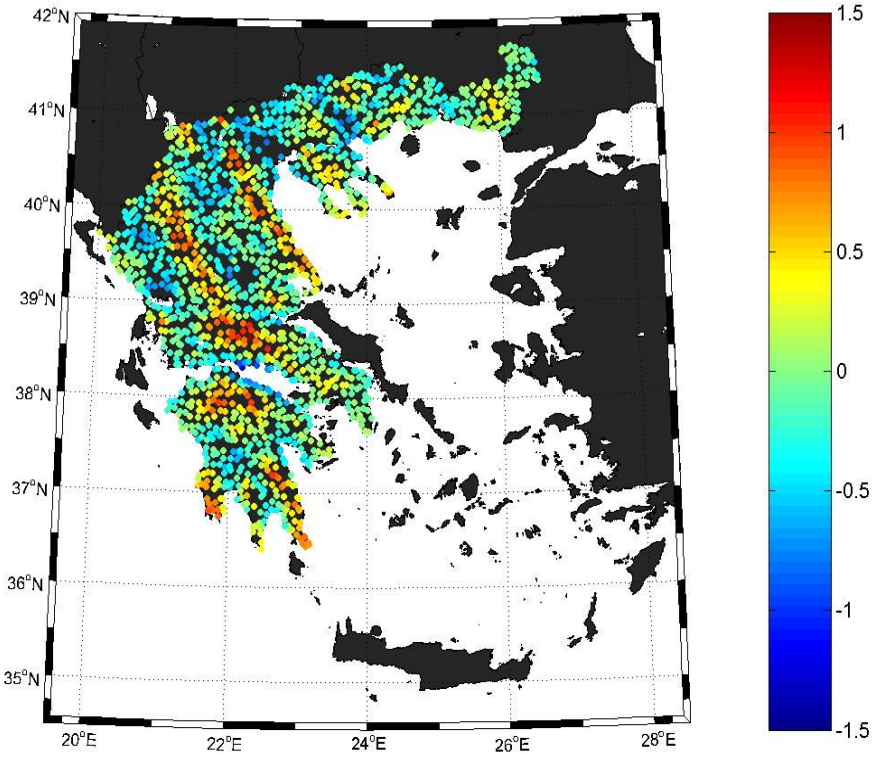
EIGEN-CG01C (n_{max}=360)



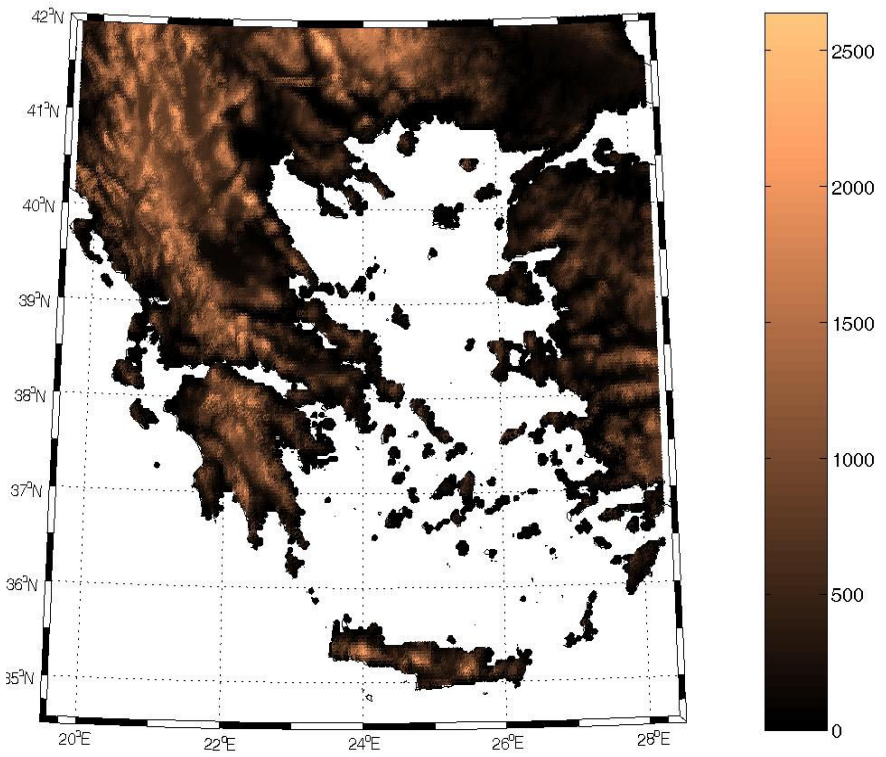


Residuals h-H-N vs. Topo heights

(after bias fit)



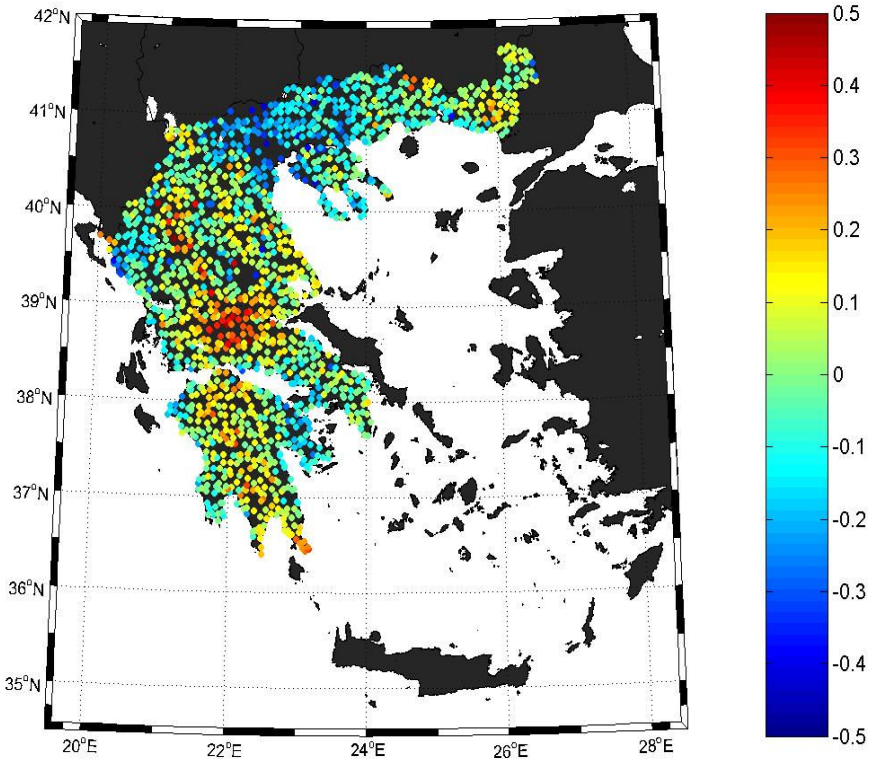
EGM08 (n_{max}=360)



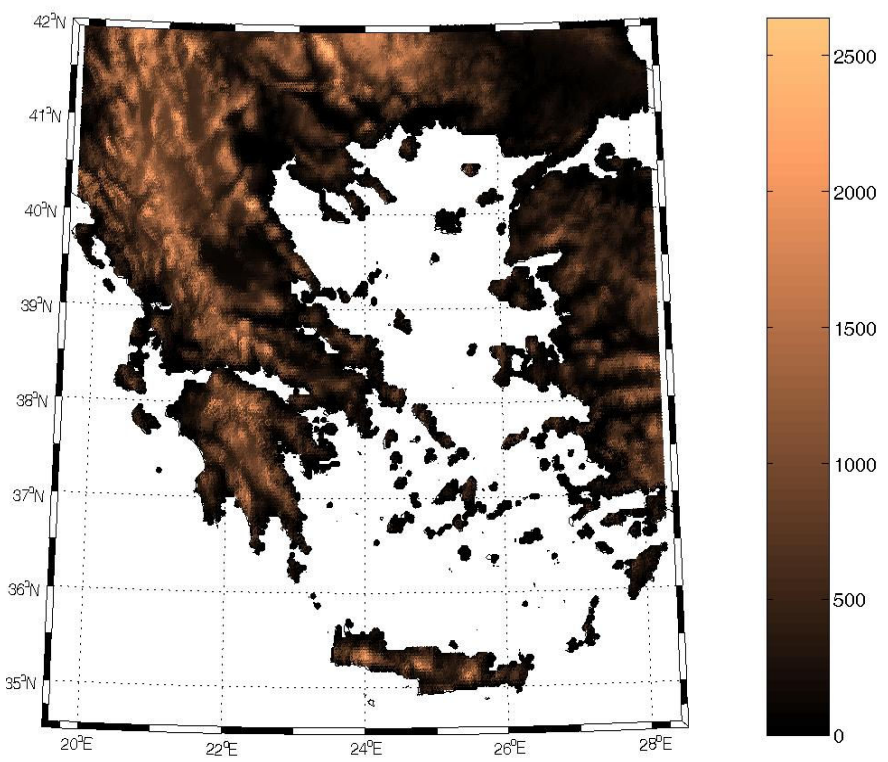
ETOPO2 DTM

Residuals h-H-N vs. Topo heights

(after bias fit)



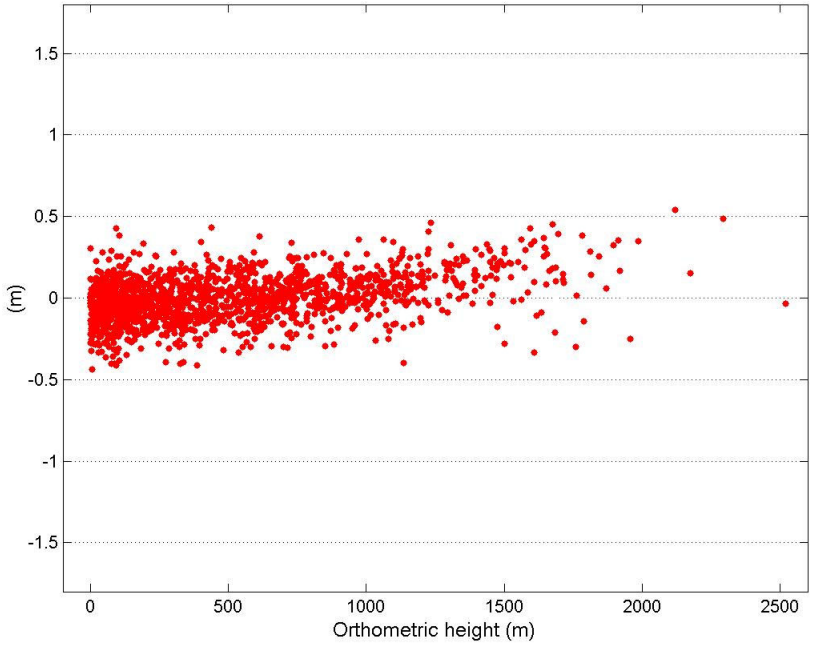
EGM08 (n_{max}=2190)



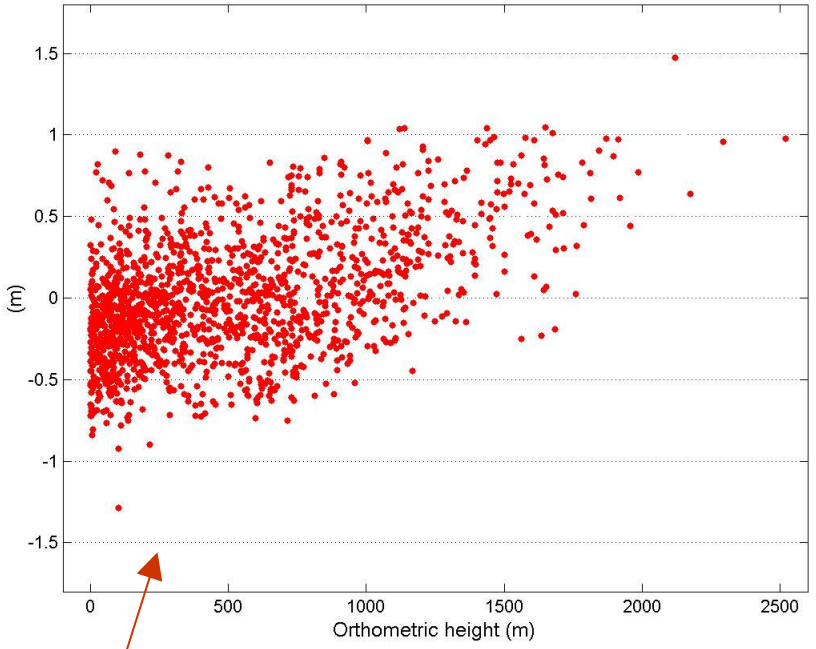
ETOPO2 DTM

Height-dependent variations of h-H-N

(after bias fit)



EGM08 (n_{max}=2190)

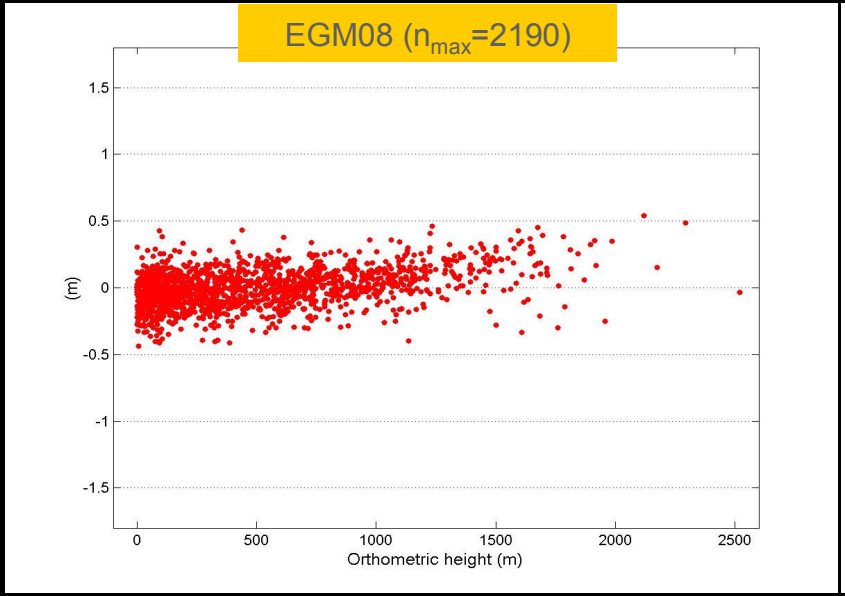


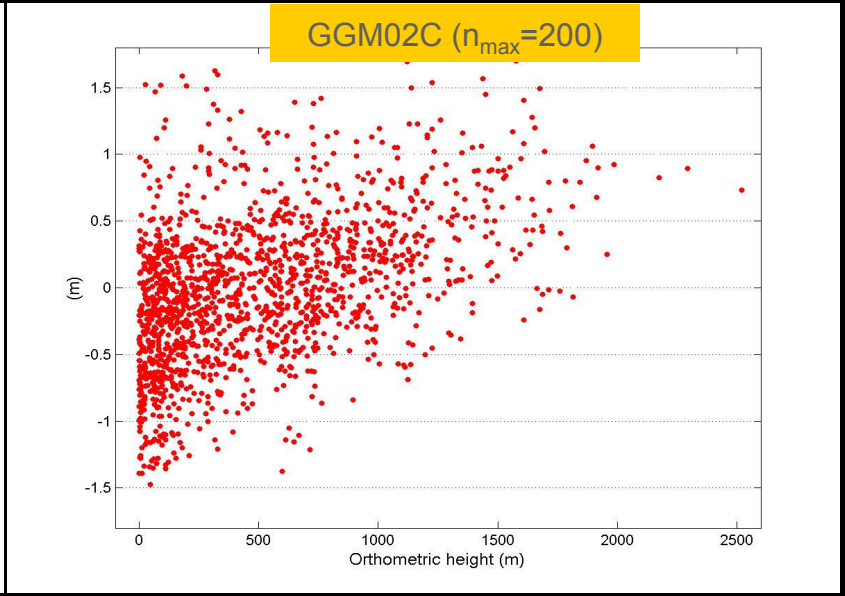
EGM08 (n_{max}=360)

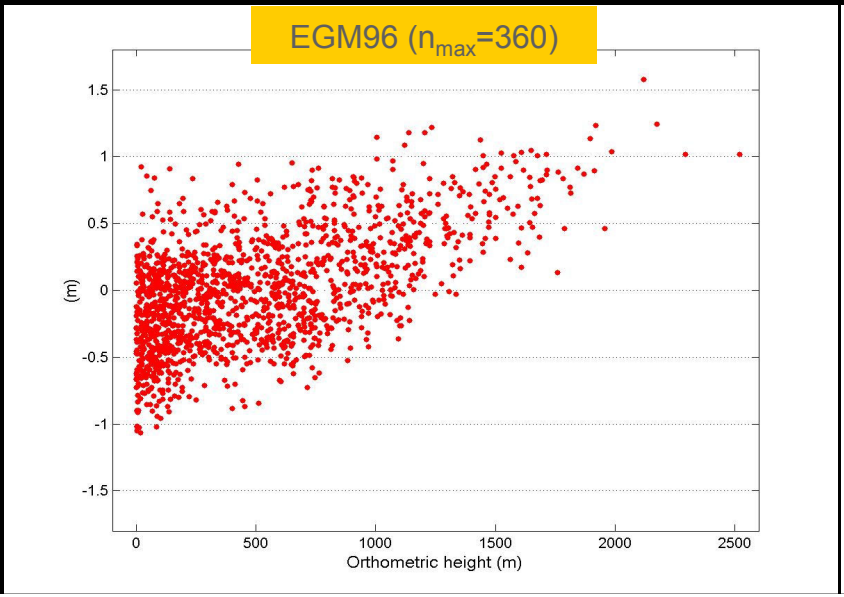
(*) existence of *height-dependent bias* in the residuals h-H-N

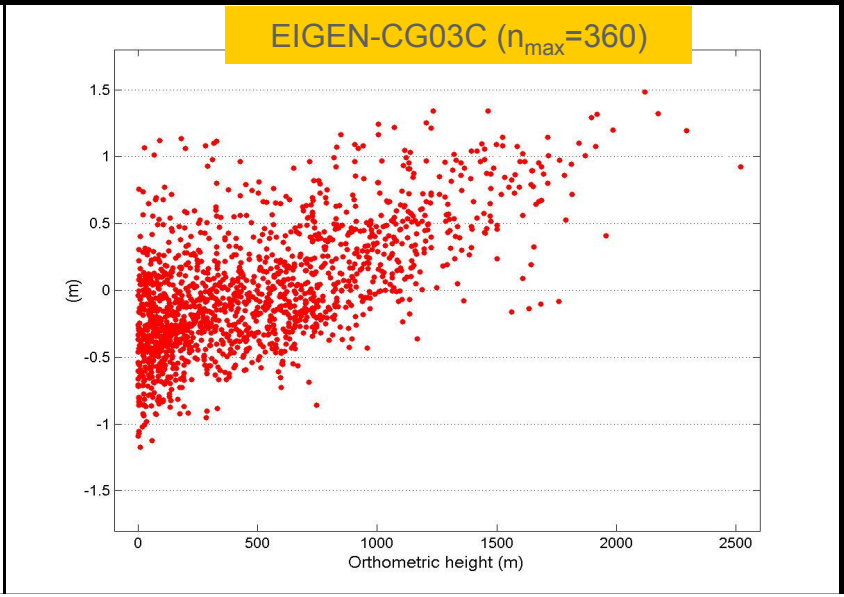
Height-dependent variations of h-H-N

(after bias fit)



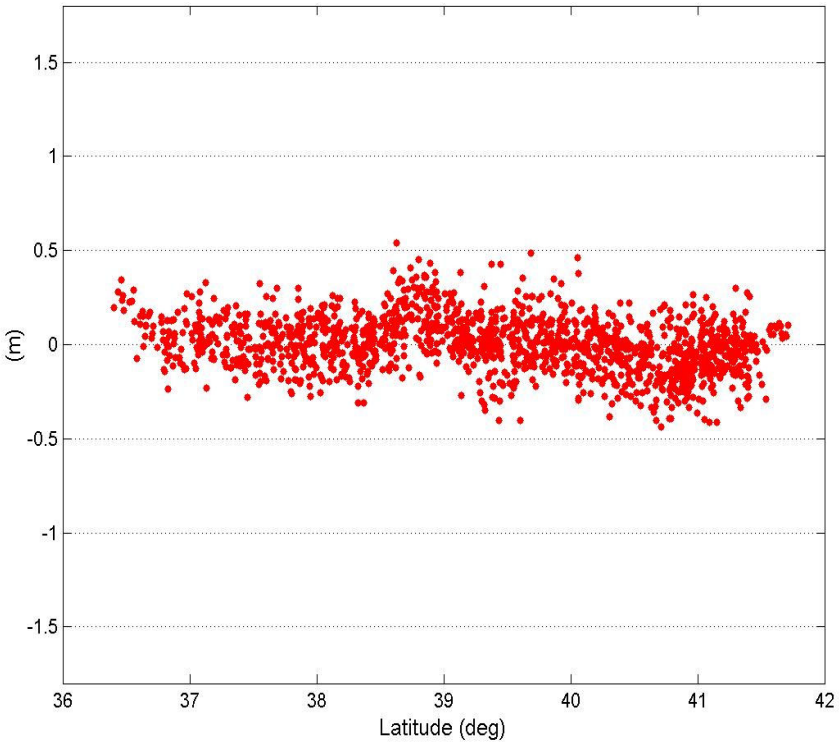


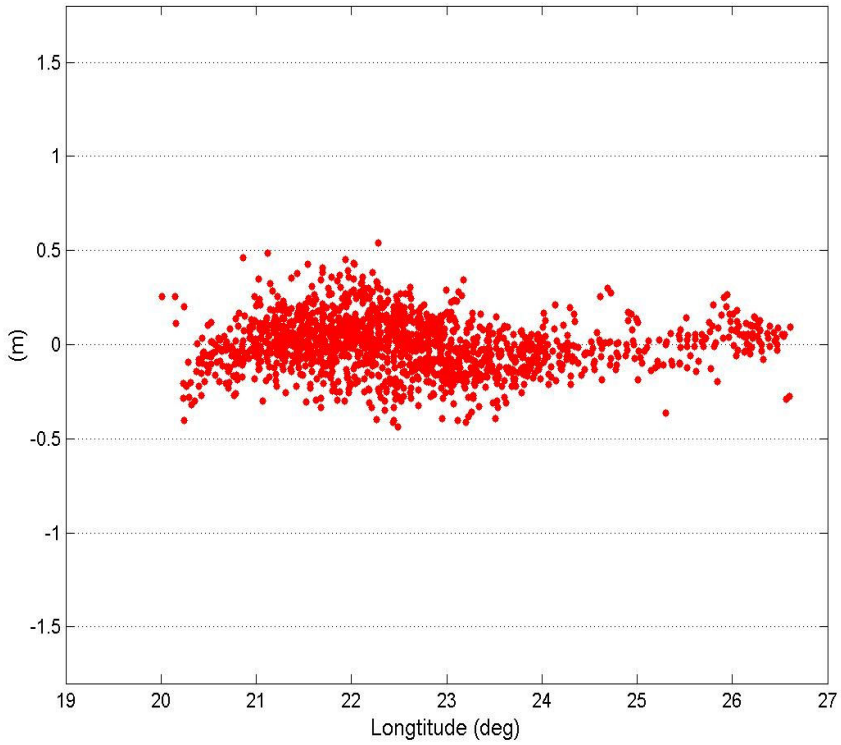




Lat/Lon-dependent variations of h-H-N

(after bias fit)



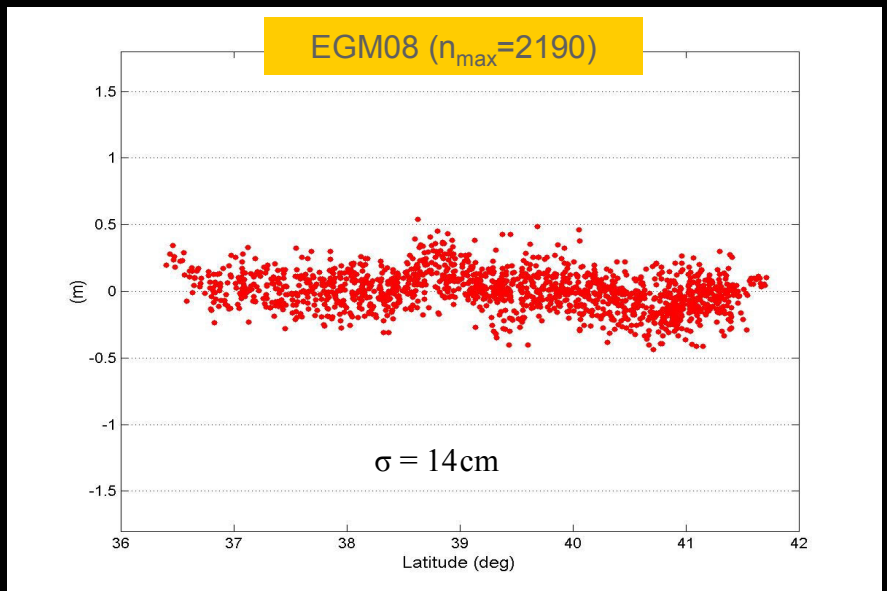


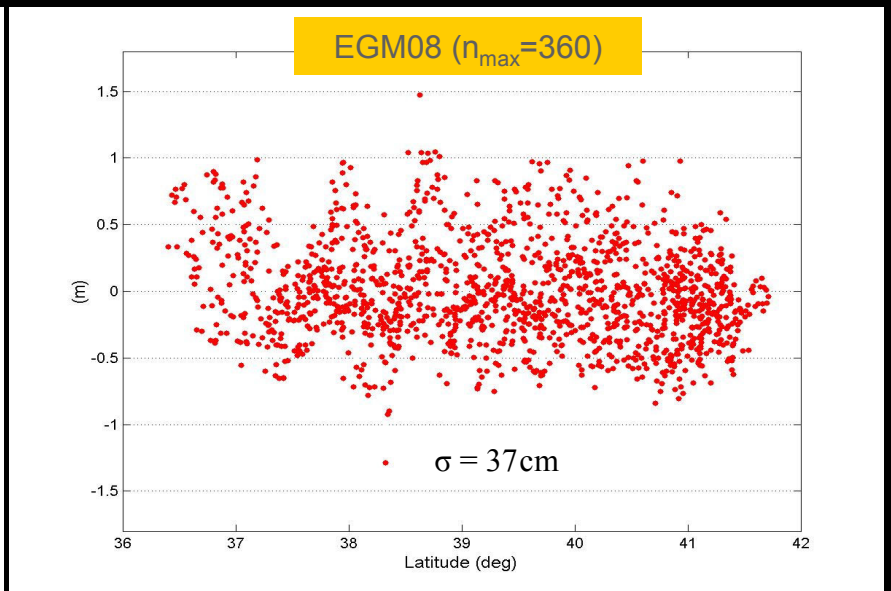
EGM08 (n_{max}=2190)

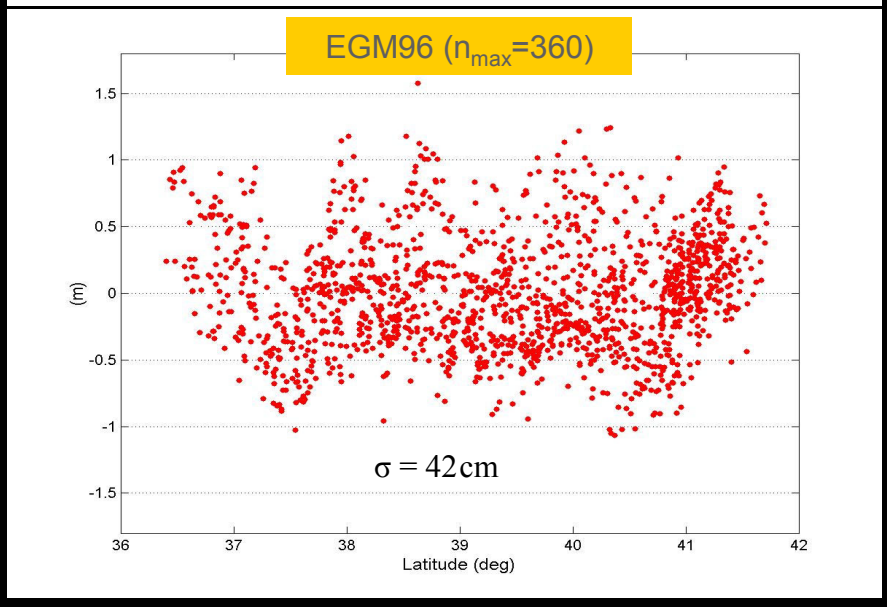
(*) No apparent N/S or W/E tilts in the residuals h-H-N at national scale

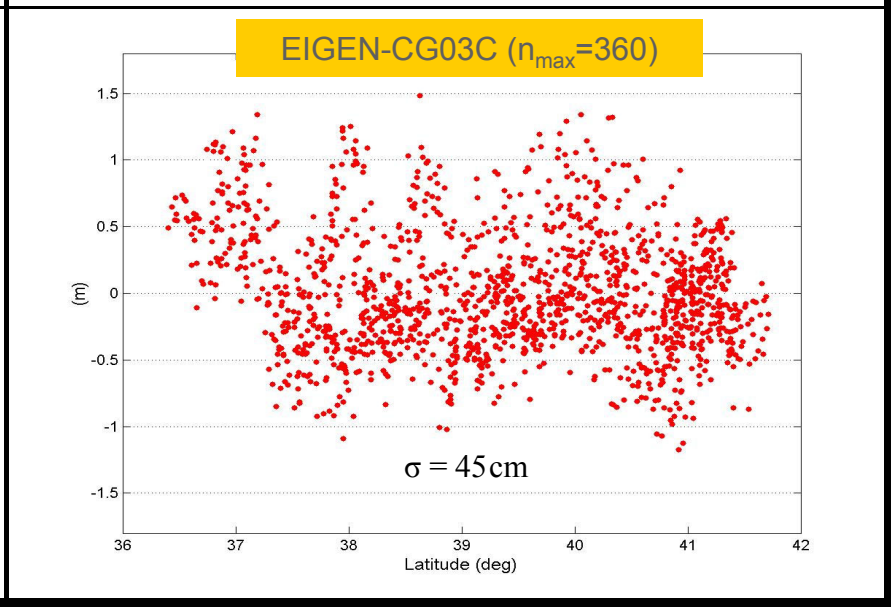
Lat-dependent variations of h-H-N

(after bias fit)



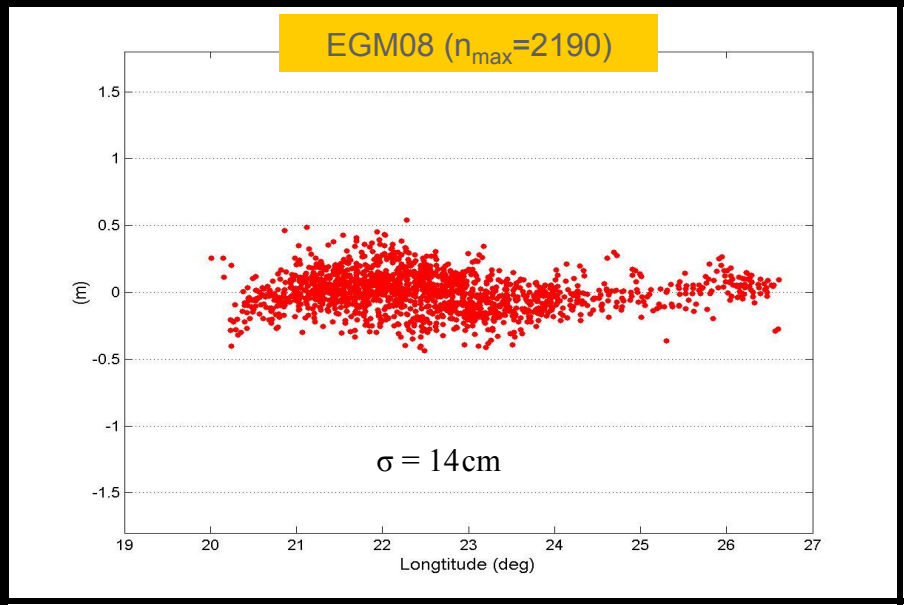


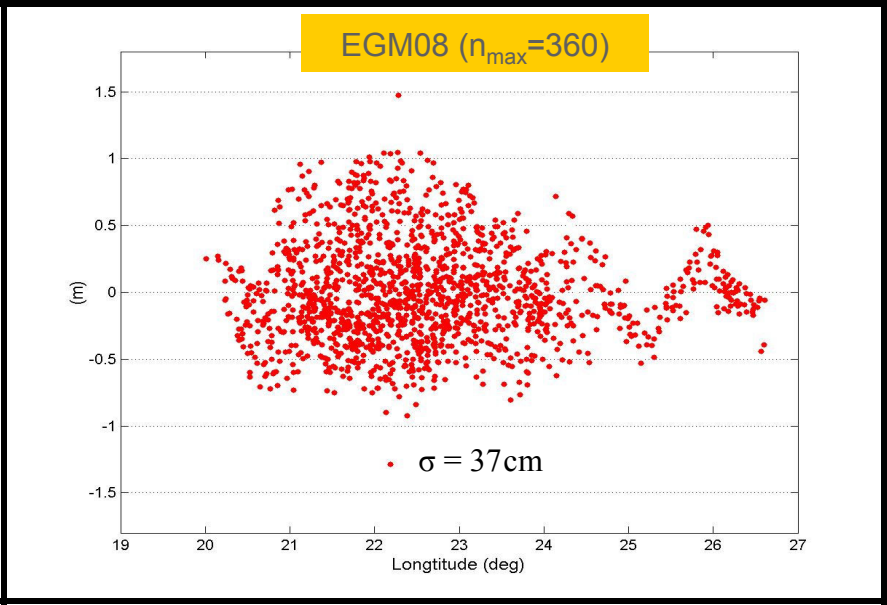


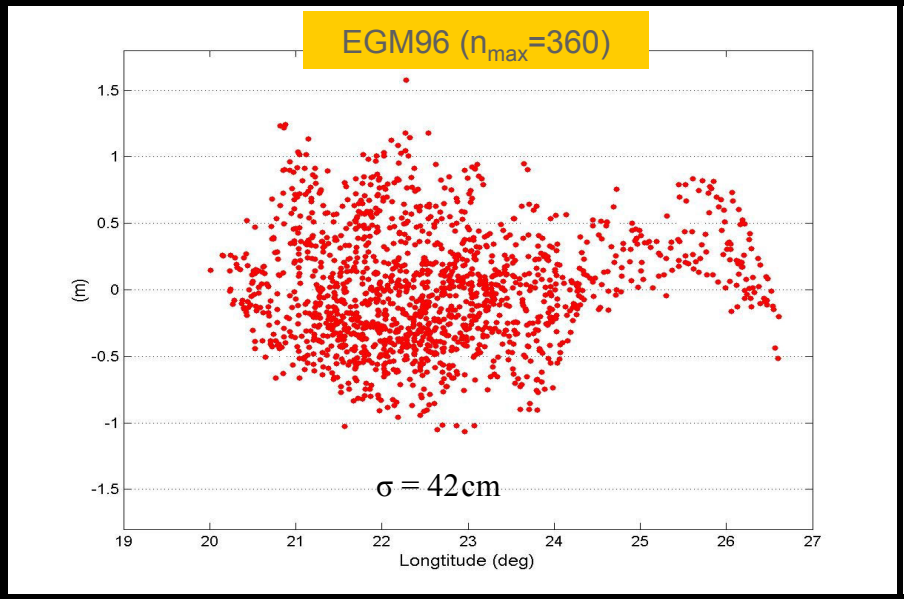


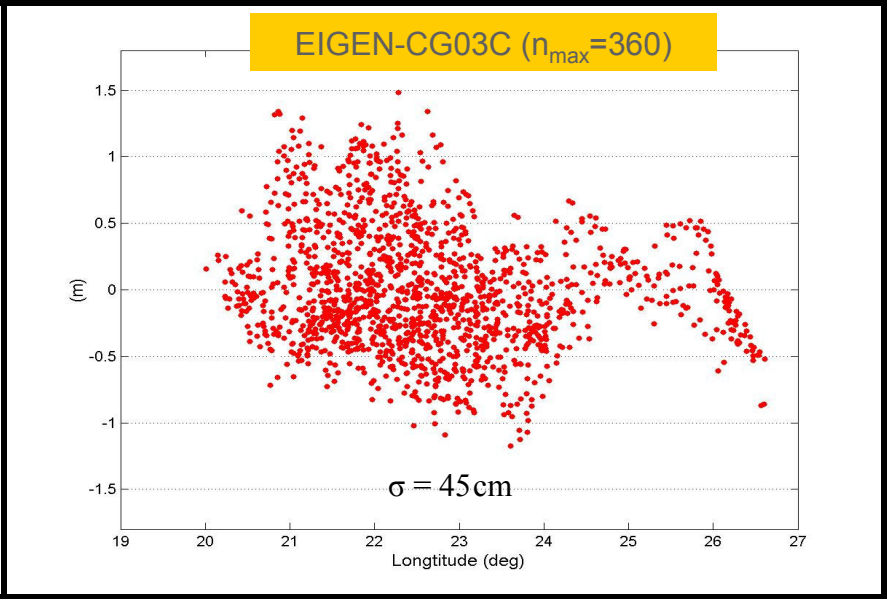
Lon-dependent variations of h-H-N

(after bias fit)









Baseline evaluation

$$\Delta N_{ij}^{GPS} = (h_j - H_j) - (h_i - H_i)$$

$$\Delta N_{ij}^{GGM} = N_j^{GGM} - N_i^{GGM}$$

$$\Delta N_{ij}^{GPS} - \Delta N_{ij}^{GGM} = v_{ij}$$

Residuals computed **after** a pointwise bias/tilt fit has been applied to the GGM-based geoid heights

Forming all possible baselines in the network of 1542 BMs

Statistical assessment for different baseline-length classes

Indicative of the performance of EGM08 in GPS/leveling projects over mainland Greece

Statistics of $\Delta N^{GPS} - \Delta N^{GGM}$

Models	Max	Min	σ	Bias
EGM08 (n_{max}=2190)	**0.643**	**-0.474**	**0.111**	0.006
EGM08 (n_{max}=360)	0.648	-0.534	0.154	0.003
EIGEN-GL04C (n_{max}=360)	0.649	-0.542	0.155	0.005
EIGEN-CG03C (n_{max}=360)	0.643	-0.540	0.155	0.005
EIGEN-CG01C (n_{max}=360)	0.640	-0.536	0.156	0.005
GGM02C (n_{max}=200)	0.685	-0.571	0.162	0.003
EGM96 (n_{max}=360)	0.643	-0.553	0.154	0.005

* values in m

for baselines **< 5 km** number of baselines: 289

avg length: 3.87 km

Statistics of $\Delta N^{GPS} - \Delta N^{GGM}$

Improvement by a factor of 2 !

Models	Max	Min	σ	Bias
EGM08 (n_{max}=2190)	**0.465**	**-0.629**	**0.125**	0.001
EGM08 (n_{max}=360)	1.022	-1.044	0.248	-0.004
EIGEN-GL04C (n_{max}=360)	0.983	-0.988	0.251	-0.000
EIGEN-CG03C (n_{max}=360)	0.971	-1.026	0.251	-0.001
EIGEN-CG01C (n_{max}=360)	0.976	-1.039	0.252	-0.002
GGM02C (n_{max}=200)	0.967	-0.991	0.264	0.002
EGM96 (n_{max}=360)	0.963	-1.002	0.251	0.003

* values in m

for baselines **5 – 10 km** number of baselines: 2119

avg length: 7.87 km

Statistics of $\Delta N^{GPS} - \Delta N^{GGM}$

Improvement by a factor of >3 !

Models	Max	Min	σ	Bias
EGM08 (n_{max}=2190)	**0.859**	**-0.781**	**0.164**	-0.001
EGM08 (n_{max}=360)	2.778	-2.417	0.514	-0.012
EIGEN-GL04C (n_{max}=360)	2.480	-2.430	0.552	-0.019
EIGEN-CG03C (n_{max}=360)	2.335	-2.488	0.550	-0.021
EIGEN-CG01C (n_{max}=360)	2.335	-2.445	0.555	-0.021
GGM02C (n_{max}=200)	3.221	-2.760	0.627	-0.012
EGM96 (n_{max}=360)	2.532	-2.393	0.542	-0.013

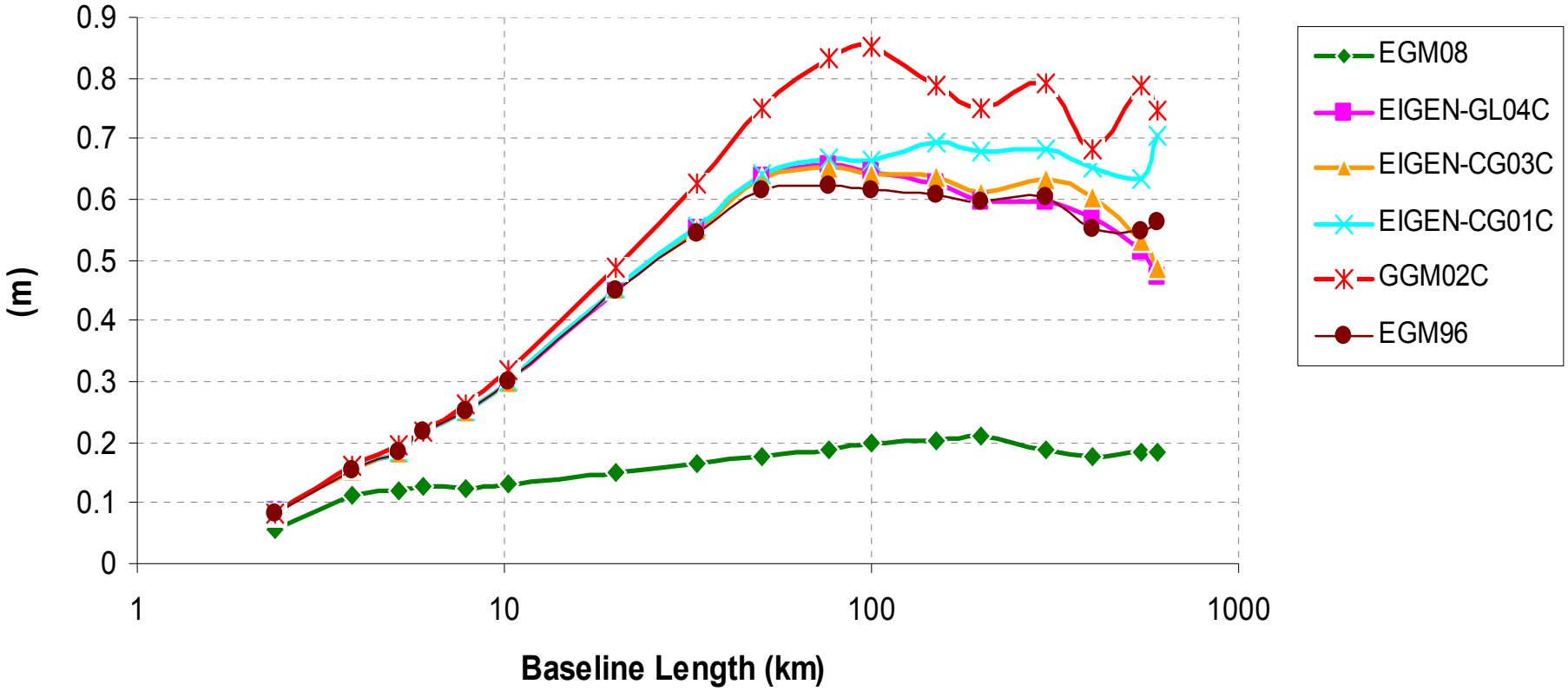
* values in m

for baselines **10 – 50 km** number of baselines: 56,575

avg length: 33.62 km

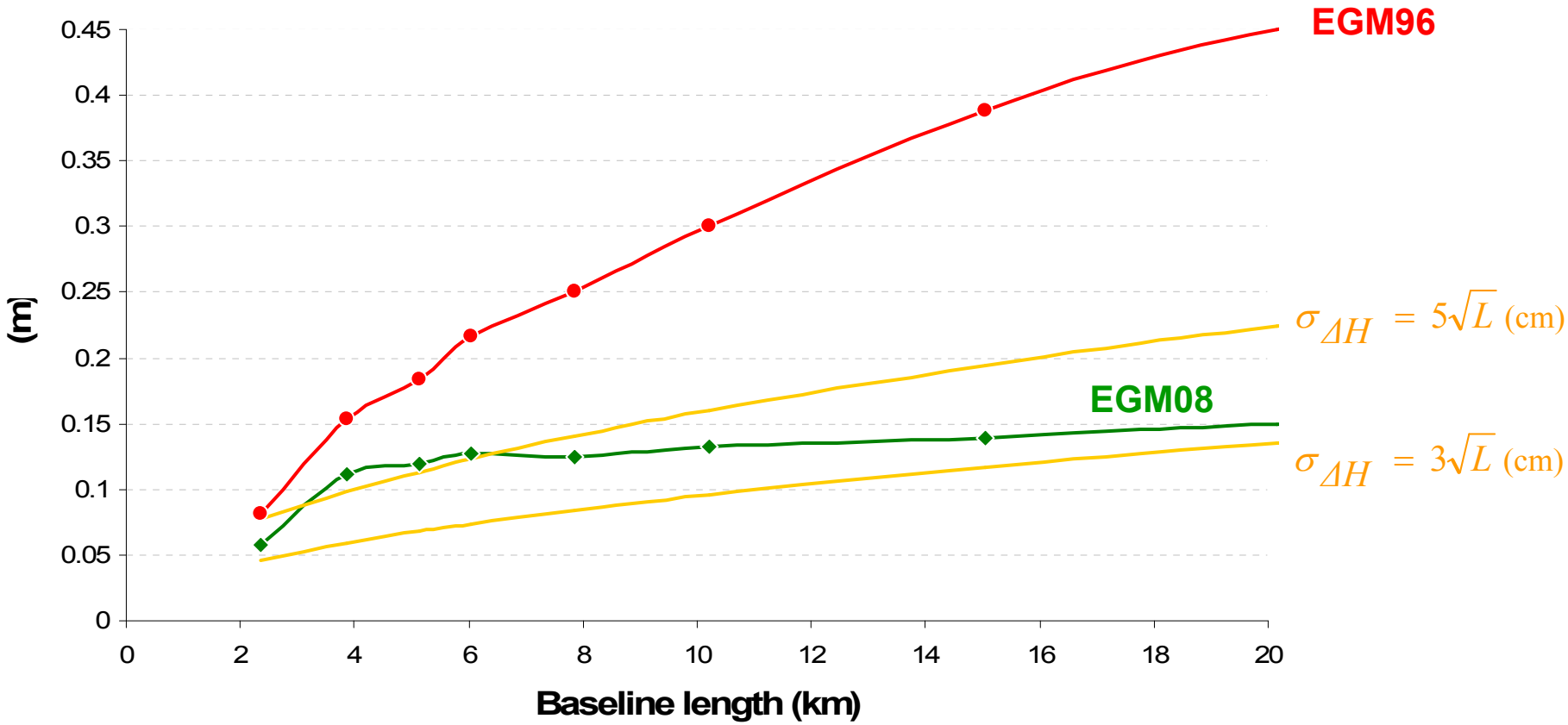
Baseline evaluation (summary)

Std values for $\Delta N_{ij}^{GPS} - \Delta N_{ij}^{GGM}$



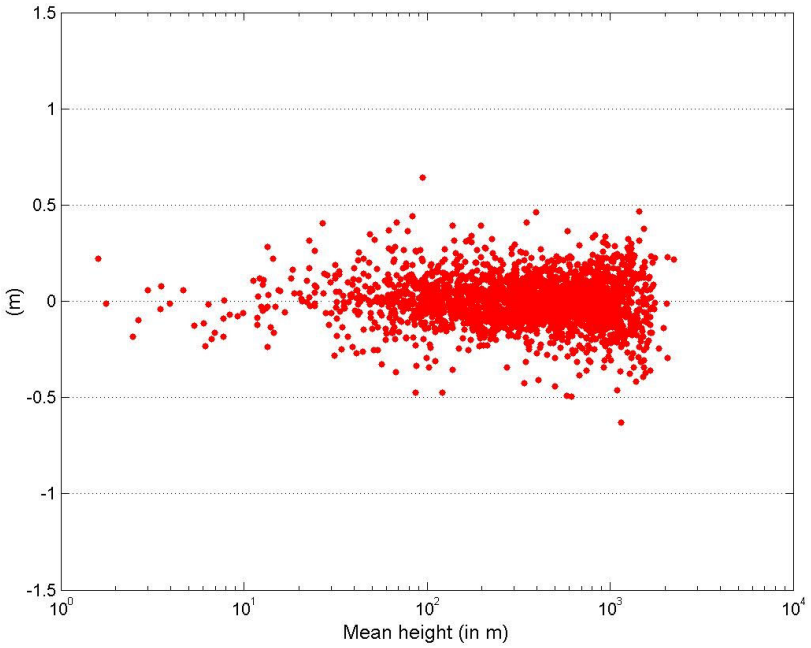
Feasible for GPS/leveling ?

Std values for $\Delta N_{ij}^{GPS} - \Delta N_{ij}^{GGM}$



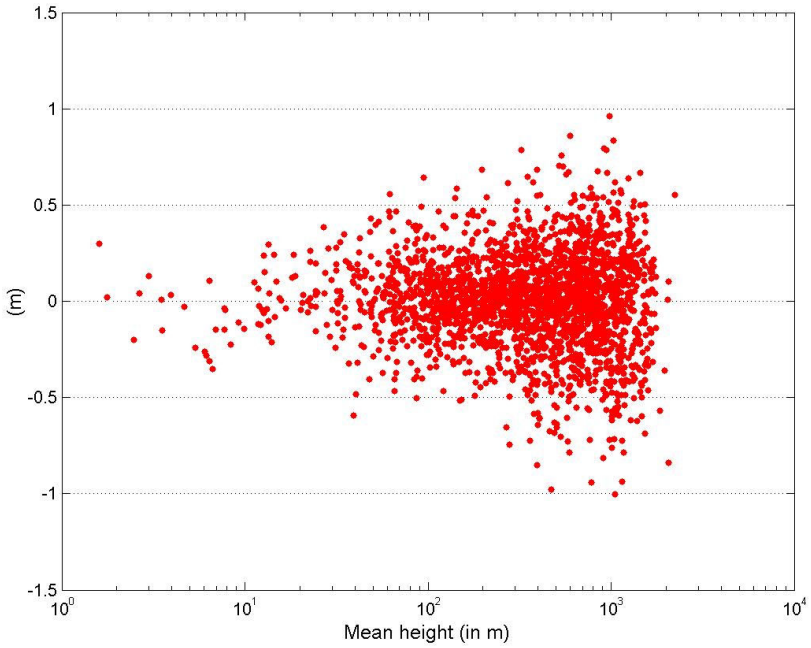
Height-dependent variations of ΔN^{GPS}-ΔN^{GGM}

EGM08 (n_{max}=2190)



σ = 12 cm

EGM96 (n_{max}=360)



σ = 24 cm

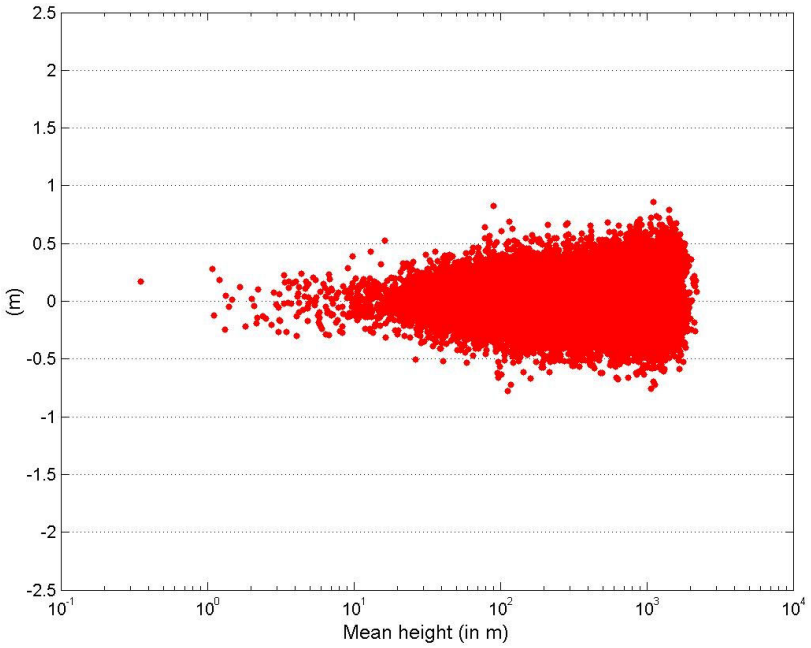
for baselines < 10 km

avg length: 7.39 km

number of baselines: 2408

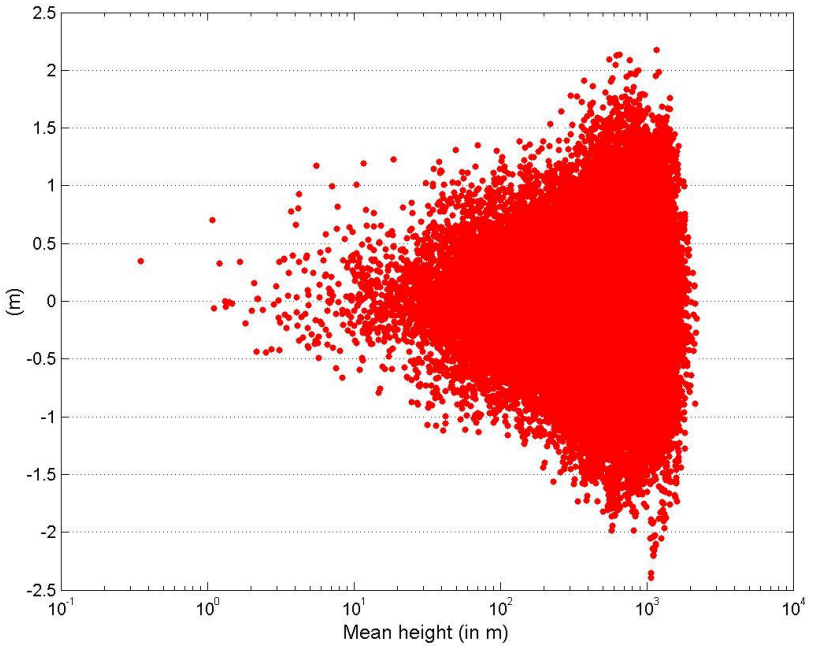
Height-dependent variations of ΔN^{GPS}-ΔN^{GGM}

EGM08 (n_{max}=2190)



σ = 16 cm

EGM96 (n_{max}=360)



σ = 54 cm

for baselines 10 - 50 km

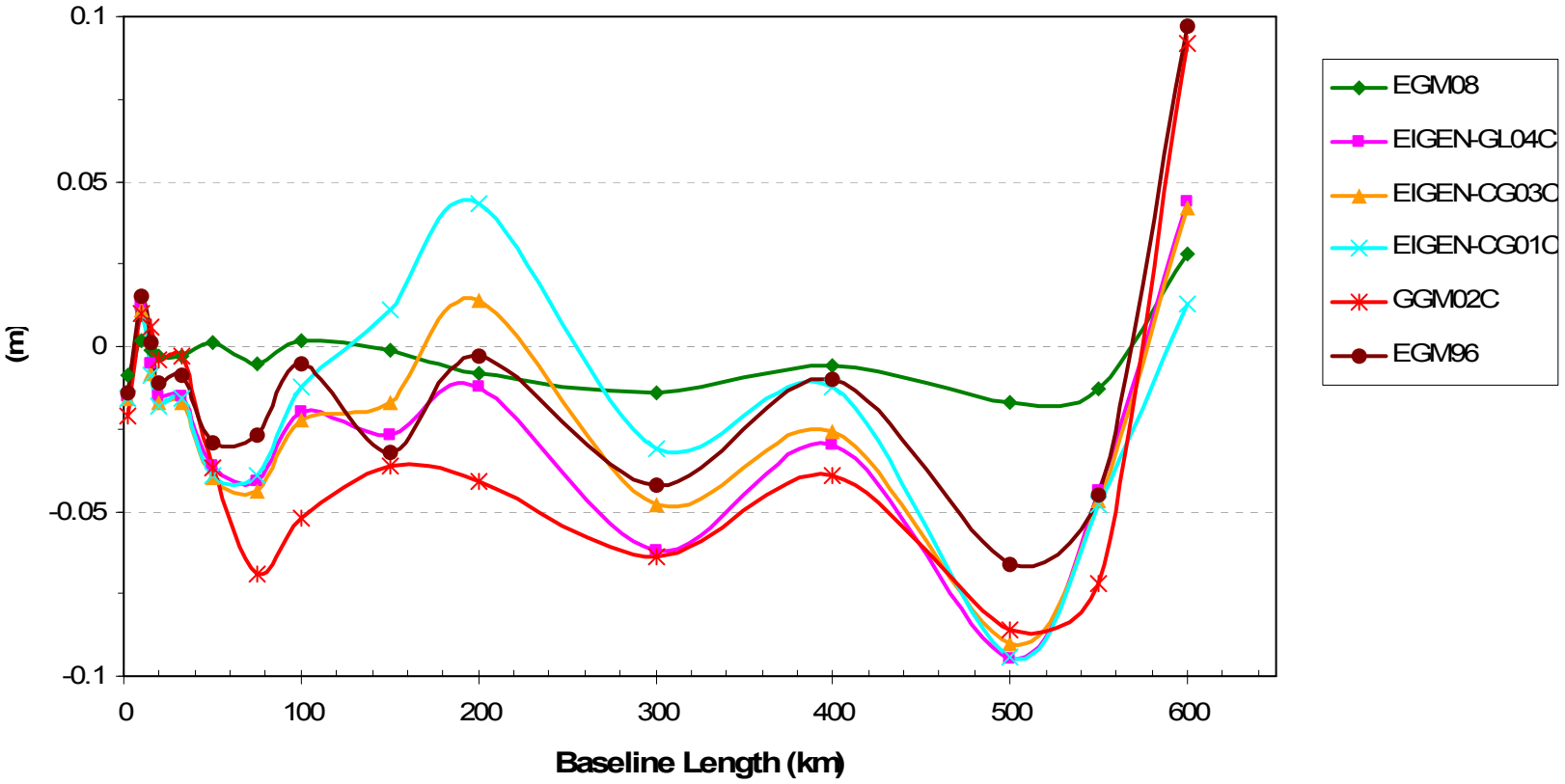
avg length: 33.62 km

number of baselines: 56,575

Baseline evaluation (summary)

Mean values for $\Delta N_{ij}^{GPS} - \Delta N_{ij}^{GGM}$

'Scaling' errors (?)



Conclusions

- EGM08 shows a **remarkable improvement** in the agreement level among GPS, orthometric and geoid heights over the Greek mainland
- Our tests indicate the presence of **6-15 cm systematic differences** in the geoid realization over Greece (as obtained from different combined GGMs)
- 'Corrector surface modeling' for GPS/leveling apps would require an *H-dependent* parametric model
- Complete the EGM08 assessment over Greek islands
- Quality analysis in the HVD

Thanks for your attention !

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