



# Spectral characteristics of the Hellenic vertical network - Validation over Central and Northern Greece using GOCE/GRACE global geopotential models

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## Outline

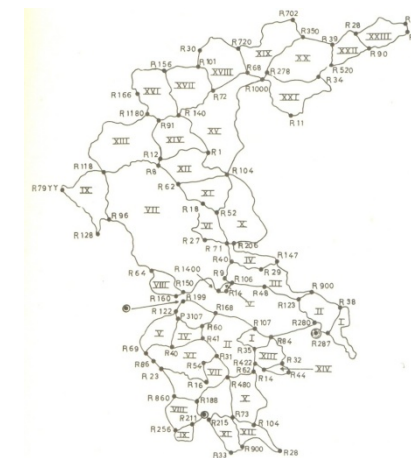
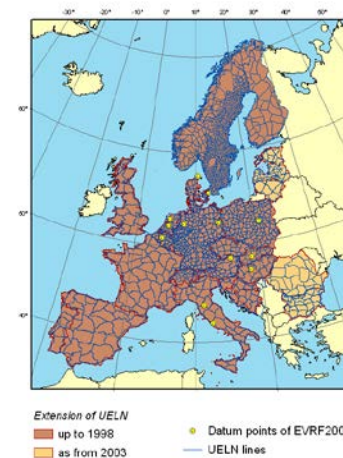
- Description of the E.LE.V.A.T.I.ON project
- Validation methodology
- Test areas and data description
- Results
- Conclusions and future plans





## E.LE.V.A.T.I.ON Project

- **E**valuation of the **He**l**l**enic **V**ertical network in the **fr**ame of the European **S**ys**T**ems and **C**ontrol **N**etworks **I**nterconnect**ON** – Application in the areas of Attica and Thessaloniki
- TEI of Athens – Aristotle University of Thessaloniki – National Technical University of Athens
- Hellenic Vertical Network has not been connected with EVRS
- Validation before the connection
- GRACE and GOCE data provide valuable information





## Validation methodology

- GPS/leveling benchmarks ( $N^{GPS/Lev}$ ) over test areas and validation using spectral enhancement approach
- GRACE/GOCE GGM ( $N^i$ ) to some maximum degree of expansion ( $n_1$ )
- EGM2008 is used to fill-in medium and high frequency content
- Residual Terrain Modeling ( $N^{RTM}$ ) effects complete the high and ultra high frequency information

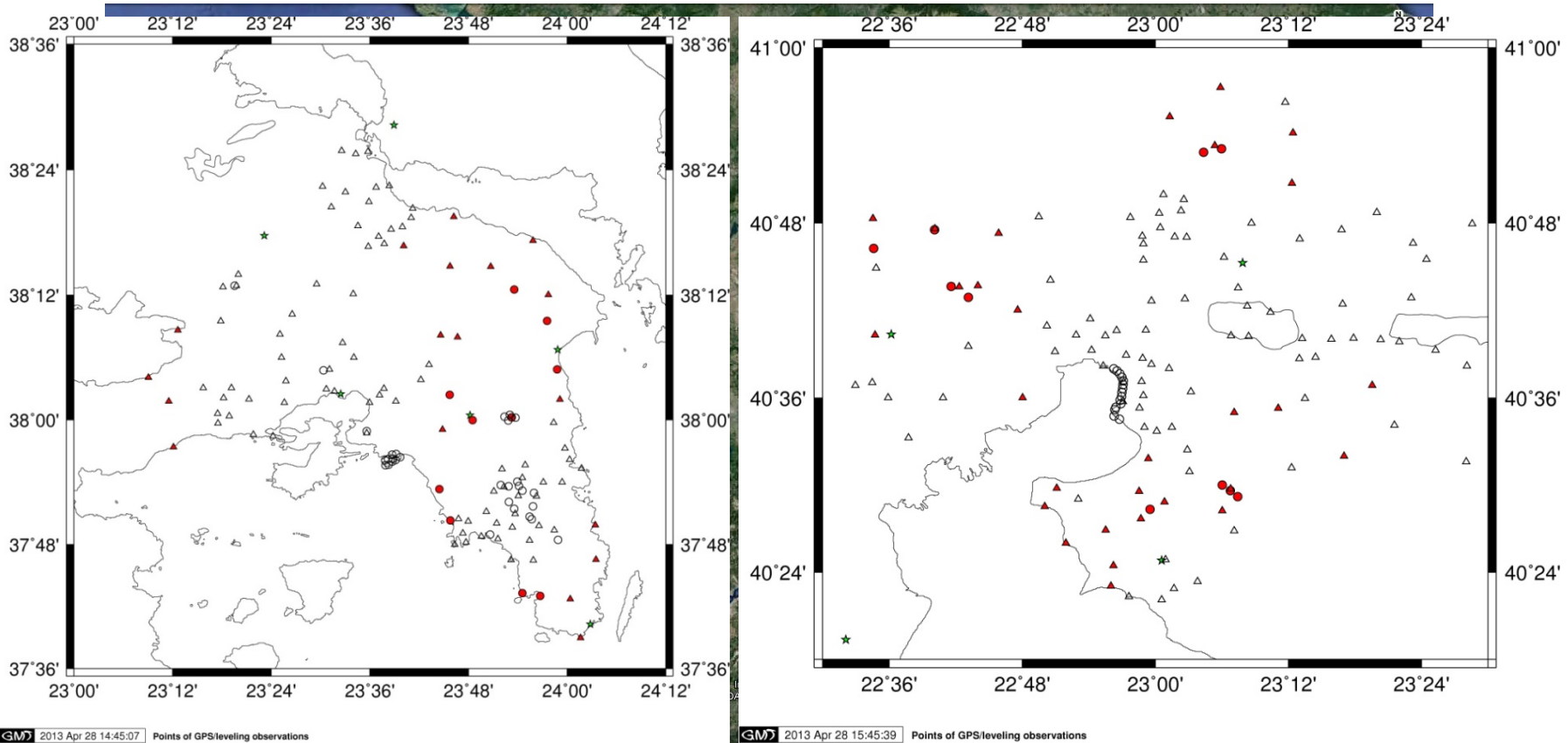
$$\Delta N = N^{GPS/Lev} - N^i \Big|_2^{n_1} - N^{EGM2008} \Big|_{n_1+1}^{2160} - N^{RTM} - N_0$$





## Data availability (1/4) – Test areas

- 2 test areas 100 km × 100 km each – 233 benchmarks





## Data availability (2/4) – Global Geopotential Models

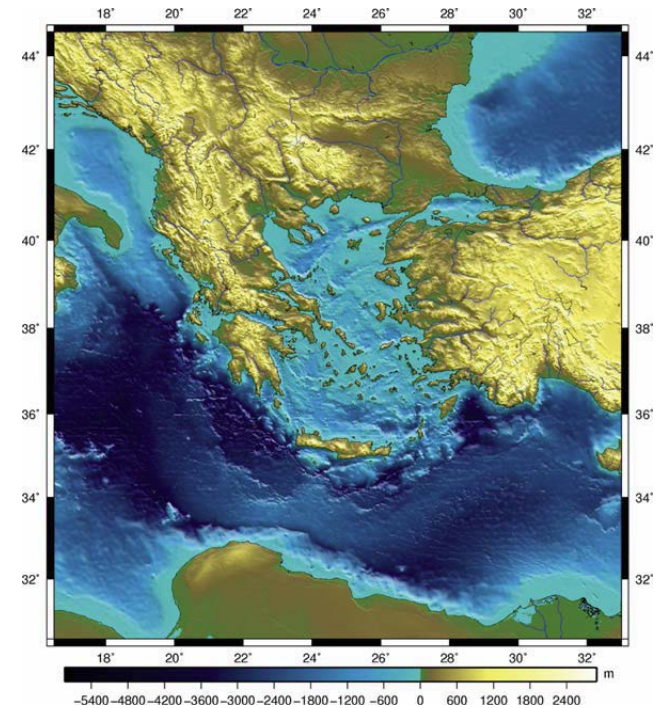
- **18 Global Geopotential Models** used to their maximum d/o (satellite only – GOCE/GRACE – and combined information)
- **EGM2008** as reference model (Pavlis et al., 2008 - expansion to d/o **2160**)
- **EIGEN models** (5C, 6C, 6C2 and 6C3-stat – Förste et al., 2008, 2011, 2012, 2014)
- **GOCE models** (**DIR 1 – 4**, Bruinsma et al., 2010, 2013 and **TIM 1 – 4**, Pail et al., 2010, 2011)
- **GOCO models** (**01S – 03S**, Pail et al., 2010; Goingerer et al., 2011; Mayer-Gürr et al., 2012)
- **ITG-Goce02** (Schall et al. 2014)
- **GOGRA02S** (Yi et al., 2013)
- **JYY-GOCE02S** (Yi et al., 2013)





## Data availability (3/4) – High frequency (RTM effects)

- 3 arcsec resolution digital terrain and bathymetry model is used for the RTM effect on geoid heights
- the omission error is below the 1 mm level
- the d/o of expansion that these synthetic GOCE/GRACE GGMs now represent is at 216,000



Digital terrain model from Tziavos et al. 2010



## Data availability (4/4) – Datum and reference system concepts

- **Tide – Free system** (Zero – Tide model ITG-GOCE02 was transformed to the Tide – Free system)

$$\delta C_{2,0}^{TF} = \delta C_{2,0}^{ZT} + 3.1108 \times 10^{-8} \frac{0.3}{\sqrt{0.5}}$$

- Orthometric heights in Greece are referenced to the Mean – Tide system → conversion to Tide – Free (Ekman et al. 1989)
- $N_0$  zero-degree harmonic w.r.t. GRS80 ( $N_0 = -0.4376$  m)

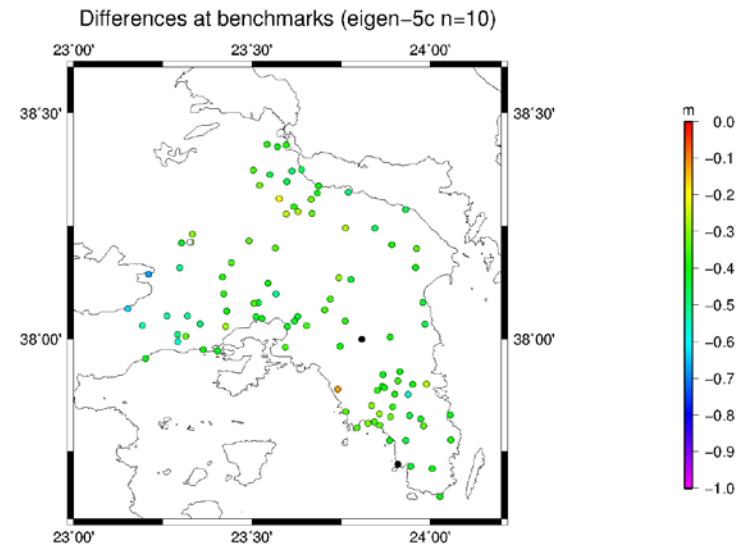
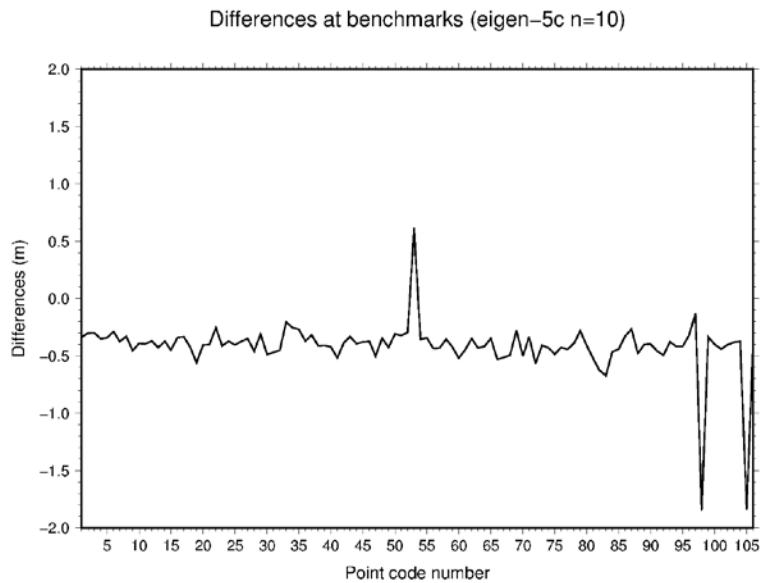
$$\zeta(r, \vartheta, \lambda) = \frac{GM}{\gamma r} \sum_{n=2}^{n_{max}} \left(\frac{a}{r}\right)^n \sum_{m=0}^n \left( \overline{\delta C_{nm}} \cos m\lambda + \overline{\delta S_{nm}} \sin m\lambda \right) \overline{P_{nm}}(\cos \vartheta) \quad N^{GGM} = \zeta + N_0 + \frac{\Delta g_B}{\gamma} H$$





## Results (1/11) – Blunders detection

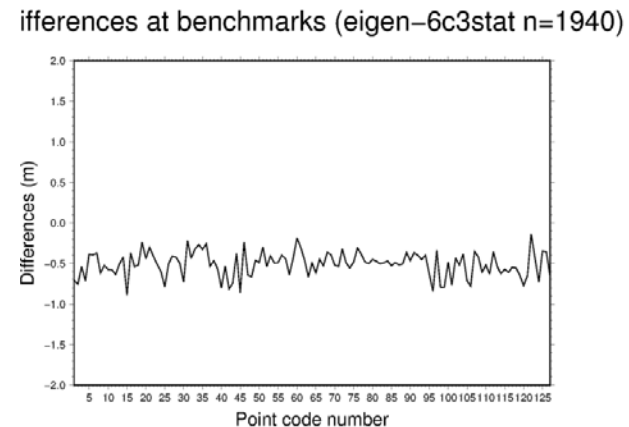
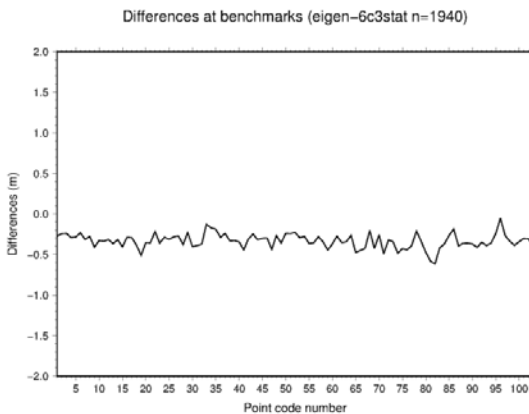
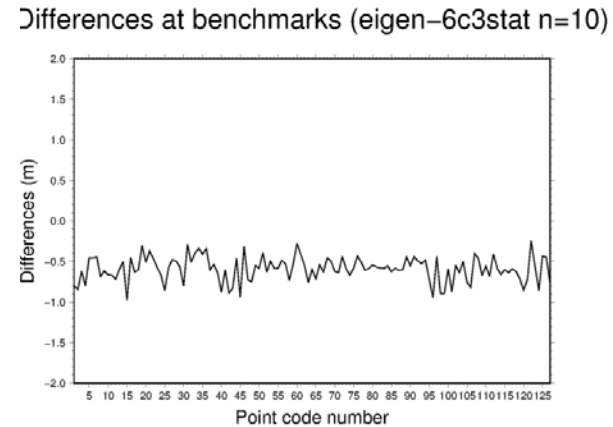
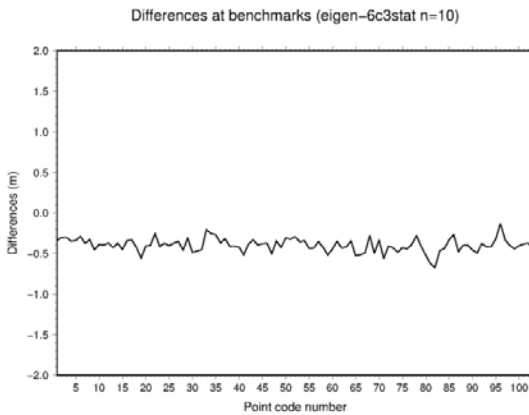
- Blunders identification in Attica using combination methodology





## Results (2/11) – Differences in Attica and Thessaloniki

- Larger std in Thessaloniki due to rough terrain → problematic BMs
- A bias of 20 cm between the two areas → LVD inconsistencies

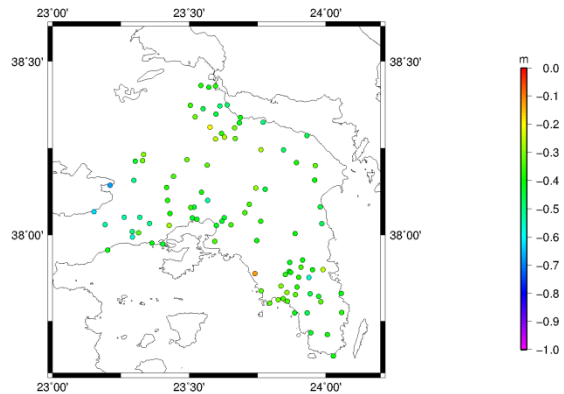




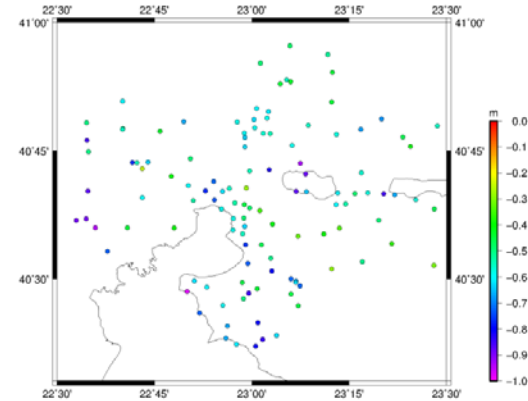
# Results (3/11) – Differences in Attica and Thessaloniki

- Local characteristics depending on the d/o of each model

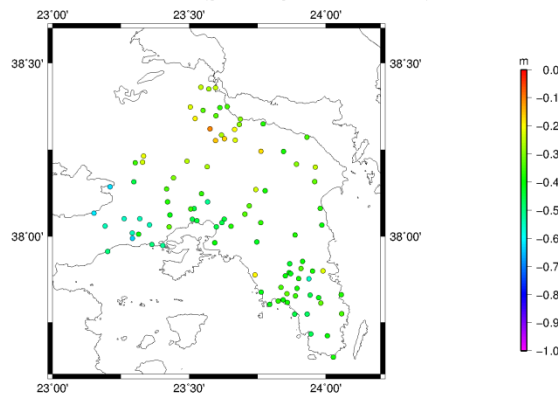
Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=10)



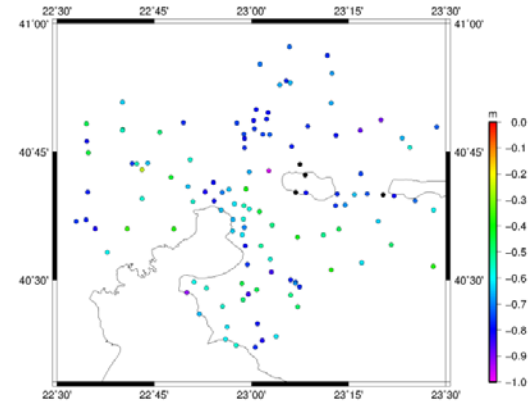
Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=10)



Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=250)



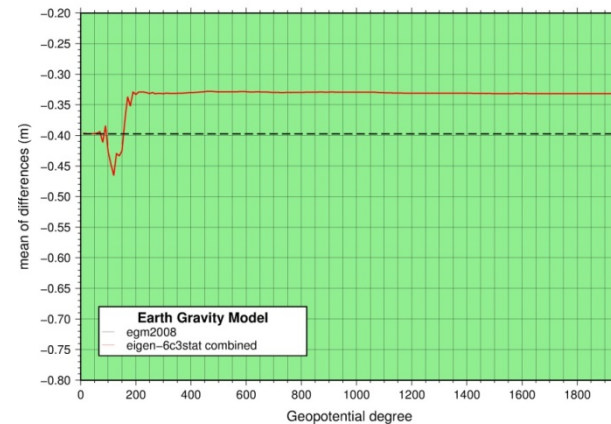
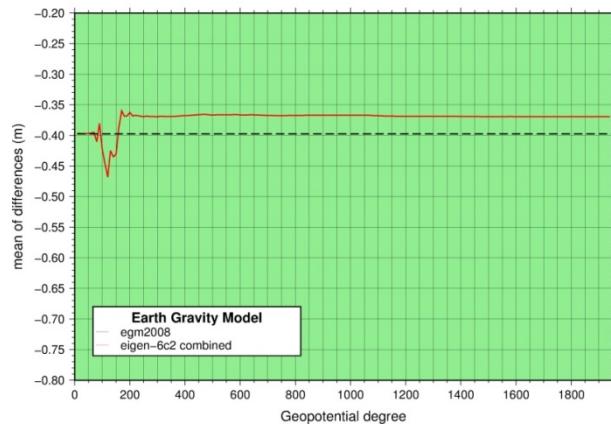
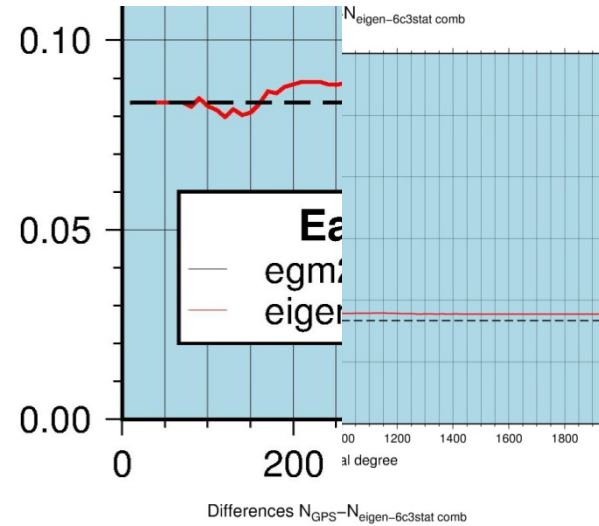
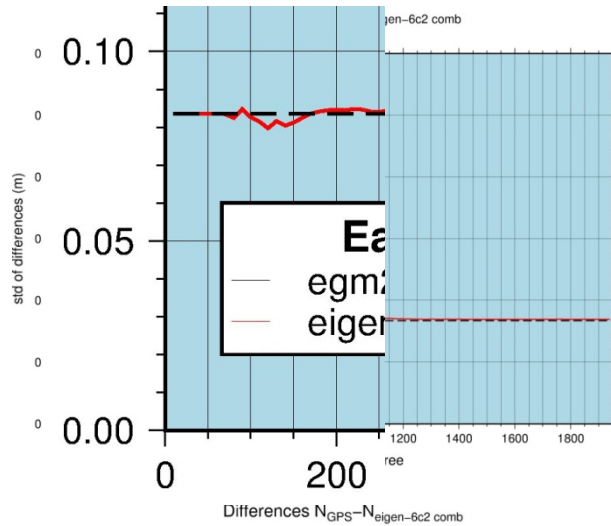
Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=250)





# Results (4/11) – Models validation and spectral characteristics

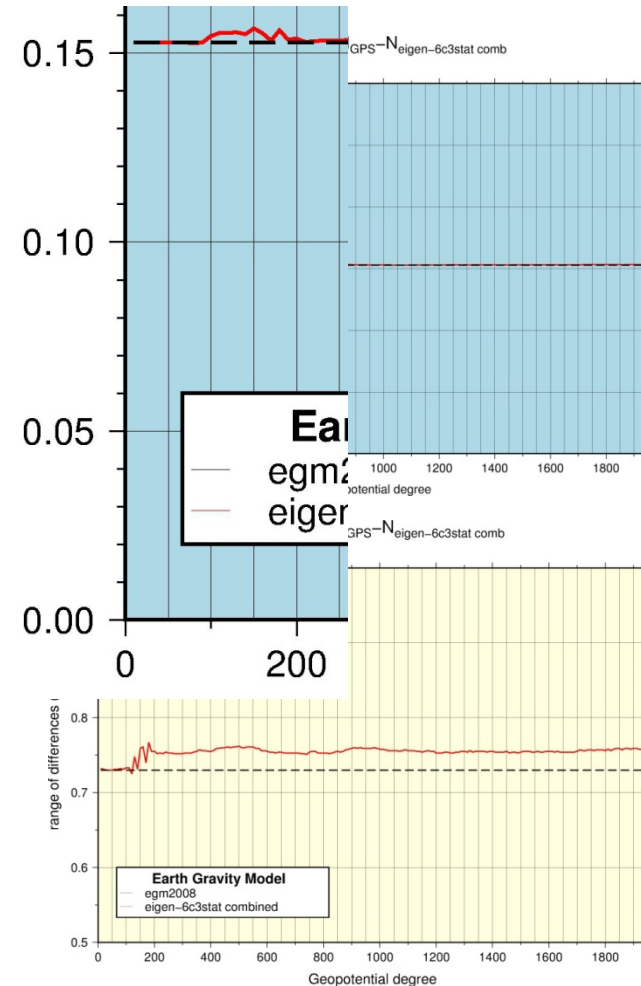
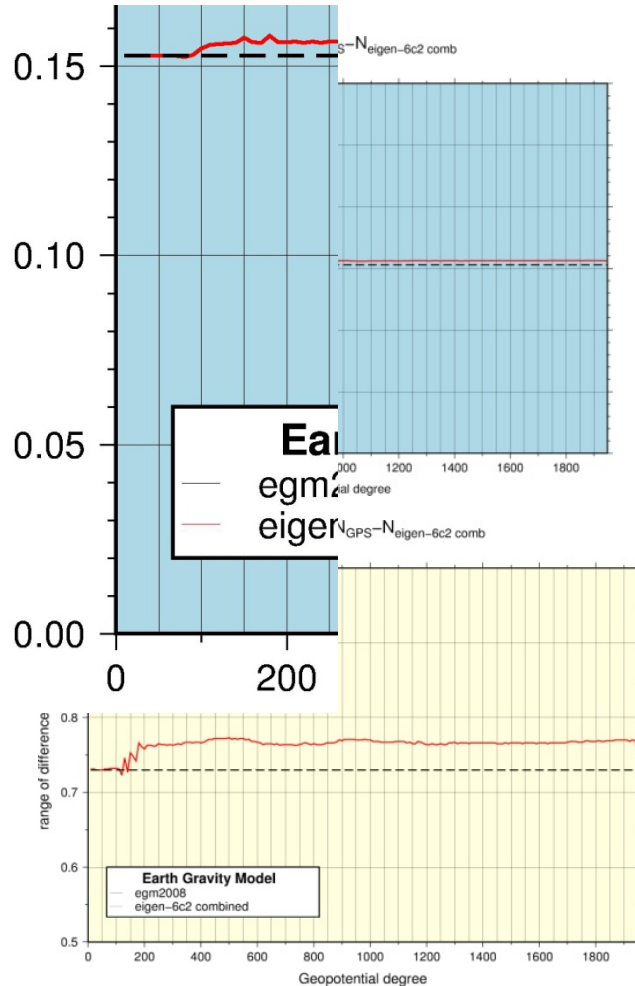
- EIGEN models over Attica → improvements below d/o 200





# Results (5/11) – Models validation and spectral characteristics

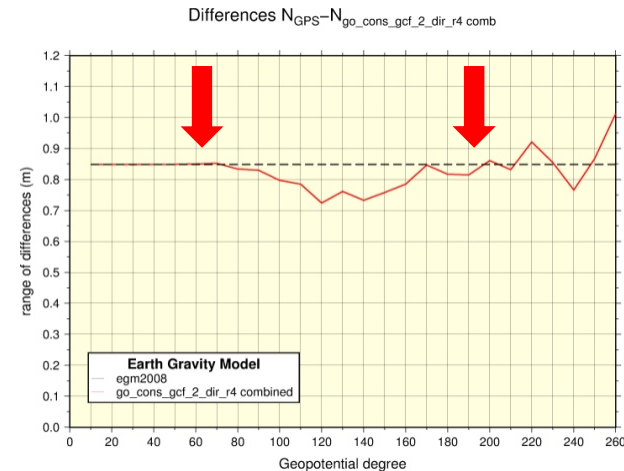
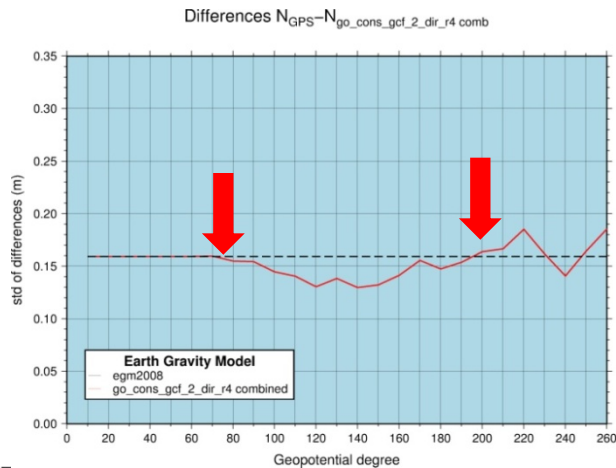
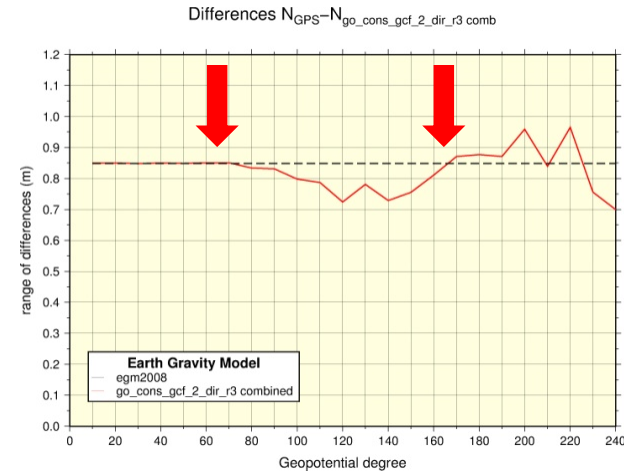
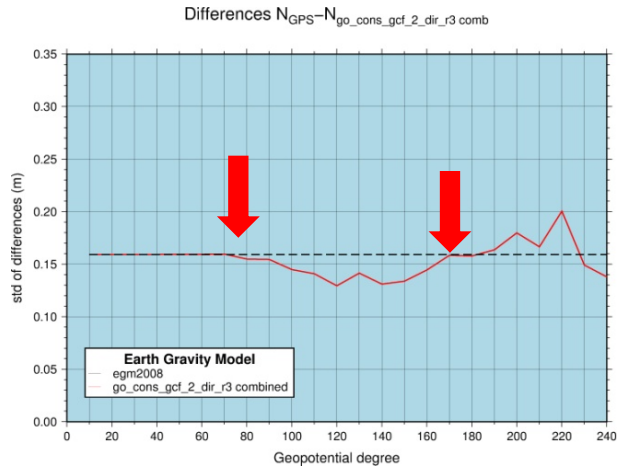
- EIGEN models over Thessaloniki





# Results (6/11) – Models validation and spectral characteristics

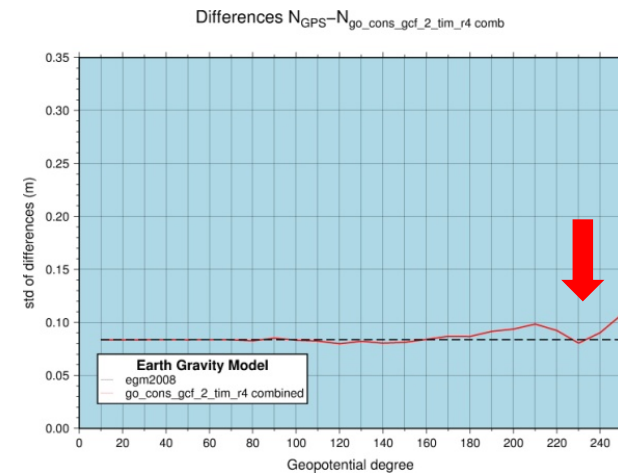
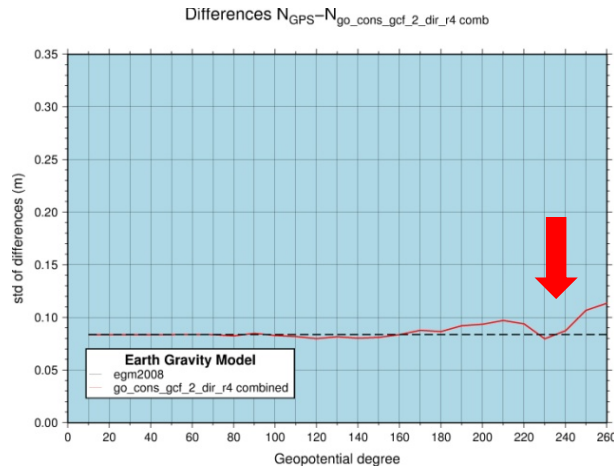
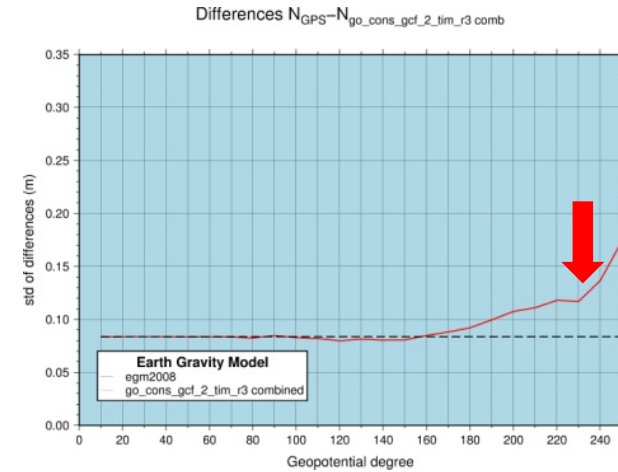
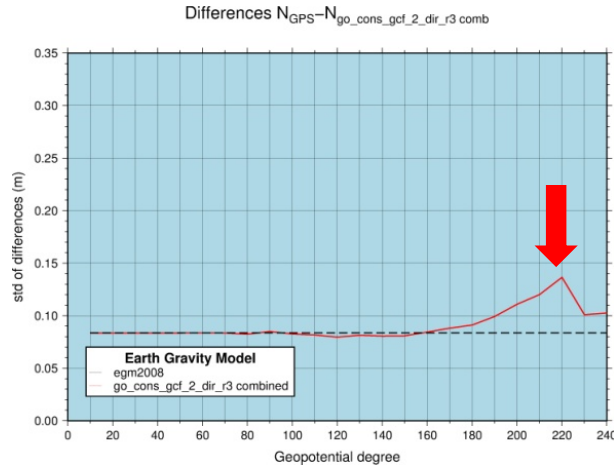
- GOCE-DIR models (R3 and R4) – Both test areas





# Results (7/11) – Models validation and spectral characteristics

- GOCE-DIR and TIM models (R3 and R4) over Attica

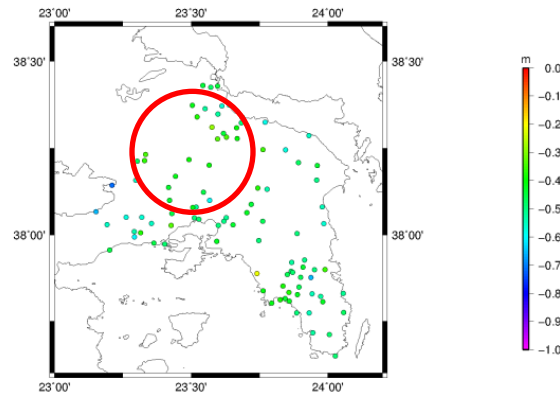




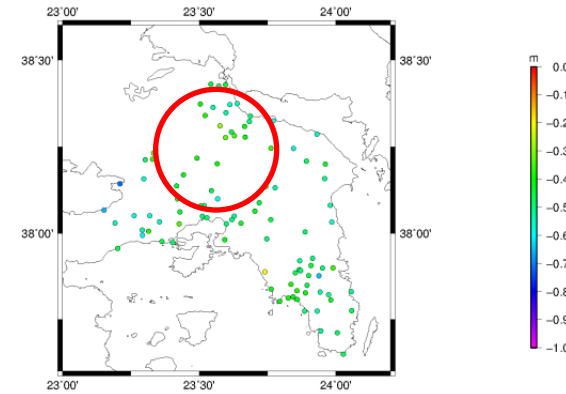
# Results (8/11) – Models validation and spectral characteristics

- GOCE-DIR and TIM models (R4) over Attica

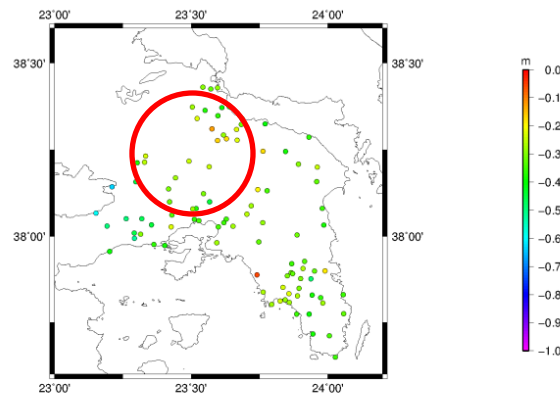
Differences at benchmarks (go\_cons\_gcf\_2\_dir\_r4 n=120)



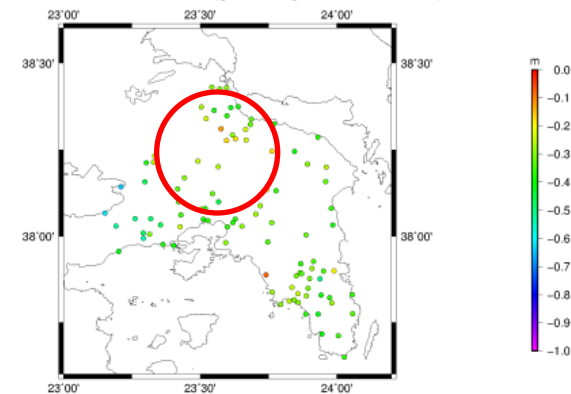
Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=120)



Differences at benchmarks (go\_cons\_gcf\_2\_dir\_r4 n=200)



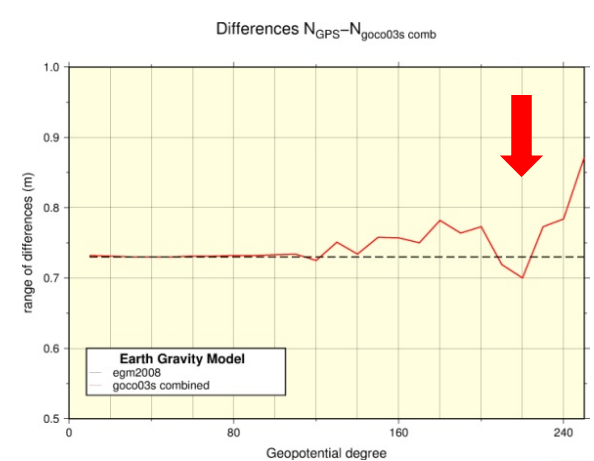
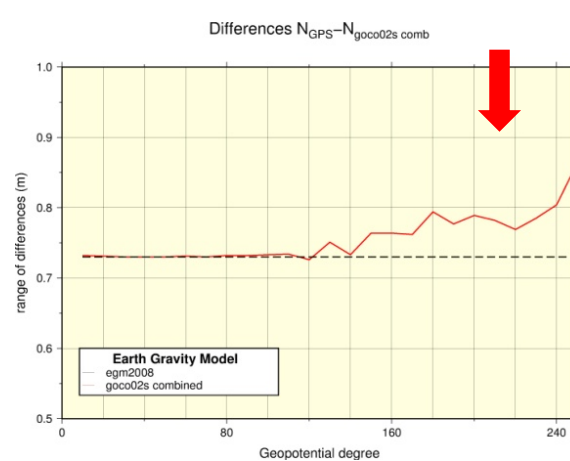
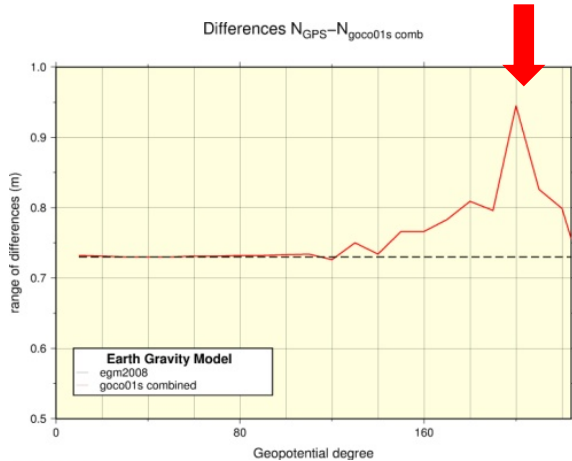
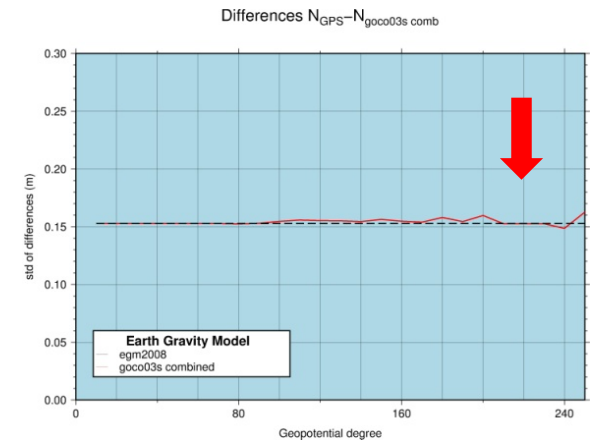
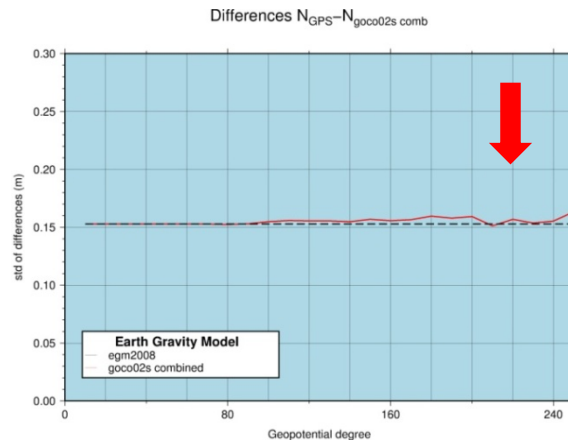
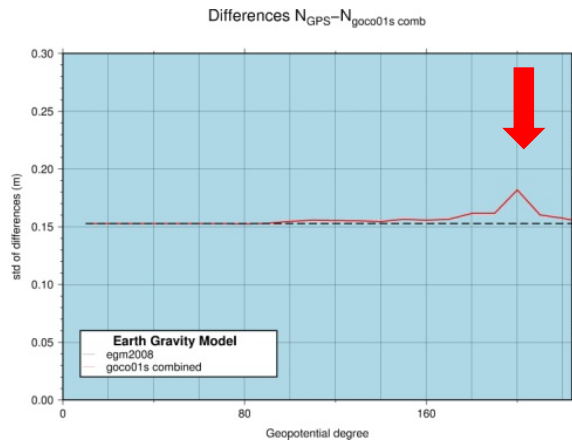
Differences at benchmarks (go\_cons\_gcf\_2\_tim\_r4 n=200)





# Results (9/11) – Models validation and spectral characteristics

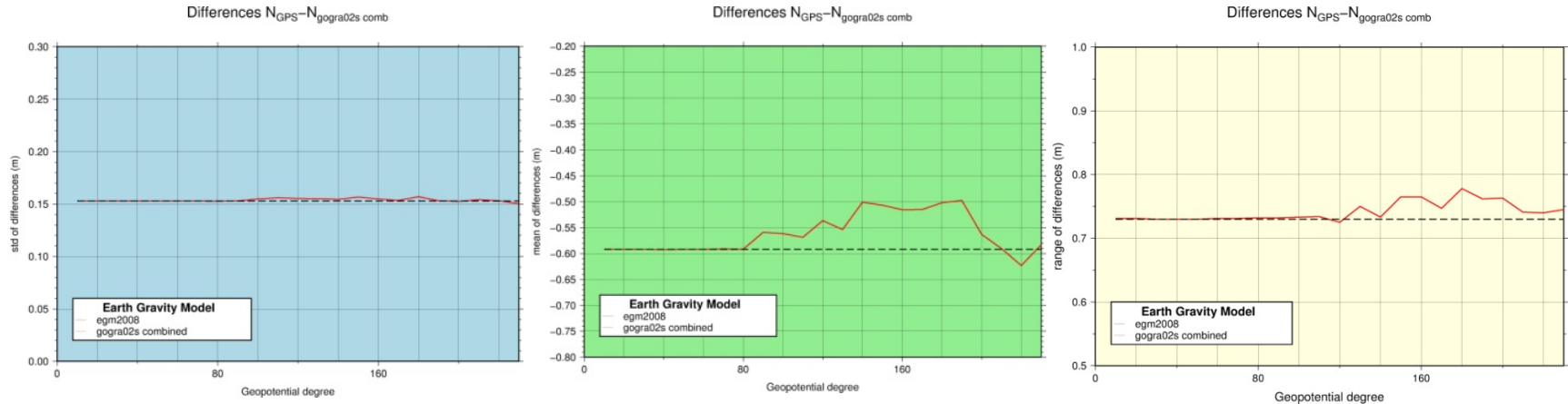
- GOCOxS models over Thessaloniki



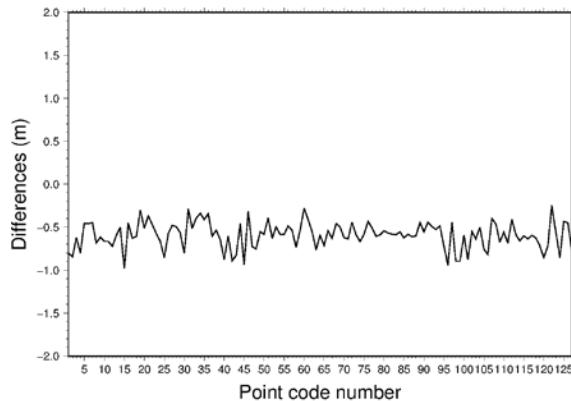


# Results (10/11) – Models validation and spectral characteristics

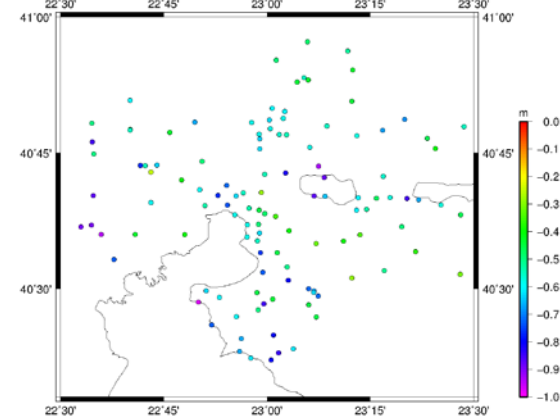
- GOGRA02S model over Thessaloniki



Differences at benchmarks (gogra02s n=10)



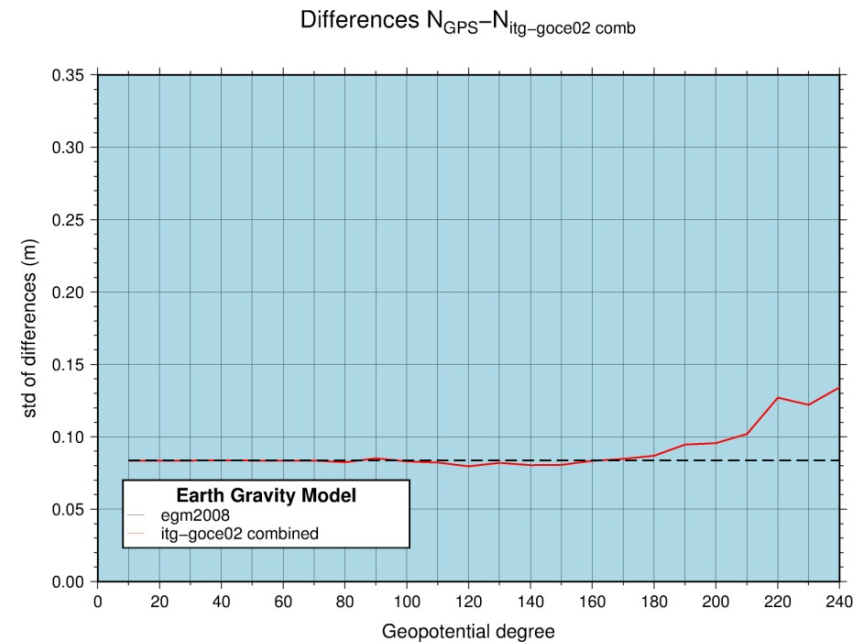
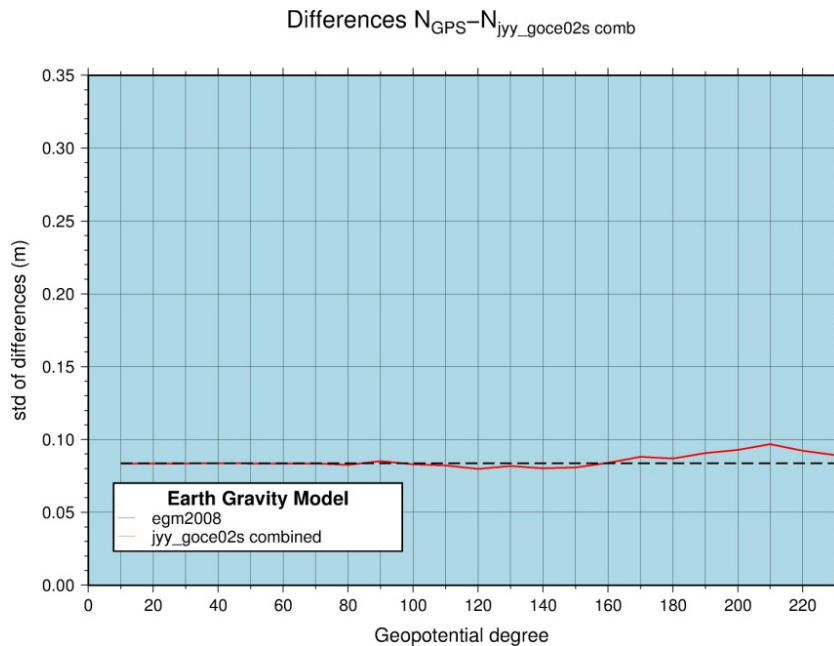
Differences at benchmarks (gogra02s n=10)





# Results (11/11) – Models validation and spectral characteristics

- JYY-GOCE02S and ITG-GOCE02 models over Attica





## Conclusions – Future Plans

- **Improvements** from GOCE/GRACE data at **80 – 180 d/o band**
- **2 cm** in terms of std of the differences at Thessaloniki BMs **around d/o 120**
- GOCE models evolution → optimization around **d/o 200**
- Larger std of differences → **dependence on the rough terrain** of Thessaloniki
- Bias identification between Central and Northern test areas → **LVD inconsistencies**
- Vertical Datum homogeneity → **computation of the  $W_0$**  in the area (IGFS – Shanghai, June - July 2014)





# Acknowledgement

## E.LE.V.A.T.I.ON. Project

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