



# COMPARISON OF METHODS APPLIED FOR MARINE GEOID MODELLING IN THE BALTIC SEA PROJECT FAMOS

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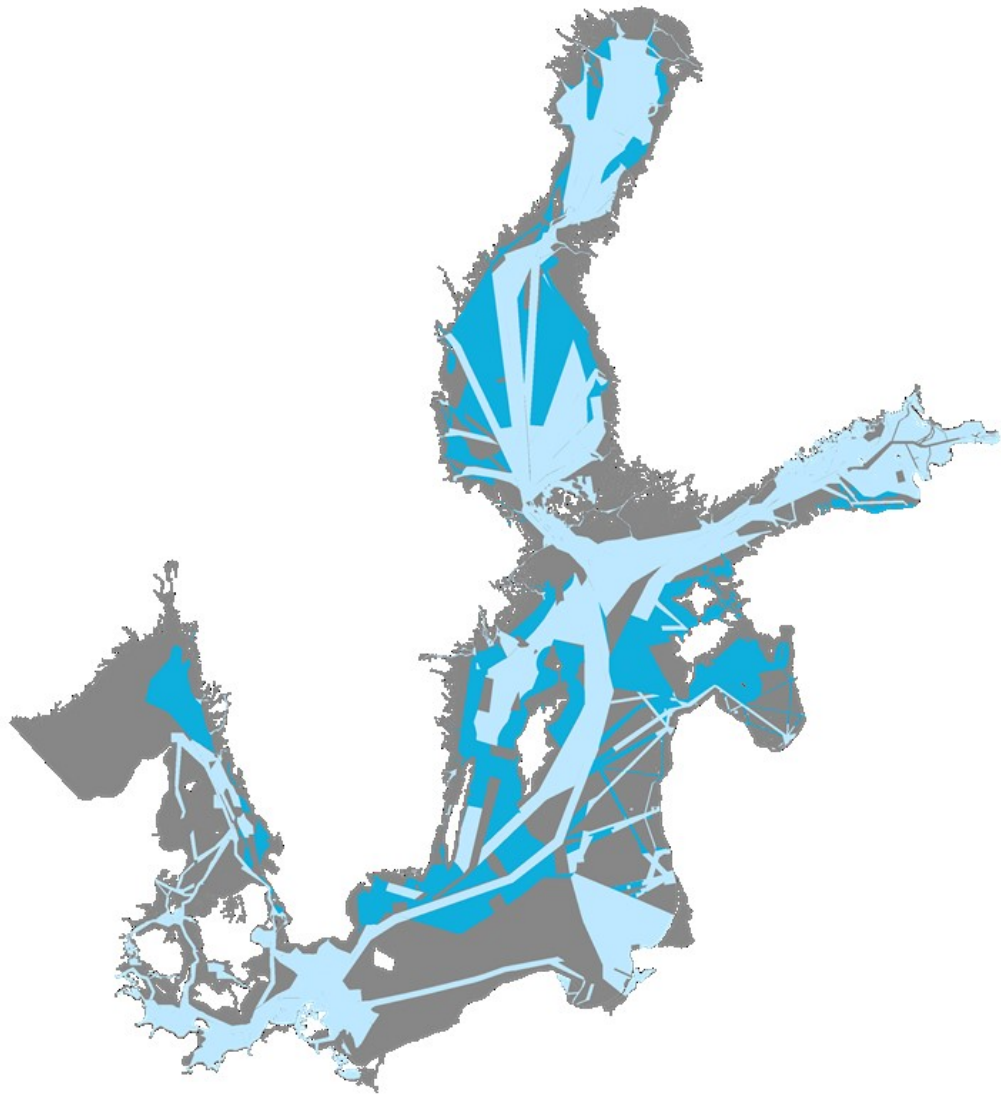
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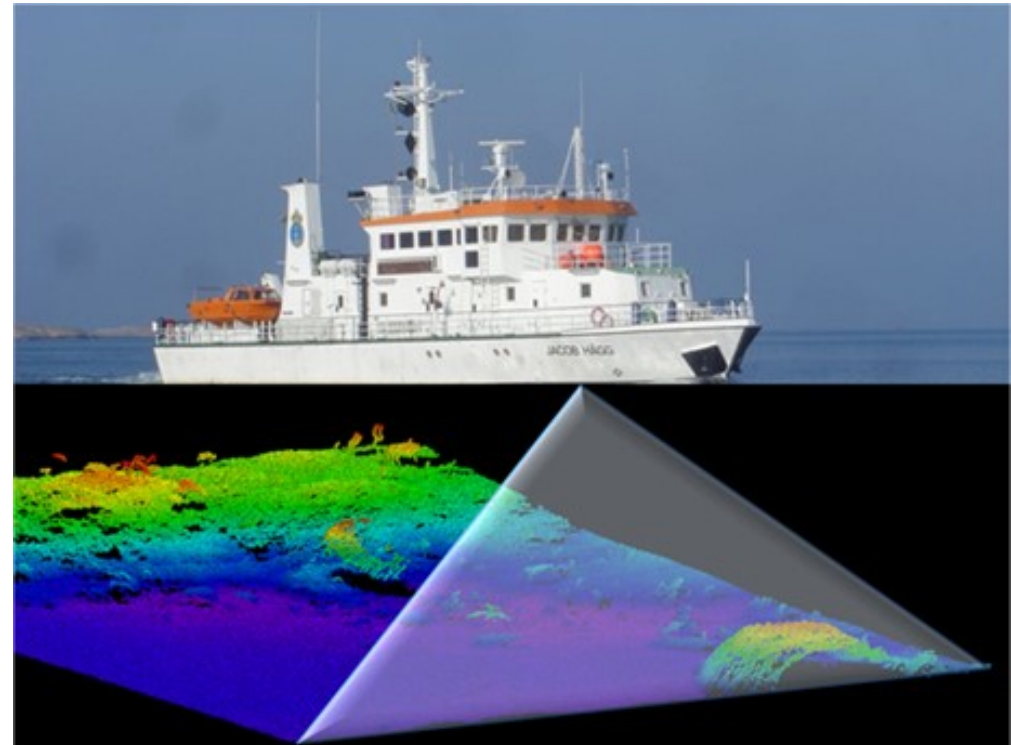
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# FAMOS – FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA



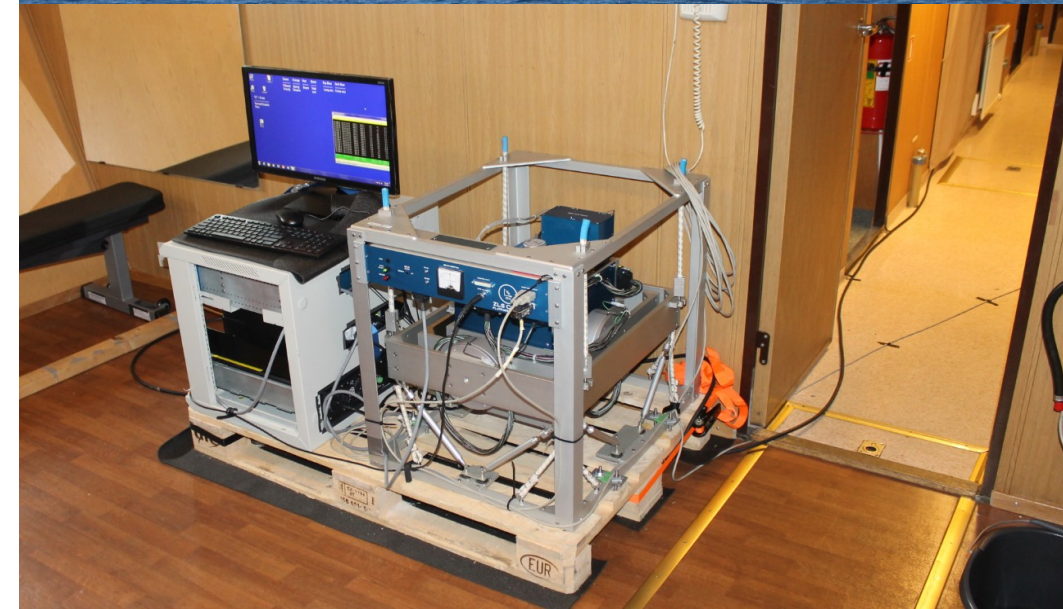
- The largest part of the EU project **FAMOS (Activity I)** is to finalize **hydrographic surveying** in areas of the Baltic Sea of most interest for commercial shipping.
- The EU project FAMOS started in 2014 and is planned to end in 2022 (hopefully).



## FAMOS ACTIVITY 2

## HARMONISING VERTICAL DATUM/ IMPROVING VESSEL NAVIGATION FOR THE FUTURE

- One major purpose is to support the introduction of the **Baltic Sea Chart Datum 2000 (BSCD2000)** as the common unified chart datum in the Baltic Sea.
- BSCD2000 is a **geodetic height system** (EVRS, epoch 2000) that uses an **equipotential surface (the geoid)** as zero level.
- Offshore, BSCD2000 will be **realized** by **GNSS** (relative to national networks of permanent reference stations) and a height reference surface constructed based on a **gravimetric geoid model**.
- It is required that the **FAMOS geoid model** is finished by **2022** and has a well corroborated standard **uncertainty better than 5 cm** (preferably better than that).
- To reach this goal, **new marine gravity measurements** are made on the FAMOS hydrographic surveying vessels, and other boats. The plan is to check, complement or replace the existing datasets and to fill data gaps.



# INTRODUCTION

- An important part of FAMOS activity 2 is also to compute **interim gravimetric geoid models** using different regional geoid determination methods, mainly to evaluate the uncertainty stemming from the computation **method**.
- **Five computation centers** (LM, BKG, FGI, TUT, DTU) are working on interim geoid computations, using basically three different well-established **regional geoid modeling methods**,
  - **Least Squares Modification of Stokes' formula** with Additive corrections (LSMSA-method). Least squares collocation used for gravity anomaly gridding in a Remove-Interpolate-Restore way.
  - Stokes' formula with **Wong and Gore** kernel modification, Remove-Compute-Restore with **RTM** topographic reduction,
  - **Point-mass modelling**, Remove-Compute-Restore with **RTM** topographic reduction.
- The **purpose** here is to present and analyze a selection of regional geoid computations based on version 2 of the FAMOS gravity database.
- The FAMOS partners have computed a large number of geoid models. Only a small selection can be dealt with here.

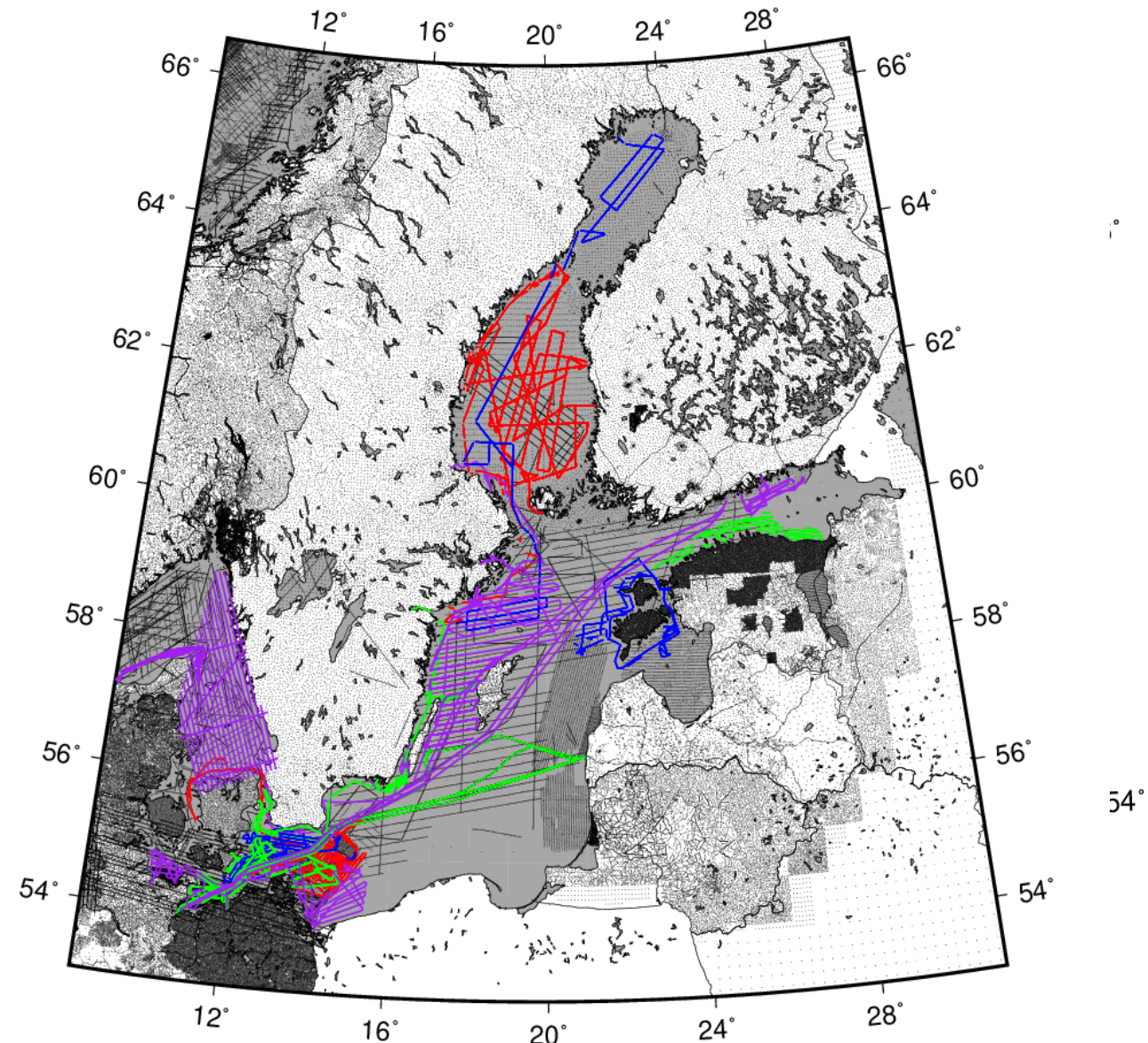
# MARINE GRAVIMETRY CAMPAIGNS MEASURED IN FAMOS UP TO 2018

## FAMOS Freja:

- Deneb 2015
- Airisto 2015
- Jacob Hägg 2015
- Jens Sørensen 2015
- Deneb 2016
- Jacob Prei 2016
- Jacob Hägg 2016
- Jens Sørensen 2016

## FAMOS Odin:

- Deneb 2017
- Sektori 2017
- Jacob Hägg 2017a
- Jacob Hägg 2017b
- Jens Sørensen 2017
- Urd 2017
- Deneb 2018
- Jakob Hägg 2018
- Geomari 2018
- Fyrbyggaren 2018a,b
- Jens Sørensen 2018
- Finnlady 2018
- Kattegatt 2018\* (airborne)

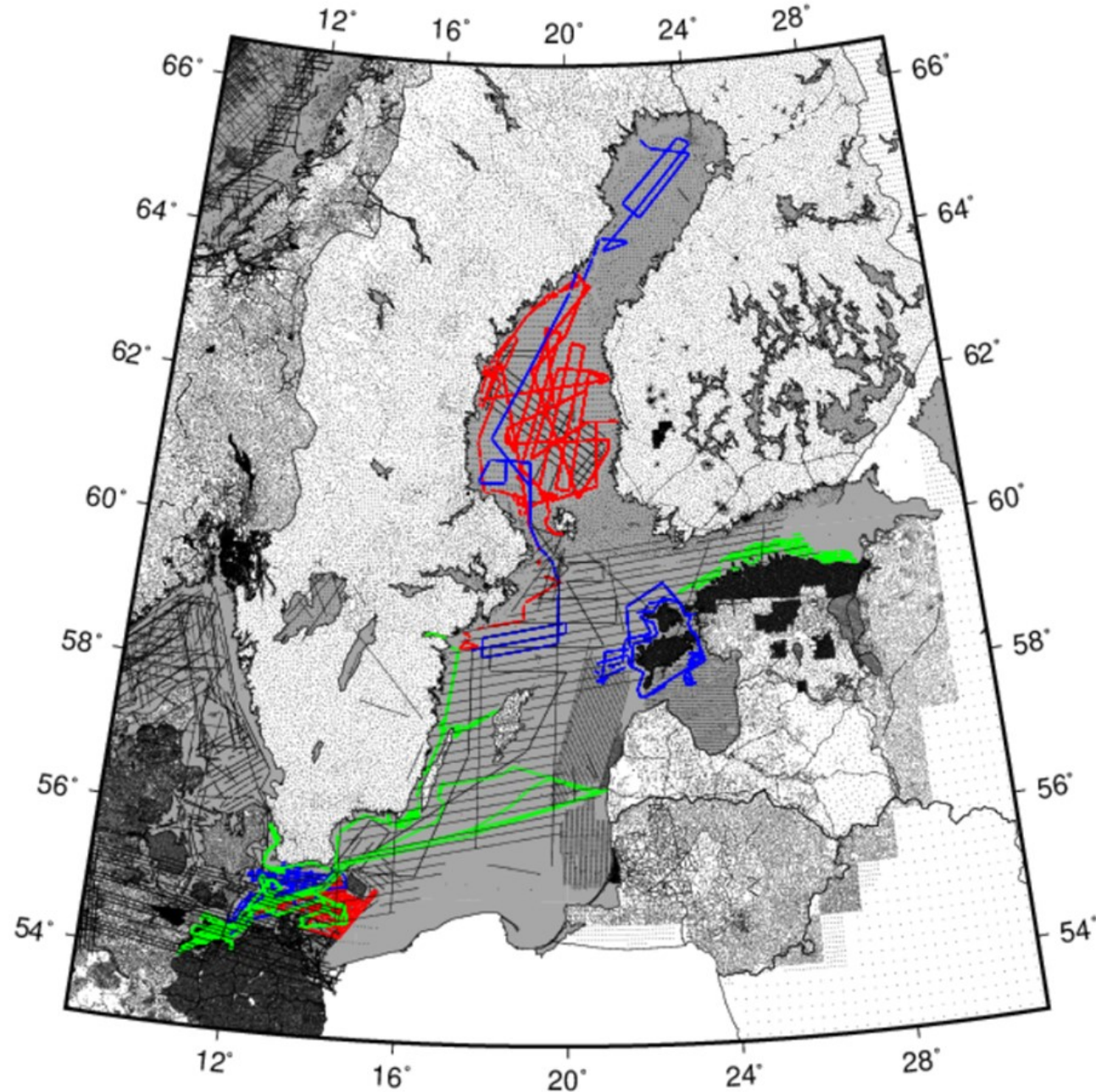


# SPECIFICATION OF THE INTERIM GEOID COMPUTATIONS

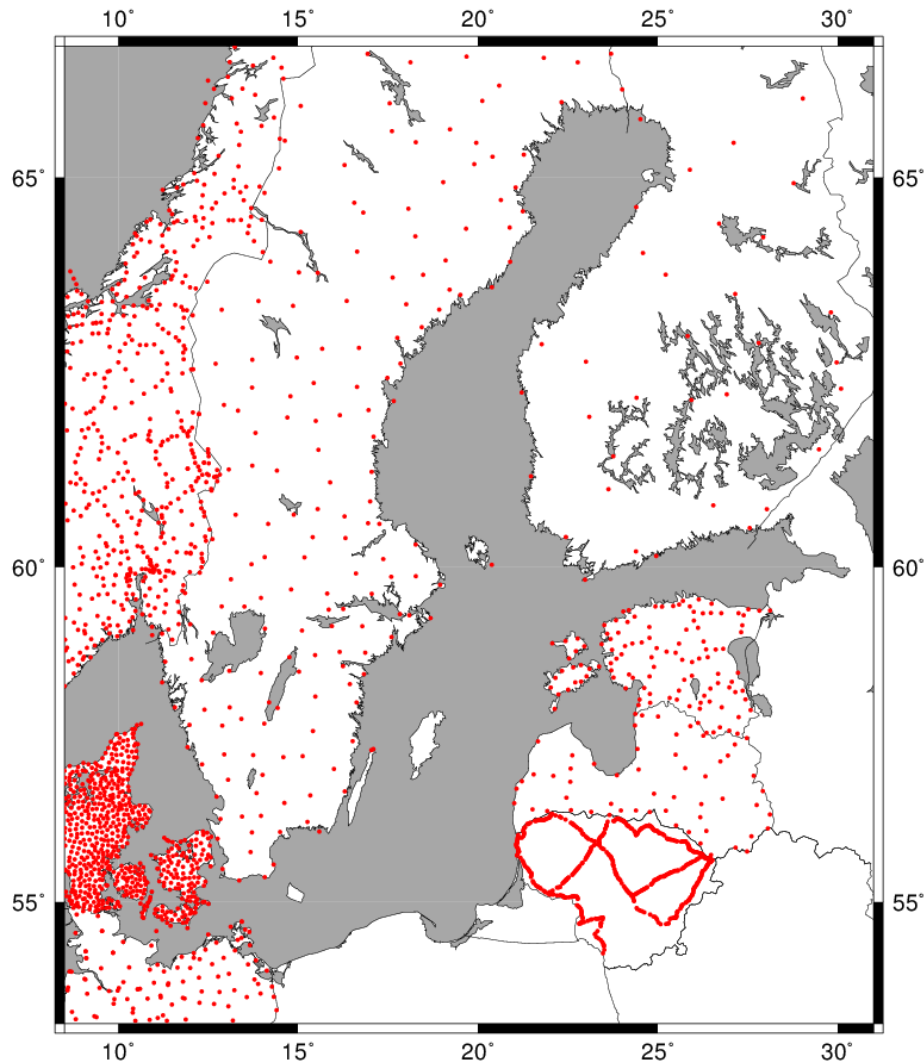
- Compute the **gravimetric quasigeoid**.
- Use the **zero** permanent tide system.
- Use the **FAMOS gravity database version 2** (2018-10-03c).
- Use the **FAMOS GNSS/levelling database version 1** (2017-01-09) to evaluate the gravimetric model.
- Use the **FAMOS DEM version 1** (2016-12-27).
- Areas/grids:
  - FAMOS quasigeoid grid: 53 66.5 8.5 31 0.01 0.02 (1351 x 1126 nodes)
  - FAMOS gravity area: 52 67.5 5.5 34 (This is the area covered by the FAMOS gravity database)
- In areas with significant uplift: **Postglacial land uplift epoch 2000.0**.
- It is **not specified** which EGM to prefer, nor whether to use bathymetry, gravity anomalies from satellite altimetry or how to fill in empty areas.

# FAMOS GRAVITY DATABASE

- Latest large update is **version 2**, released 2018-10-03,
- Start version created based on the corresponding **NKG** and **BKG** databases
- Data still missing in some areas (Poland are working on joining the next phase of FAMOS ☺)
- **Version 3** will be released soon and will include all campaigns made in FAMOS so far.



# FAMOS GNSS/LEVELLING DATABASE

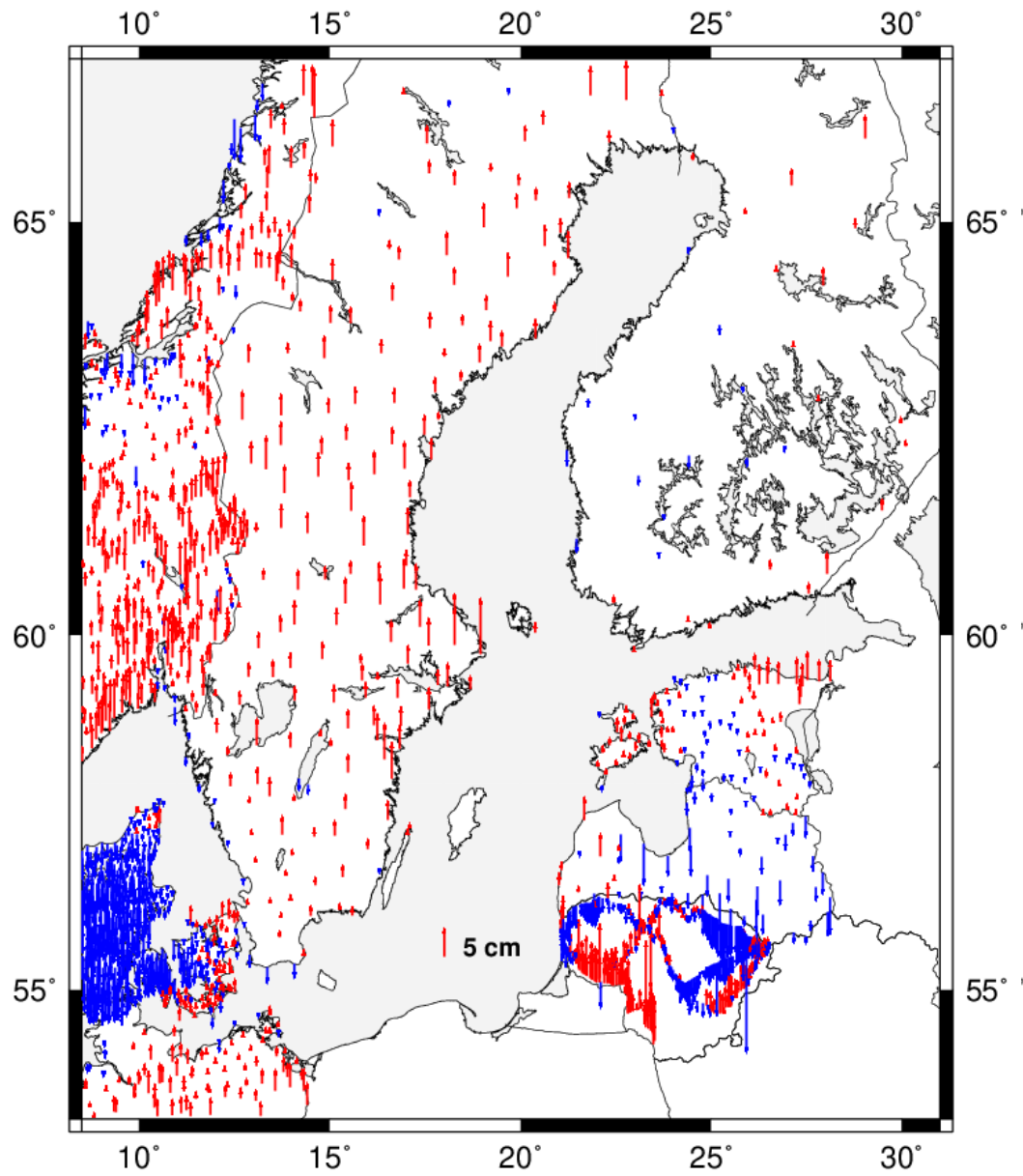


- **Version I**, 2017-01-09
- Created based on the corresponding **NKG** and **BKG** databases
- Available in three different **reference frames variants** depending on the GNSS frame,
  - A. ITRF2008 with epoch 2000.0 (in countries with significant land uplift)
  - B. ETRF2000 with epoch 2000.0 (in countries with significant uplift).
  - C. National ETRS 89 realizations.
- Levelled heights in **national height reference frames** (EVRS realizations with epoch 2000.0, DVR90 and DHHN2016).

## A SELECTION OF FAMOS INTERIM GEOID MODELS

Partner	BKGI-PUMA	BKG3A	BKG3C	LM6A	LM6C	LM6E	TUTIA	TUTIC	FGI-IA
Method	Point-mass, RTM	RCR W&G, RTM	RCR W&G, RTM	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	RCR W&G, RTM
Software implementation	BKG	BKG, SPFOUR	BKG, SPFOUR	LM/KTH	LM/KTH	LM/KTH	TUT/KTH	TUT/KTH	GRAVSOFT
FAMOS g DB	Ver. 1	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver.2
EGM	GECO	GECO	GECO	DIR_R5	XGM2016	DIR_R5	GOCO05C	COCO05S	DIR_R5
Max. degree	2190	2190	2190	240/300	719	240/300	240	200	300
Bathymetry	GEBCO2014	GEBCO2014	GEBCO2014	No	No	GEBCO2019	No	No	No
Fill-in with altimetric gravity anom. (DTUI3)	Yes, sel. method 1	No	In good areas, sel. method 2	No	No	No	No	No	No

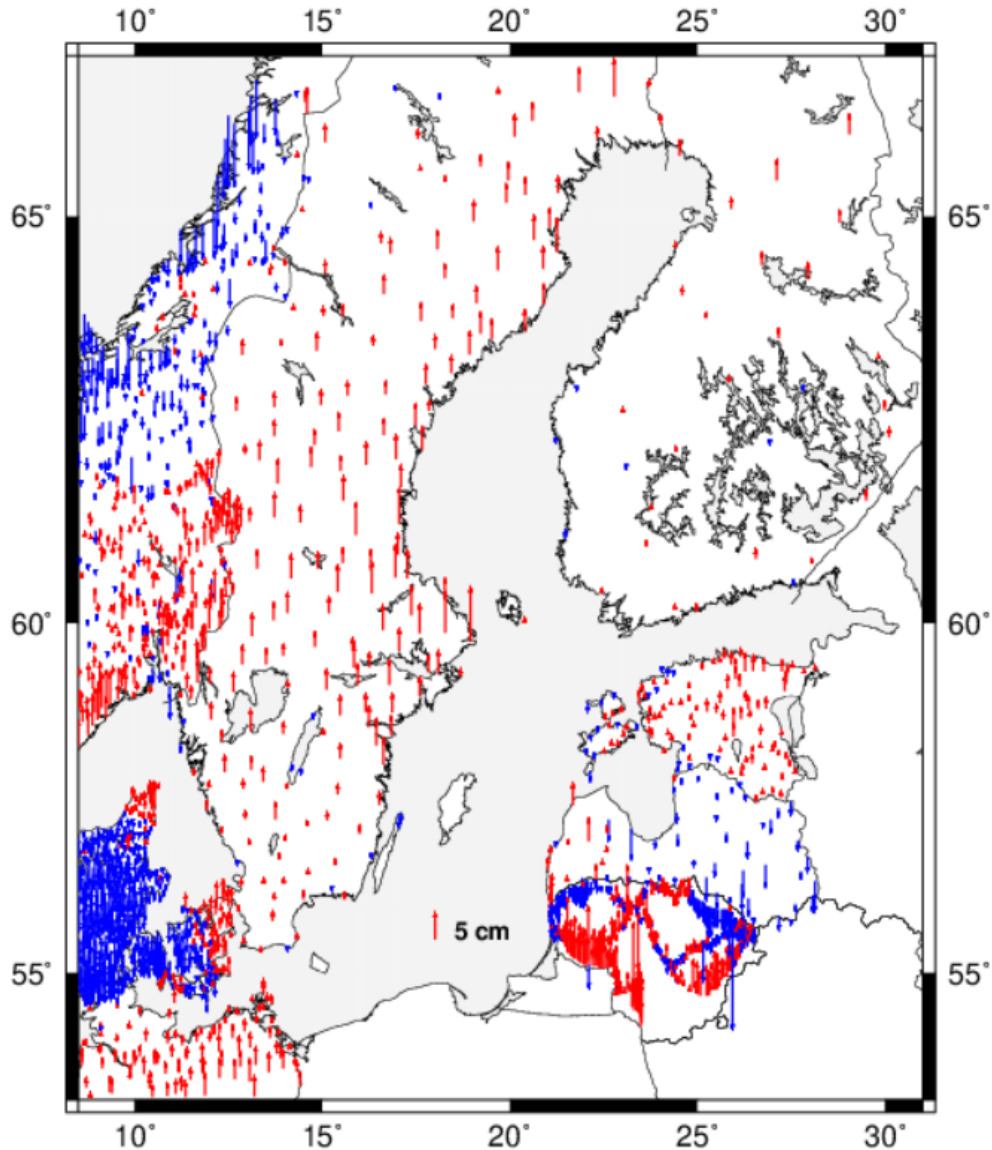
# GNSS/LEVELLING RESIDUALS FOR LM6A



- Computed by Jonas Ågren, Lantmäteriet
- Least squares modification of Stokes' formula with additive corrections using remove-interpolate-restore method and remove-interpolate-restore gridding with collocation.  
Exactly the same method as for NKG2015.
- EGM: DIR\_R5, M=240/300 (satellite-only)
- Residuals after a 1-parameter fit/transformation.

Data	#	Mean	<u>StdDev</u>
<b>FAMOS</b>	2122	<b>0.000</b>	<b>0.029</b>
<b>Germany</b>	100	<b>0.012</b>	<b>0.015</b>
<b>Denmark</b>	617	<b>-0.022</b>	<b>0.018</b>
<b>Estonia</b>	114	<b>0.006</b>	<b>0.015</b>
<b>Finland</b>	36	<b>0.004</b>	<b>0.017</b>
<b>Latvia</b>	54	<b>-0.021</b>	<b>0.025</b>
<b>Lithuania</b>	546	<b>-0.003</b>	<b>0.032</b>
<b>Norway</b>	473	<b>0.021</b>	<b>0.021</b>
<b>Sweden</b>	182	<b>0.025</b>	<b>0.019</b>
<b>FAMOS, red. of country offsets, without Norway</b>	1649	<b>0.000</b>	<b>0.024</b>

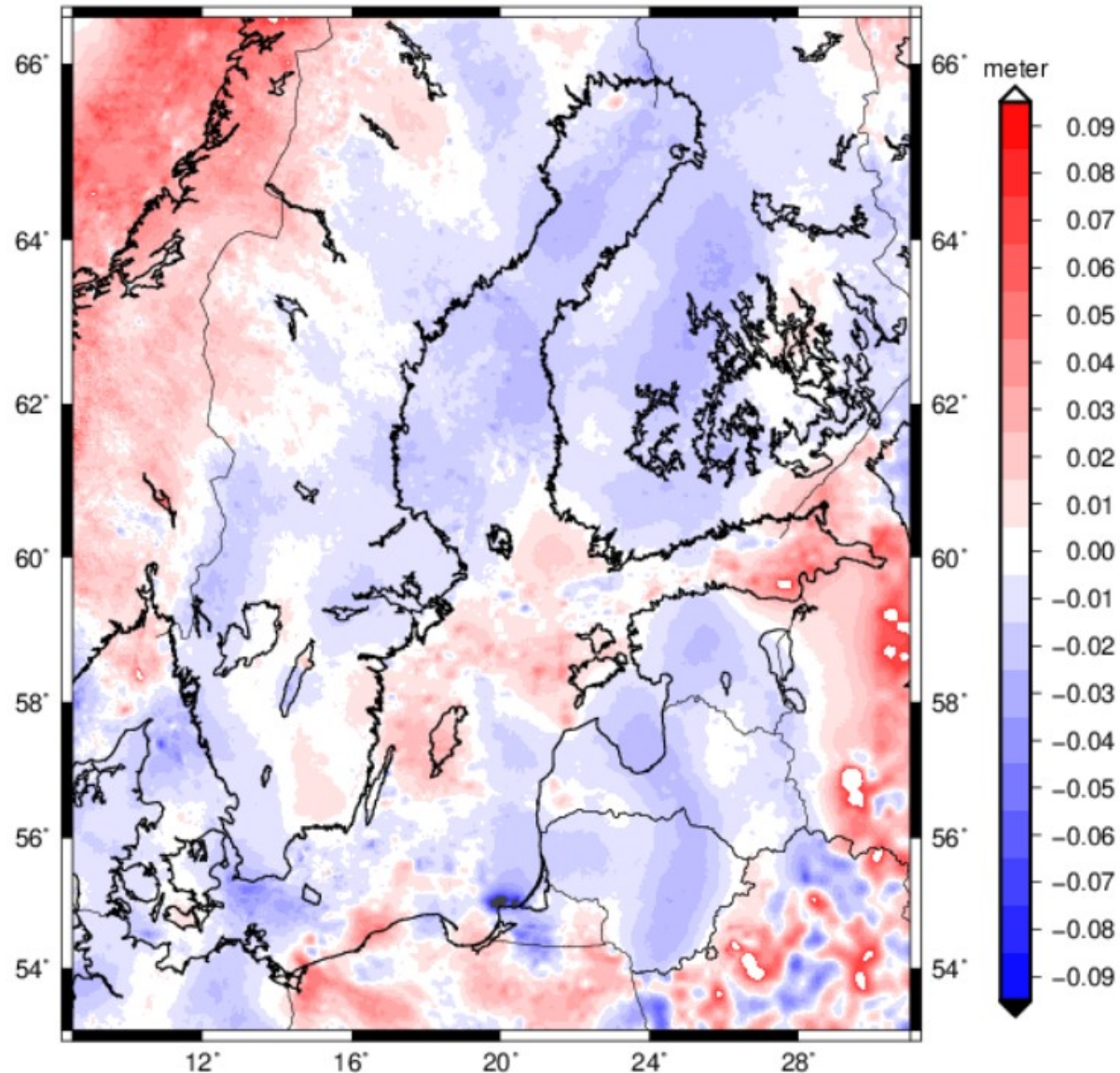
# GNSS/LEVELLING EVALUATION OF **BKG3A**



- Computed by Joachim Schwabe, BKG
- Remove-compute-restore using the RTM method and Wong & Gore kernel modification (SPFOUR). Optimum modification chosen by analysing hundreds of models.
- EGM: GECO, M=2190 (combined)
- Residuals after a 1-parameter fit/transformation.

Data	#	Mean	StdDev
<b>FAMOS</b>	2122	<b>0.000</b>	<b>0.027</b>
<b>Germany</b>	100	<b>0.018</b>	<b>0.011</b>
<b>Denmark</b>	617	<b>-0.017</b>	<b>0.018</b>
<b>Estonia</b>	114	<b>0.008</b>	<b>0.010</b>
<b>Finland</b>	36	<b>0.011</b>	<b>0.013</b>
<b>Latvia</b>	54	<b>-0.014</b>	<b>0.021</b>
<b>Lithuania</b>	546	<b>0.006</b>	<b>0.030</b>
<b>Norway</b>	473	<b>0.000</b>	<b>0.029</b>
<b>Sweden</b>	182	<b>0.026</b>	<b>0.019</b>
<b>FAMOS, est. of country offsets, without Norway</b>	1649	<b>0.000</b>	<b>0.022</b>

# COMPARISON BETWEEN INTERIM GEOID MODELS **BKG3A** AND **LM6A**



- Main differences between the models:
  - Method
    - BKG3A: RCR with W&G
    - LM6A: LSMSA
  - EGM
    - BKG3A: Combined GECO, M=2190
    - LM6A: Satellite-only DIR\_R5, M=300
  - Bathymetry only for BKG3A
- Note:
  - Same patch used for the empty eastern part of the Gulf of Finland

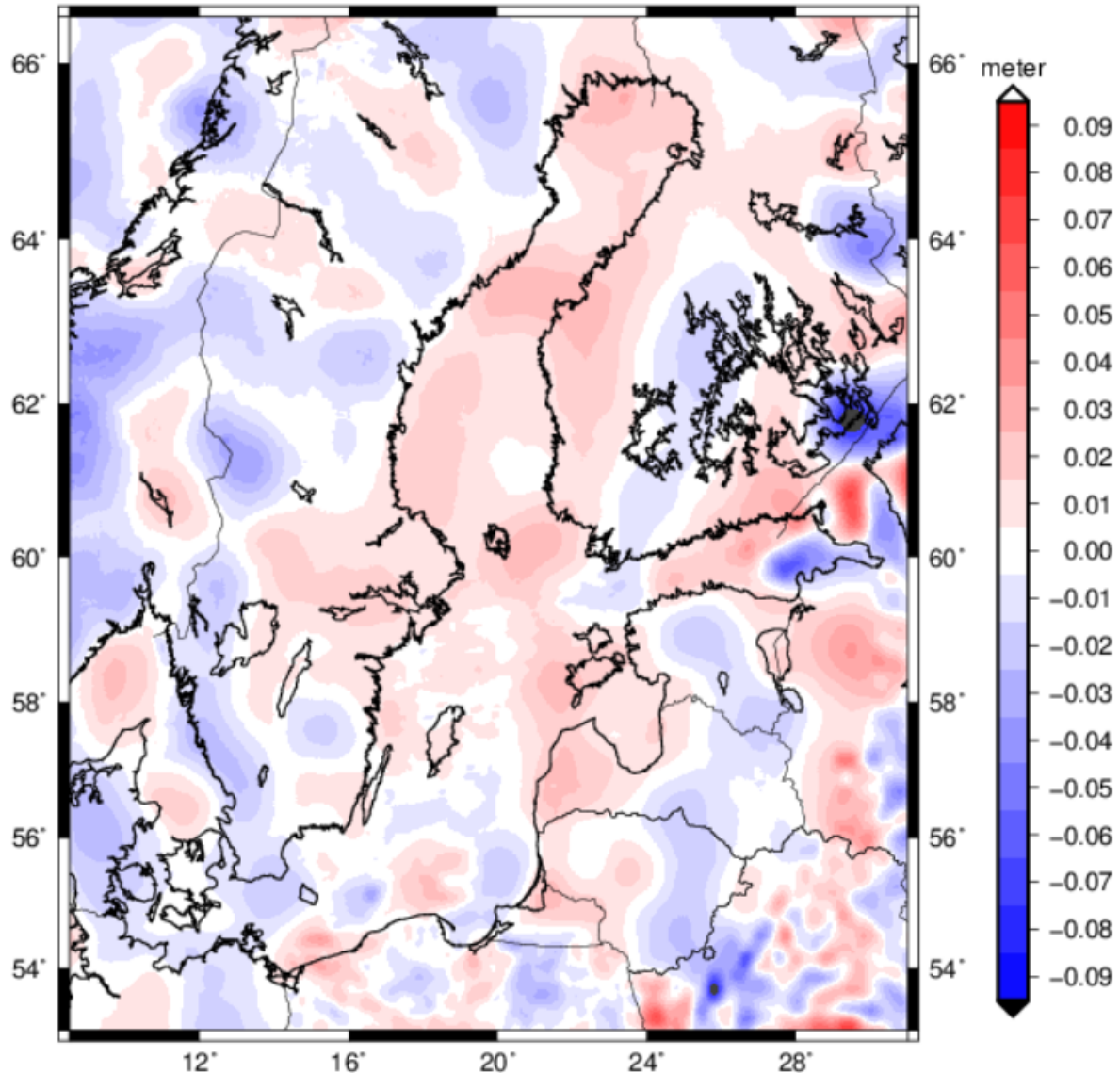
# A SELECTION OF FAMOS INTERIM GEOID MODELS

Partner	BKG I-PUMA	BKG3A	BKG3C	LM6A	LM6C	LM6E	TUT IA	TUT IC	FGI-IA
Method	Point-mass, RTM	RCR W&G, RTM	RCR W&G, RTM	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	LSMSA, LSC gridding	RCR W&G, RTM
Software implementation	BKG	BKG, SPFOUR	BKG, SPFOUR	LM/KTH	LM/KTH	LM/KTH	TUT/KTH	TUT/KTH	GRAVSOFT
FAMOS gravity DB	Ver. 1	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver. 2	Ver.2
EGM	GECO	GECO	GECO	DIR_R5	XGM2016	DIR_R5	GOCO05C	COCO05S	DIR_R5
Max. degree	2190	2190	2190	240/300	719	240/300	240	200	300
Bathymetry	GEBCO2014	GEBCO2014	GEBCO2014	No	No	GEBCO2019	No	No	No
Fill-in with altimetric gravity anomalies (DTU13)	Yes, sel. method 1	No	In good areas, sel. method 2	No	No	No	No	No	No
GNSS/lev StdDev*	0.029	0.027	0.027	0.029	0.028	0.029	0.030	0.032	0.047
GNSS/lev StdDev**	0.023	0.022	0.022	0.024	0.021	0.024	0.024	0.022	0.040

\*) Standard deviation relative to the mean value for the whole area, including Norway.

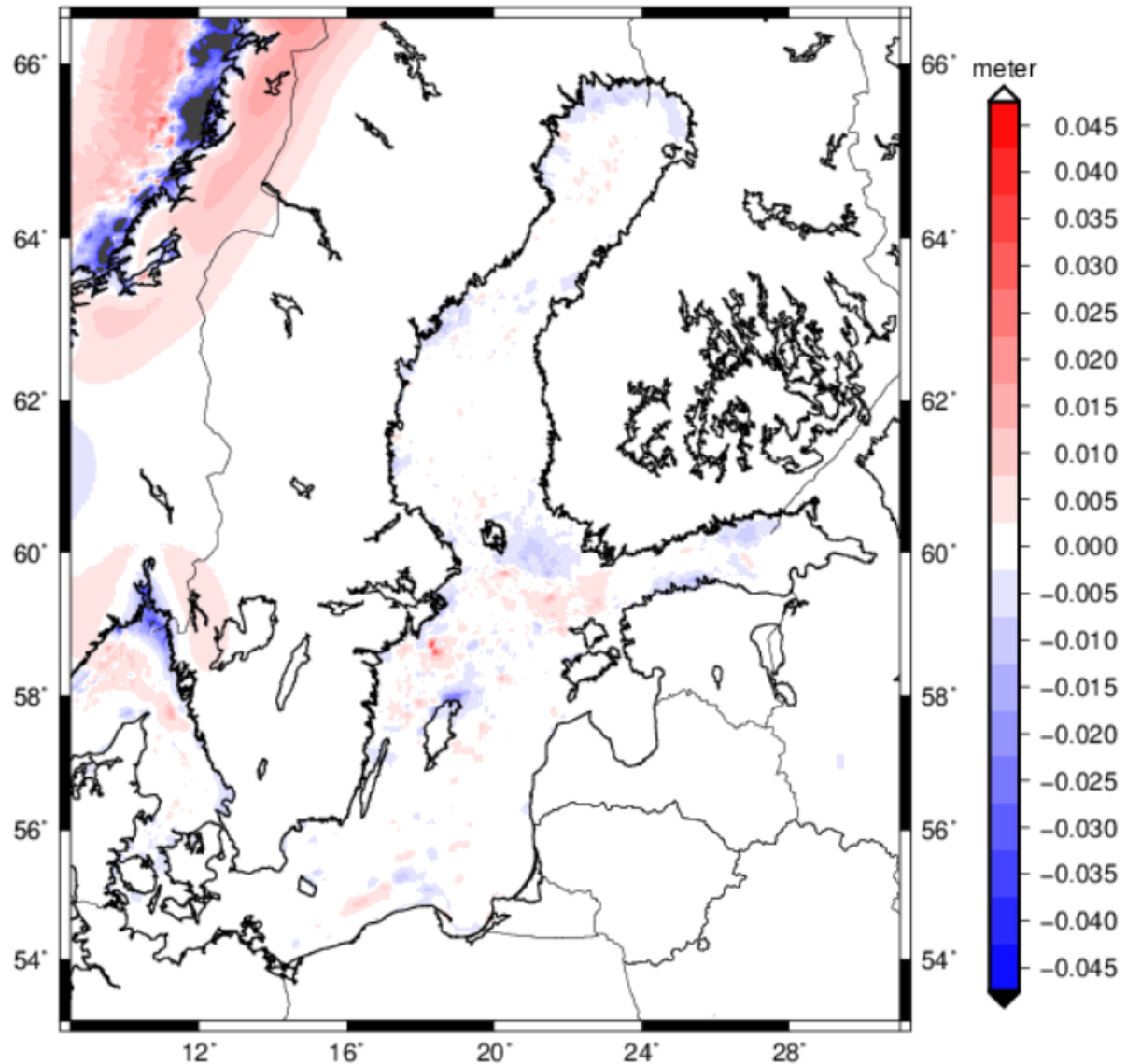
\*\*) Standard deviation with respect to individual data offsets per country, excluding Norway.

## COMPARISON BETWEEN INTERIM GEOID MODELS **LM6C** AND **LM6A**



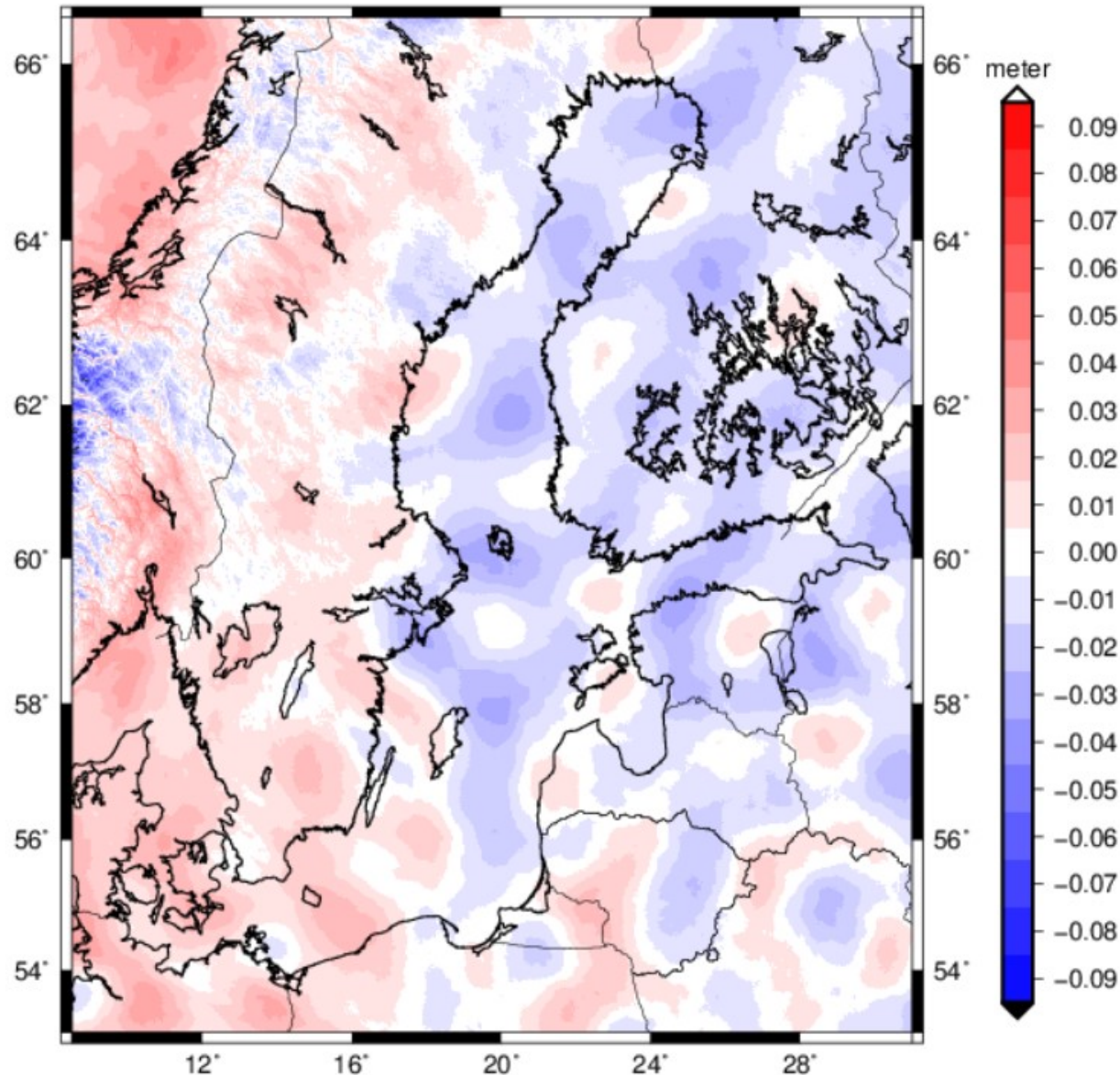
- Everything is the same except for the EGM.
  - LM6A: Satellite-only, DIR\_R5, M=300
  - LM6C: Combined XGM2016, M=719

## COMPARISON BETWEEN INTERIM GEOID MODELS LM6E AND LM6A



- Everything is the same, except for that **Bathymetry** is used for LM6E but not for LM6A
- Note that the scale is different in this slide

# COMPARISON BETWEEN INTERIM GEOID MODELS **TUT3C** AND **LM6A**



- Same computation method and surface gravity anomaly grid.
- Main differences between the models:
  - **Software implementation:**

TUT3C: TUT/KTH  
LM6A: LM/KTH
  - **Different satellite-only EGMs:**

TUT3C: GOCO05S, M=240  
LM6A: DIR-R5, M=300 vs
  - Different tunings of the least squares modification.
- Note:
  - This computation started from the LM6A surface gravity anomaly grid (i.e. no gridding differences).

# CONCLUSIONS AND RECOMMENDATIONS

- The majority of the selected FAMOS interim geoid models agree well with each other.
- The agreement to **GNSS/levelling on land** is about the same for all selected models (except for one solution that is still rather preliminary). It is not possible to say which model that is best based on this.
- In the **Baltic Sea**, the RMS values of the differences between the models are around **2-3 cm**.
- Note, however, that the **same FAMOS gravity database version 2** has been used for all the selected models (except for BKG-PUMA).
- The **same patch** has been used for the empty hole in the eastern **Gulf of Finland**.
- It is important that the FAMOS efforts to improve the gravity data situation and geoid model over the Baltic Sea continue. We aim for **FAMOS marine gravity with a reasonable area coverage**.
- The final phase of FAMOS, **STM-FAMOS**, is currently under preparation. A suitable EU call is expected at the end of 2019. The STM-FAMOS project can start in 2020 and go on till 2022 or 2023.

