Nordic Geodetic Commission
General Assembly
Copenhagen, September 5-8, 2022

Automated 2014-2019 Marine Gravity Surveys in Danish Waters: the Cross-Survey Modelling and Beyond

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Introduction. In years 2014-2019 DTU Space conducted 18 two-week ”opportunity” marine gravity surveys in Danish waters piggybacked on hydrographic survey vessels ”Jens Sørensen” (until 2018) and ”Poul Løwenørn” (from 2019). The data collection was highly automated with no dedicated personnel onboard. 3 out of 18 surveys suffered from the malfunction of the gravimeter (CHEKAN-AM) and the collected data could not be processed.

For each survey, the stand-alone (SA) processing of mostly incomplete and patchy navigation and gravity data was challenging and required new and flexible software. Although SA results at intra–survey crossings (the intra-crossings) seem reasonable (std. dev.: 0.3mGal to 0.7mGal; min/max: +/-1mGal to +/-1.5mGal) the inconsistencies of SA results at cross-survey crossings (the extra-crossings) were, for some surveys, as high as15mGal (or sometimes even larger).

Based on the scrutinous processing of the above 15 surveys, we conclude, that the mentioned inconsistency of SA results at extra-crossings is generic and a consequence of a deeper methodological challenge of marine gravimetry. The SA results are genericaly ambiguous caused by the choice of the assumed correction model. For each survey, the imposed correction model is (to some degree) constrained in harbors and, subsequently, extrapolated offshore between the harbors. However, the extrapolated correction model at sea cannot independently be verified/controlled. Consequently, the existing misfit of the SA processing results at (intra-/extra) crossings is a consequence of inadequate/incomplete corrections.

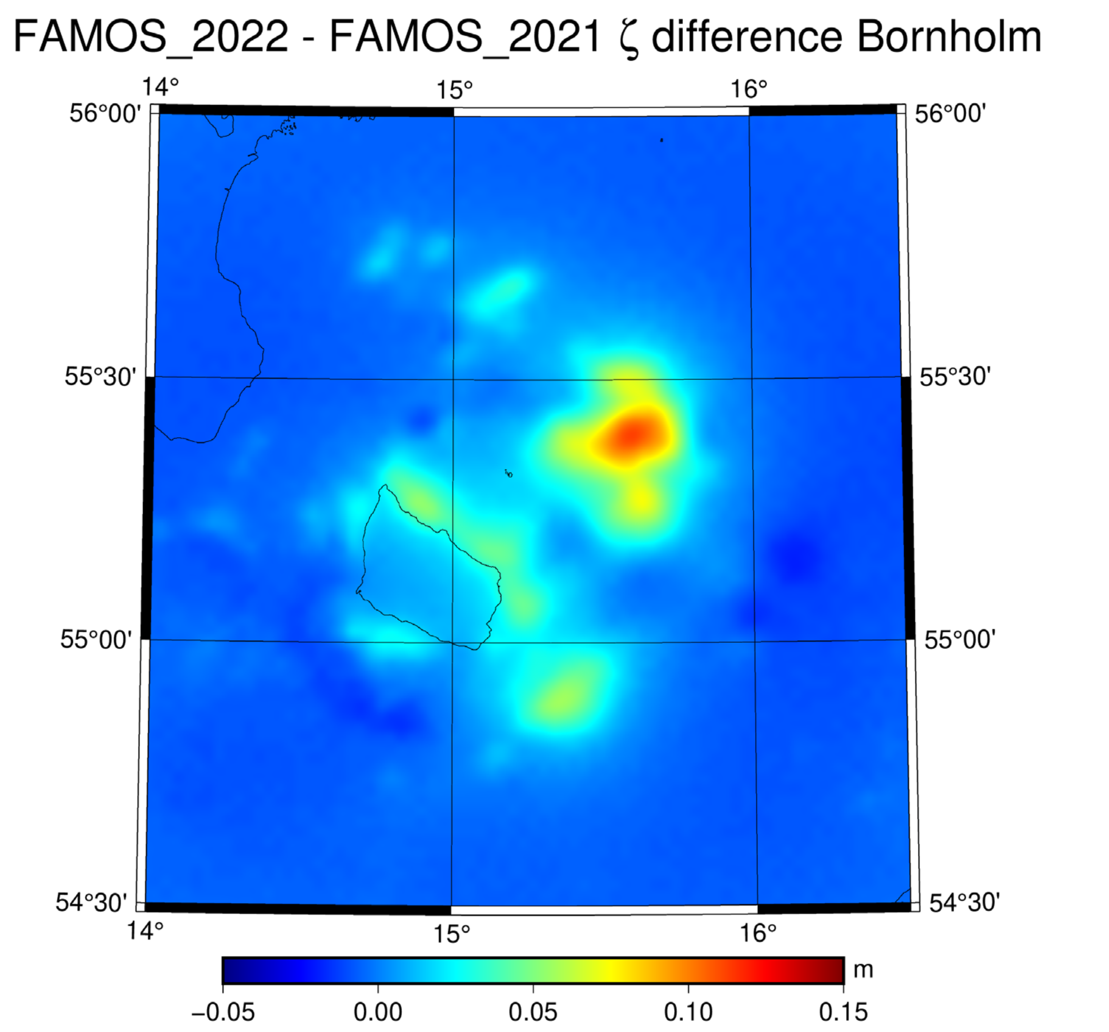

Figure 3. Illustrating the effect of cross-survey correction of the marine data on the local quasigeoid model. FAMOS-project quasigeoid difference near Bornholm from 2021 to 2022 FAMOS data versions. **2021 version:** The included 2014-1019 automated marine gravity data from the area were the SA processed results (shown on Figure 2) with the discussed possible cross-project inconsistencies. **2022 version:** The same data set, but the 2014-2019 automated marine data were cross-project corrected, see Figure 1. The 2014-2019 automated marine data set is the main marine data source in the area. Some other data sets (i.e. from the neighbouring countries) were also corrected between 2021 and 2022 versions of the FAMOS data set. The quasigeoid difference is between -2cm and 11cm. The large maximum is not related to the discussed correction. Notice that the correction has an effect on land.

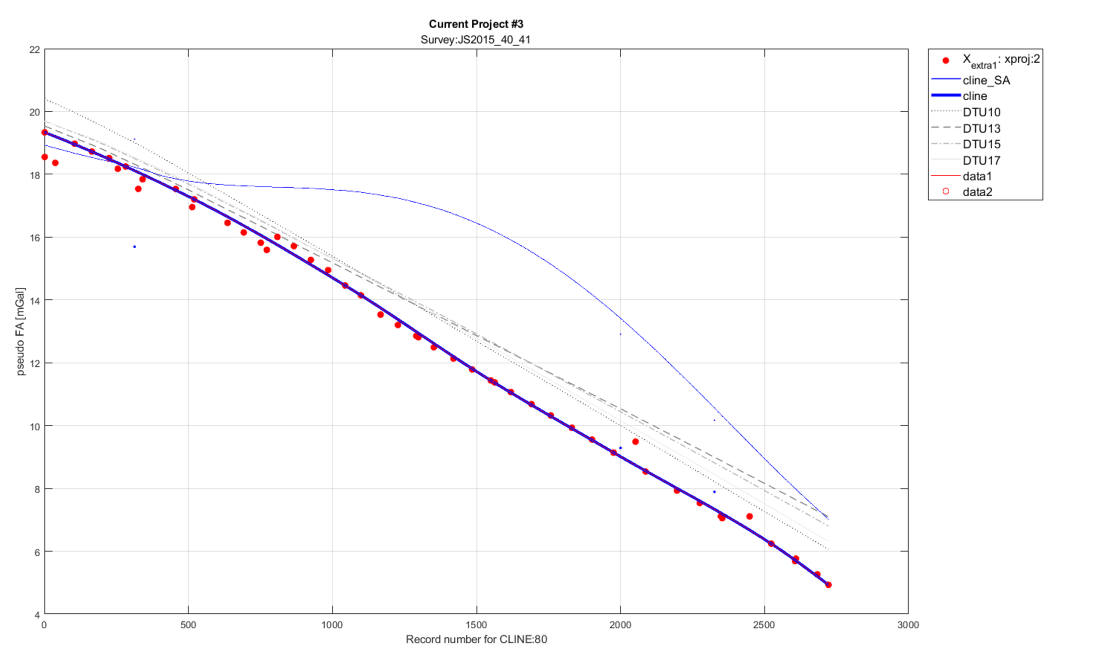

Figure 1. *Example of cross-project line processing for line #80 of project #3.* **Thin blue line:** best SA fit of pFA Δg_t through the actually measured marine gravity readings $\tilde{r}_t$ using SA corrections $\tilde{c}_t$. **Red dots:** pFA values corresponding to the joint modelling frame (under construction), see explanation in the poster. The cross-survey corrected pFA records of survey lines of other projects (in red) are only few meters away from the records of the current line #80. **Thick blue line:** The new cross-survey corrected line signal of line #80. **Background:** Along-line free-air gravity anomalies from altimetry (DTU10, DTU13, … etc.)

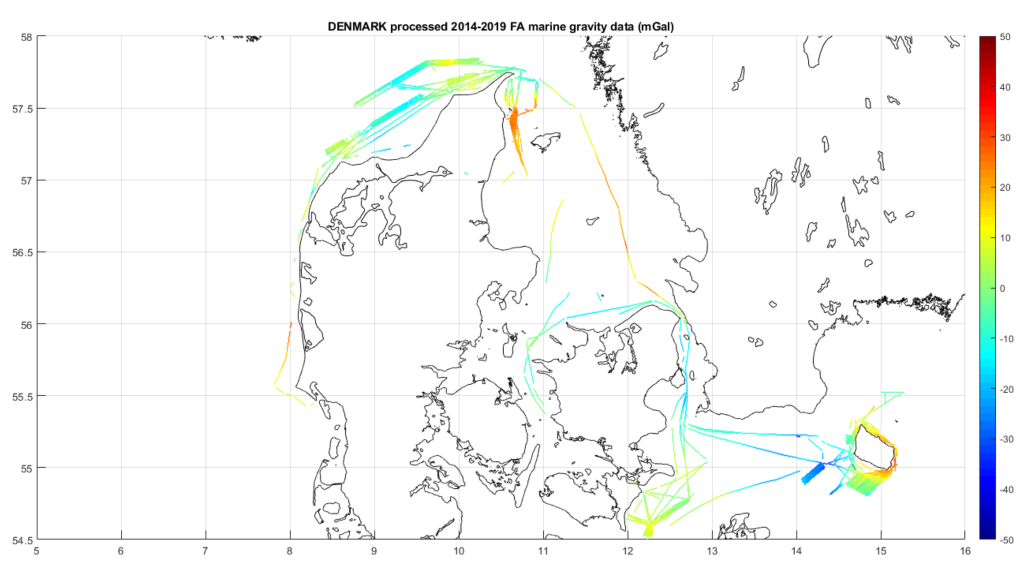

Figure 2. SA processed results of 15 automated 2014-2019 marine gravity surveys in Danish waters. The figure shows the geographical distribution of the results and the corresponding SA processed pFA values (in colour). For each survey, these results were characterized by reasonable intra-survey crossing statistics (the intra-crossings), but (for some surveys) an inconsistent cross-survey statistics (the extra-crossings). An example of the effect of these inconsistencies on the quasigeoid model around Bornholm can be seen in Figure 3.

New paradigm in marine gravity processing

- All crossing marine gravity surveys should be expressed in a joint modelling frame ensuring from the start the consistency of the results at extra-crossings. Future (crossing) surveys, when included, add new information to the joint modelling frame.
- SA processing should be abandoned as it is ambigious, see Introduction. Instead, use as absolute reference for line processing models based on altimetry (DTU17 … and/or others) and the above modelling frame, see Figure 1.
- Keep track of the correction history for each survey to be dynamically reversed/modified.

Pseudo free-air gravity anomalies

$$\Delta g_t = \Delta g_{ref,t_0} + \alpha \cdot \left[\left(\tilde{r}_t - \tilde{c}_{\Delta g,t} \right) - r_{ref,t_0} \right]$$

For a survey record associated with time *t* we express the fundamental equation of relative gravimetry as *pseudo free-air gravity anomalies (pFA)* Δg_t. For the reference time t_0, $\Delta g_{ref,t_0}$ refer to the pier level in the reference harbour (harbour tie) and r_{ref,t_0} is the corresponding reference reading of the marine gravimeter. For the marine gravimeter ∝ is the scale factor, $\tilde{r}_t$ is the uncorrected reading and $\tilde{c}_t$ is the applied total correction of this reading for time t.

Cross-survey correction strategy and results

In correcting the SA results of 2014-2019 automated gravity surveys prior to the recent final FAMOS-project gravity data release we have designed a new cross-survey modelling method. The cross-survey consistency of the corrected results is close to perfect, see Figure 1. The correction is in two parts:

1. The rough correction (see Figure 1): both shape and bias correction of SA results supported by FA gravity models from satellite altimetry and by crossings with corrected external surveys (the ”red dots” on Figure 1).
2. The finetuning (a bias correction) to optimize the intra-survey statistics (which can get ”out of tune” after step 1)

The principle of the new method of the cross-survey correction is: It is always the current line that is being corrected. The clear inconsistencies caused by other lines will be corrected subsequently once these lines of the crossing project are revisited by a ”correction loop”.

Example: Notice few obvious deviations of the ”red dots” from the thick blue line (the corrected line model) on Figure 1. These deviations indicate cross-project model inconsistencies that are first corrected once the crossing project is revisited.