Geophysical subsurface modelling based on the updated, enhanced regional gravity field solution in Antarctica

EGU21-10590

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I) New gravity field solution

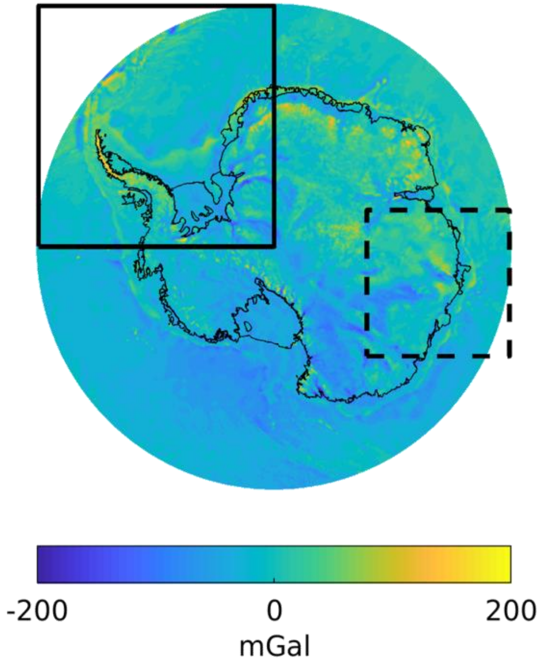

***Fig. 1:** Gravity disturbance calculated within the project **AntGrav**. Solid black box: model area of Fig. 2 (Weddell Sea). Dashed black box: model area of Fig. 3 (Queen Mary Land)*

II) Gravity forward modelling

Forward modelling with IGMAS+ (Götze und Lahmeyer 1988; Schmidt et al. 2020) of selected testing areas.

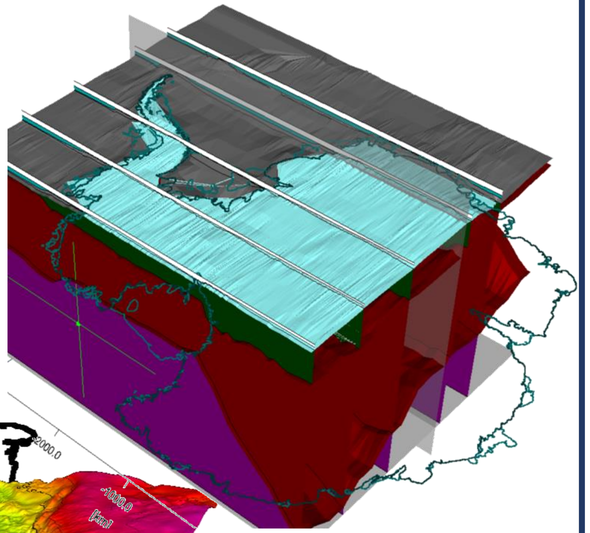

***Fig. 2:** 3D subsurface model of the Weddell Sea, Antarctic Peninsula, Ellsworth Land and Coats Land.*

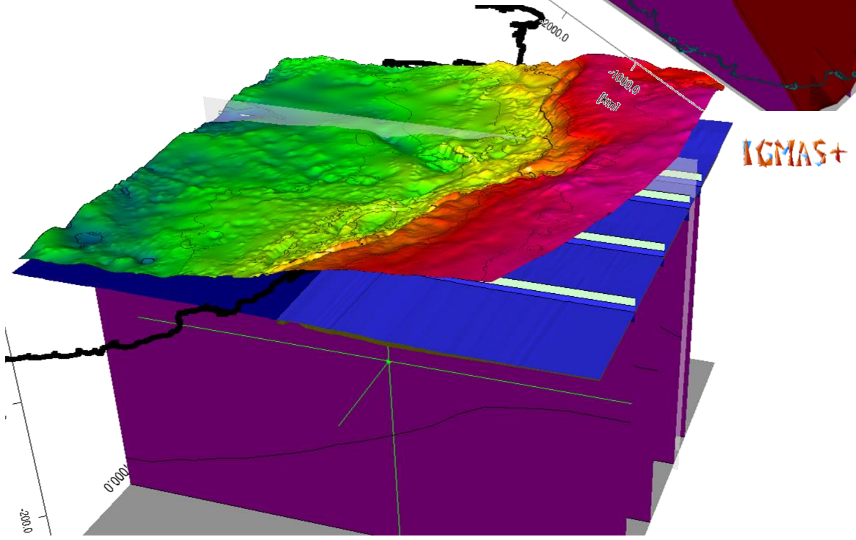

***Fig. 3:** 3D subsurface model of Queen Mary Land and Davis Sea. The Bouguer gravity disturbance of the study area is shown above the model.*

III) Parker-Oldenburg Inversion

Inversion (Oldenburg 1974) of the gravity disturbance for subglacial topography for entire Antarctica.

$$\mathcal{F}[h(x)] = -\frac{\mathcal{F}[\Delta g(x)]e^{|k|z_0}}{2\pi G\rho} - \sum_{n=2}^{\infty}\frac{(|k|^{n-1})}{n!}\mathcal{F}[h^n(x)]$$

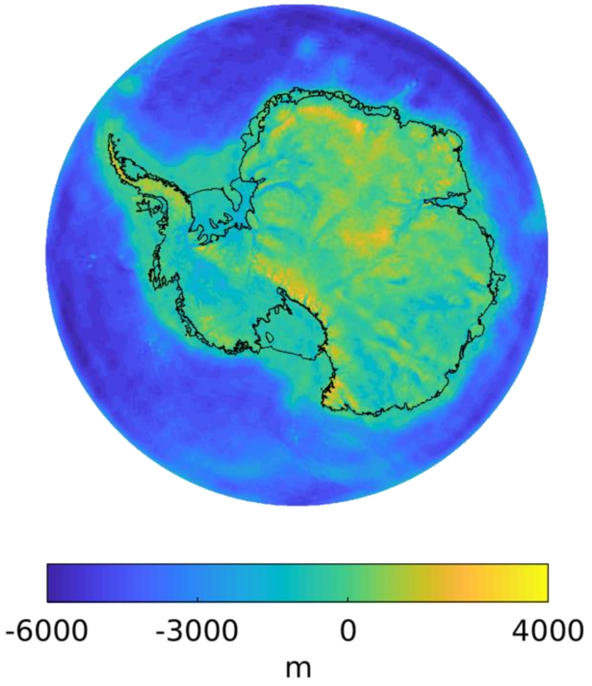

***Fig. 4:** Preliminary result of inverted subglacial topography*

Motivation

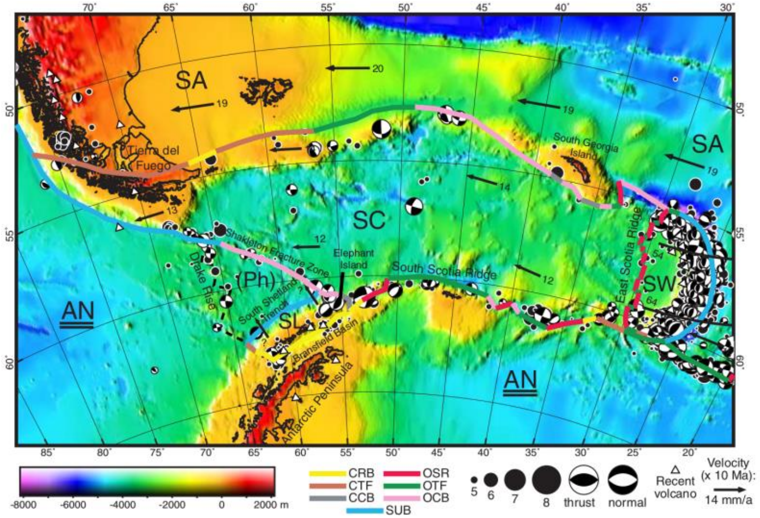

***Fig. 5:** taken from Bird et al. (2003, https://doi.org/10.1029/2001GC000252). Plates: SL – Shetland, SC – Scotia, SW – Sandwich, AN – Antarctica, SA – South America*

The Antarctic continent plays a major role in many geoscientific studies including e.g. plate tectonic reconstruction, GIA (glacial isostatic adjustment) modelling and climate change. In these studies the thickness of the ice sheet, subglacial topography, thickness of the sedimentary basins and the topography of the Mohorovičić discontinuity (Moho) are important parameters.

Still, in Antarctica it is extremely difficult to carry out geoscientific studies due to its harsh environment and difficult logistics. Additionally, the up to 5 km thick ice sheet complicates most geoscientific studies (e.g. surface geology, seismics, ...). Gravity field measurements are also difficult. Still, a large database of airborne, shipborne and ground measurements exists.

Subsurface modelling based on gravity data and constraint with results from other methods is therefore not only possible, but also very helpful to study the aforementioned boundaries on continent-wide scales.

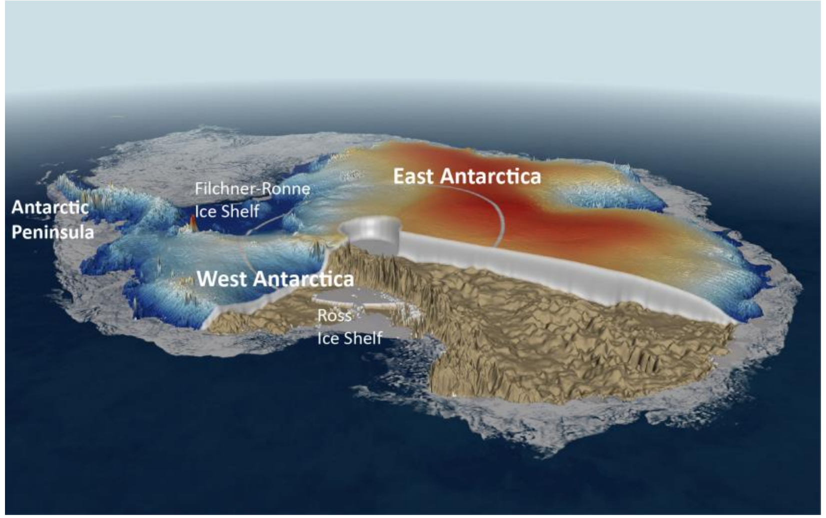

Fig. 6 *Structure of Antarctica* (©CPOM/UCL/ ESA/Planetary Visions)




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I) New gravity field solution

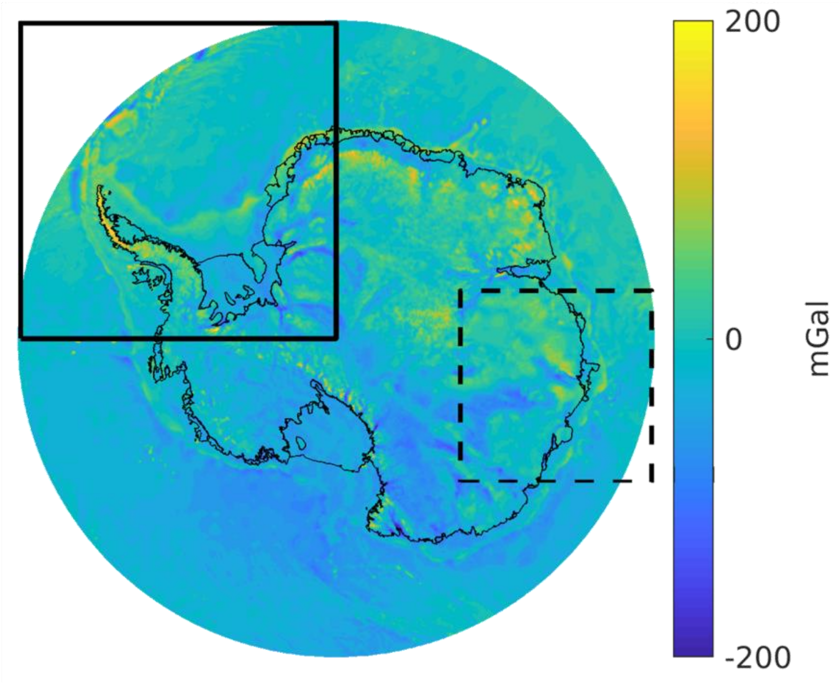

Fig. I.1: Gravity disturbance calculated within the project AntGrav. Solid black box: model area of (Weddell Sea model). Dashed black box: model area of (Queen Mary Land model)

In the framework of IAG Subcommission 2.4f "Gravity and Geoid in Antarctica" (AntGG) a large database of airborne, shipborne and ground based gravity data has been compiled. Especially airborne data have been acquired during recent years, among others in the polar gap of satellite gravity data. Now, in a joint project funded by the German Research Foundation (DFG) all existing and new gravity data were processed to infer an enhanced gravity field solution for Antarctica.

- For further information on the validation and pre-processing of the gravity data refer to:

* Zingerle et al., 2019. Evaluation of terrestrial and airborne gravity data over Antarctica – a generic approach.
https://doi.org/10.1515/jogs-2019-0004

- Also, within the AntGrav-project the well known collocation method was improved (e.g. in order to process these large amounts of data, including other improvements).
  For more details refer to:

* Zingerle et al. 2021. A partition-enhanced least squares collocation approach (PE-LSC), J. Geod. in review.

- Processed data e.g. gravity disturbances at constant height and other functionals will be provided on a regular grid with 5 km grid spacing. The results will be published this year.

  Look out for:

* Scheinert et al. 2021 (in prep.).

Refer also to these EGU 2021 contributions:

- Zingerle et al. 2021. Integrating NGS GRAV-D gravity observations into high-resolution global models. EGU21-7955
- Scheinert et al. 2021. Towards an updated, enhanced regional gravity field solution for Antarctica. EGU21-9873

II.1) Gravity forward modelling – Weddell Sea (WS)

Underneath the Antarctic shelf ice large sedimentary basins are known to be present (e.g. Straume et al. 2019 https://doi.org/10.1029/2018GC008115, Fig. II.1.1). But, their extend and thickness are still not known in detail.
In continent wide compilations (e.g. Bedmap2, Fretwell et al. 2013, https://doi.org/10.5194/tc-7-375-2013) they are mostly not considered.

In Antarctica the largest sediment basin is present in the Weddell Sea area. In the framework of the AntGrav project we use gravity forward modelling with IGMAS+ (Götze und Lahmeyer 1988 http://dx.doi.org/10.1190/1.1442546; Schmidt et al. 2020 https://doi.org/10.5194/egusphere-egu2020-8383) to study this sediment basin in more detail.

The model also includes the Antarctic Peninsula, parts of the Antarctic continent (Ellsworth Land, Coats Land), the Filchner and Ronne ice shelfs and adjacent Seas (e.g. Bellingshausen Sea) (Fig. II.1.4) and is based initially on data from Bedmap2, GlobSed and Pappa et al. 2019 (Moho und LAB, https://doi.org/10.1029/2019JB017997).

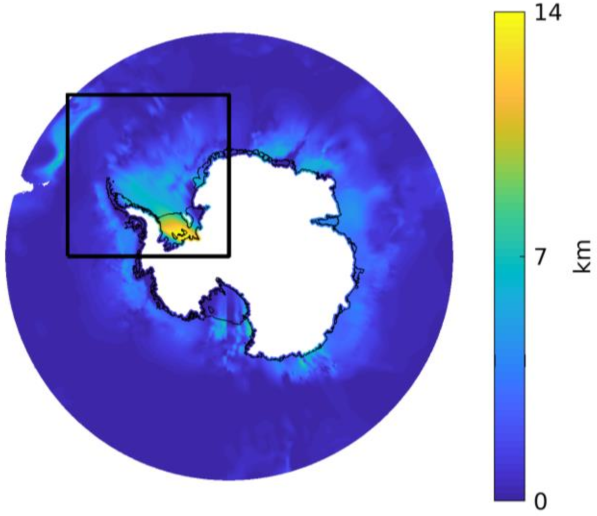

Fig. II.1.1: *Sediment thickness from GlobSed (Straume et al. 2019). Black box: study area of the WS- model.*

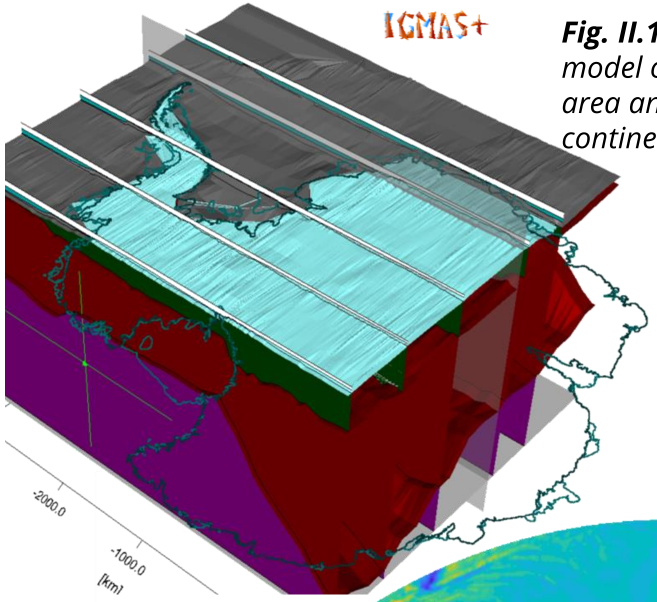

Fig. II.1.2: *3D subsurface model of the Weddell Sea area and the surrounding continent (WS- model).*

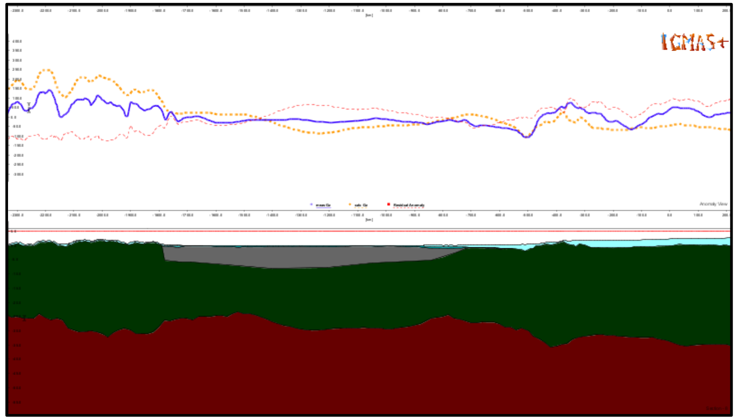

Fig. II.1.3: *Cross-section through the WS- model. Dashed orange line: calculated gravity effect of the WS- model. Solid blue line: Free-air gravity disturbance of the enhanced gravity field model. Thinner dashed red line: Difference between measured and calculated gravity.*

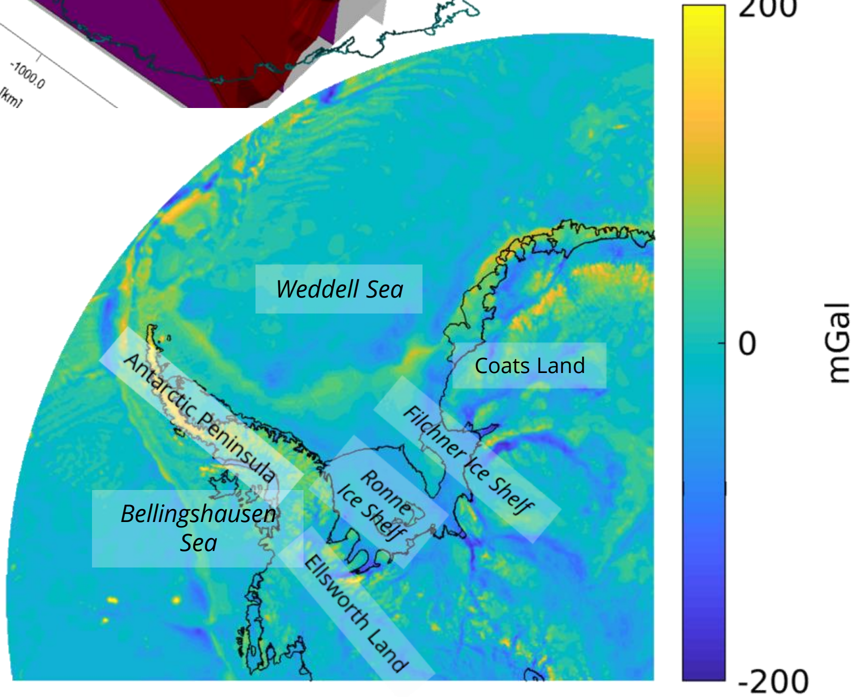

Fig. II.1.4: *Gravity disturbance of the study area.*

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II.2) Gravity forward modelling – Queen Mary Land (QML)

The enhanced gravity field solution shows an interesting anomaly in the area of Queen Mary Land (dashed black circle in Fig. II.2.1).

In the same area, the bedrock topography of Bedmap2 (Fretwell et al. 2013 https://doi.org/10.5194/tc-7-375-2013, Fig. II.2.2) shows a small valley. Still, the depth of the valley in Bedmap2 alone does not explain this pronounced gravity low. Interestingly, the Indo-Australo-Antarctic suture is assumed to be in this area (grey boxes in Figs II.2.1 and II.2.2). It's exact location remains unknown. A 3D subsurface model (Figs II.2.3 and II.2.4) built in IGMAS+ (Götze und Lahmeyer 1988 http://dx.doi.org/10.1190/1.1442546; Schmidt et al. 2020) https://doi.org/10.5194/egusphere-egu2020-8383 will, hopefully, help to shed light into the origin of this peculiar anomaly. The model is based on data from Bedmap2, GlobSed and Pappa et al. 2019 (Moho und LAB, https://doi.org/10.1029/2019JB017997)

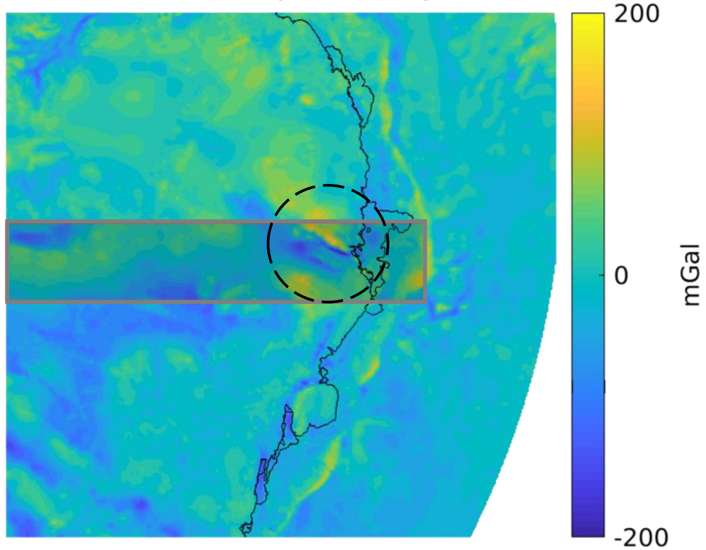

Fig. II.2.1: *Gravity disturbance (at h_{ellips} = 5 km) of the enhanced gravity field model. The black circle highlights the peculiar anomaly in the gravity field. Sold grey box: Area in which the Indo- Australo- Antarctic suture is assumed to be present.*

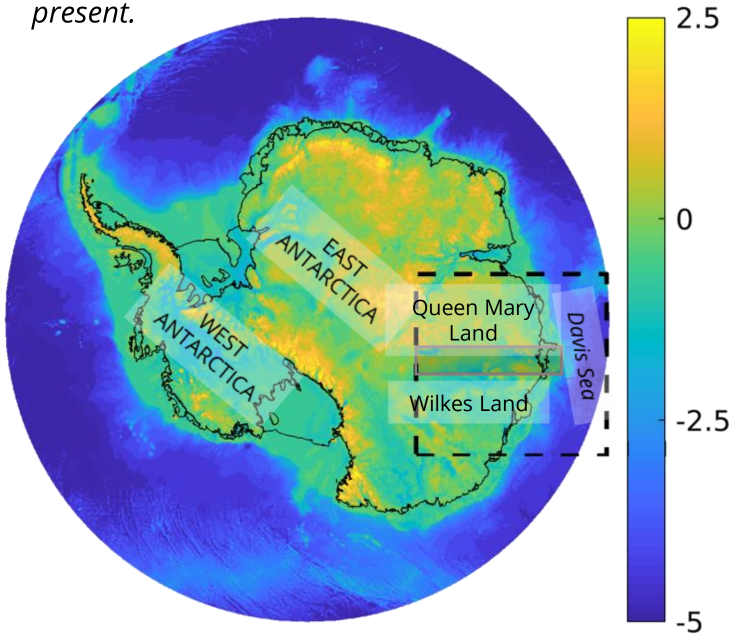

Fig. II.2.2: *Bedrock topography from Bedmap2 (Fretwell et al. 2013). Dashed black box: study area of QML- model. Solid grey box: area in which the Indo-Australo-Antarctic suture is assumed to be present.*

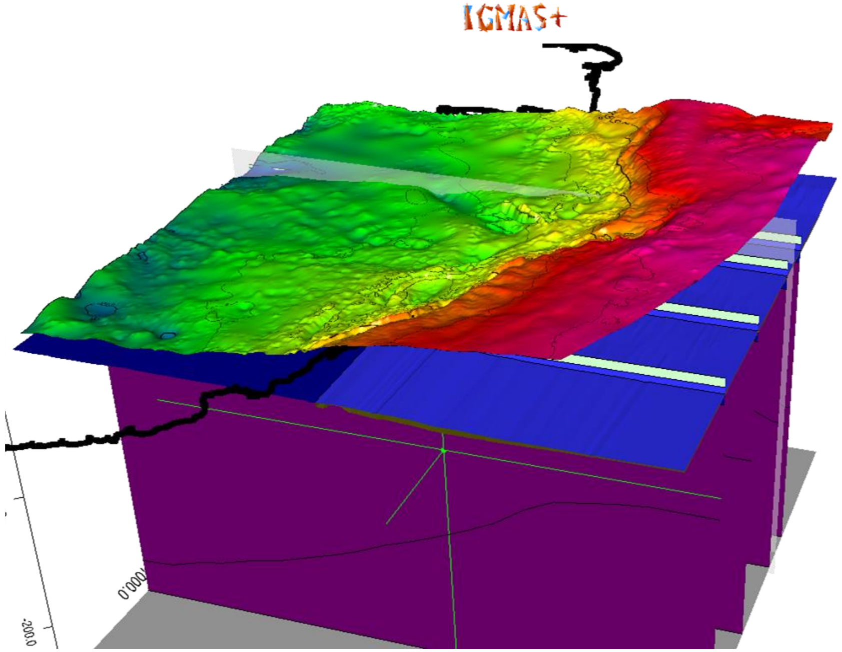

Fig. II.2.3: *3D subsurface model of Queen Mary Land and Davis Sea (QML- model). The Bouguer gravity disturbance of the study area is shown above the model.*

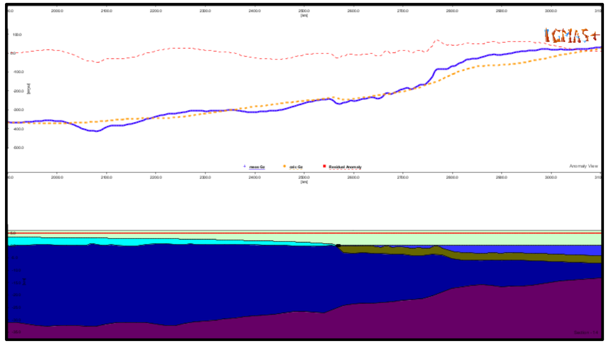

Fig. II.2.4: *Cross-section through the QML- model. Dashed orange line: calculated gravity effect of the QML- model. Solid blue line: Bouguer gravity disturbance of the enhanced gravity field model. Dashed red line (at top): Difference between measured and calculated gravity.*

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ANTARKTIS FORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

III) Parker-Oldenburg Inversion (POI)

Parker-Oldenburg Inversion (Oldenburg 1974. The Inversion and Interpretation of gravity anomalies. Geophysics. 39) is a well established method for the inversion of gravity data for the geometry of a given layer. As can be seen in Eq. 1 two parameters have to be known (or estimated) in order to calculate a plausible topography: the density contrast across the interface (ρ) and the average depth (z_0).
Additionally the gravity data has to be low-pass filtered, since high frequency noise makes the inversion highly unstable. On the other hand, the gravity field correlates with topography only at medium wavelengths (< approx. 300 km). Therefore, the resulting topography (Δh) will be band-pass limited. Short wavelengths cannot be recovered. Long wavelengths can be inferred from a regional model. (Here, we use bedmap2, Fretwell et al. 2013 https://doi.org/10.5194/tc-7-375-2013).

Workflow

1) Pre-processing
   - Input: gravity disturbance at h_{ellips} = 5 km (Fig. I.1)
   - Apply circular window (Fig. III.1)
2) Set different densities and average depths
3) Inversion
   - Calculate Δh according to Eq. 1 (Fig. III.2)
   - Compare to band-pass filtered bedmap2 with weighted standard deviation (Fig. III.3)
   - Add long wavelengths from low-pass filtered bedmap2 (Fig. III.4)

$$\mathcal{F}[h(x)] = -\frac{\mathcal{F}[\Delta g(x)]e^{|k|z_0}}{2\pi G\rho} - \sum_{n=2}^{\infty}\frac{(|k|^{n-1})}{n!}\mathcal{F}[h^n(\mathrm{x})]$$

Eq. 1: *Parker-Oldenburg Inversion (Oldenburg 1974). Δh: topography of the inverted boundary (with respect to a mean), Δg: gravity (disturbance), k: wavenumber, z_0: average depth, ρ: density contrast, G: gravitational constant, $\mathcal{F}$: Fourier transform.*

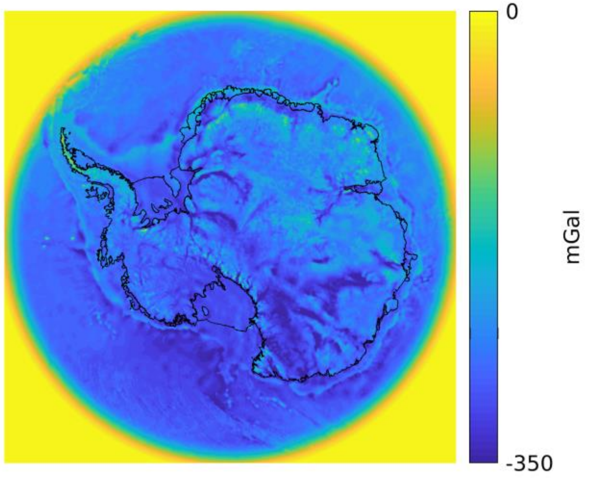

Fig. III.1: *Tukey windowed gravity data as input for POI*

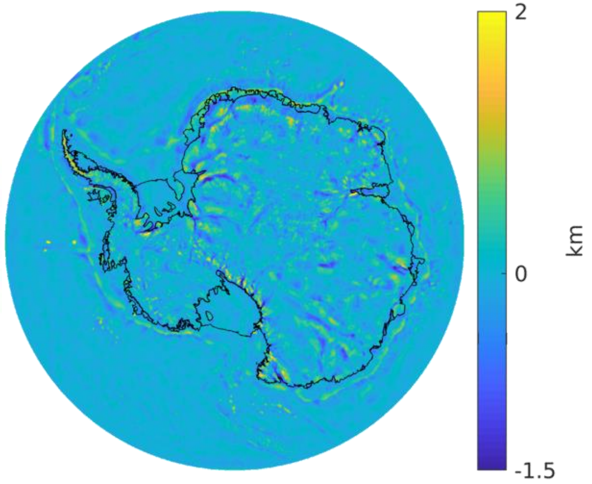

Fig. III.2: *(filtered) POI result*

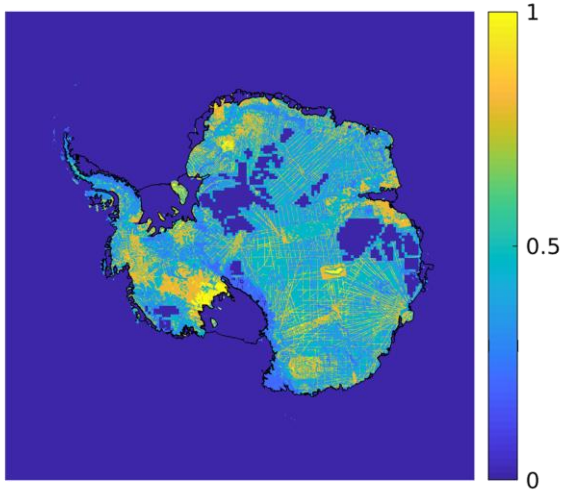

Fig. III.3: *weights for the calculation of the standard deviation. Based on Bedmap2 – distance to nearest datapoint (Fretwell et al. 2013)*

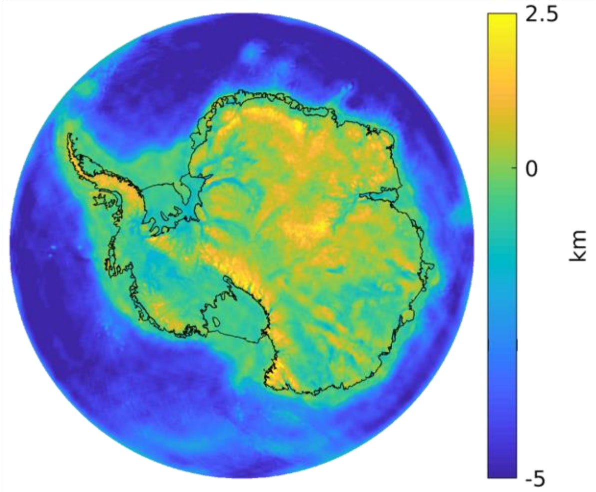

Fig. III.4: *final inversion result*