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POLAR GRAVITY FIELDS FROM GOCE AND AIRBORNE GRAVITY

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ABSTRACT

Airborne gravity, together with high-quality surface data and ocean satellite altimetric gravity, may supplement GOCE to make consistent, accurate high resolution global gravity field models. In the polar regions, the special challenge of the GOCE polar gap make the error characteristics of combination models especially sensitive to the correct merging of satellite and surface data. We outline comparisons of GOCE to recent airborne gravity surveys in both the Arctic and the Antarctic. The comparison is done to new 8-month GOCE solutions, as well as to a collocation prediction from GOCE gradients in Antarctica. It is shown how the enhanced gravity field solutions improve the determination of ocean dynamic topography in both the Arctic and in across the Drake Passage. For the interior of Antarctica, major airborne gravity programs are currently being carried out, and there is an urgent need for coordination, release and quality control of these data for the supplement of GOCE, as well as a need for an international coordinated effort to fill-in the GOCE polar gap.

1. INTRODUCTION

Airborne gravimetry provides a natural supplement to GOCE, allowing the extension of resolution to high degrees, around 3000 or so, corresponding to the typical resolution of 5-8 km of long-range airborne gravity [1]. Airborne gravimetry plays a specially important role in covering the polar gaps of the GOCE mission (the regions above latitude 83.3 N), where solutions based on GOCE only will have serious problems to match the error characteristics in lower latitudes, unless additional surface data (and GRACE data) is taken into account.

For the northern hemisphere, most of the northern polar gap has been covered by either long-range airborne gravimetry [2], or released Russian grid data. All of these data have been compiled in the Arctic Gravity Project [3], with last version computed in 2008. Opposed to the Arctic, the Antarctic polar gap is essentially uncovered, and there is a need to initiate a consorted effort the cover this region with aerogravity, to fully match the spatial resolution of GOCE.

In this paper we will compare recently released 8-month spherical harmonic gravity fields from GOCE, covering the period Nov 2009-June 2010, with the ArcGP results and new airborne data in Antarctica. The GOCE satellite-only models available are the "timewise" method [4] model, complete to degree and order 250 and based on GOCE data only, and the "direct" method [5], complete to degree and order 240, based GOCE and apriori GRACE information. Both models have been downloaded from the International Centre for Global Earth Models, see http://icgem.gfz-potsdam.de/ICGEM

2. ARCTIC COMPARISON - GRAVITY

The high quality of the GOCE results is illustrated by the comparison of the GOCE gravity (Fig. 1) and the similar ArcGP composite grid (Fig. 2). Fig. 1 highlight clearly how GOCE measures important bathymetric features such as the Lomonosov and Gakkel Ocean Ridges, but also picks up signals due to sedimentary basins, e.g. in the Nares Strait and off NE Greenland at 75 N (the "Danmarkshavn" basin, a basin of major interest for future oil exploration). If fields are extended beyond degree 180, it is apparent that noise dominates the higher wavelengths (see Fig. 3), but it is also clear that some geophysical features get even more "sharpened". However, error studies indicate that degree 180 is a reasonable cut-off for the GOCE fields, and therefore used for the investigations of this paper.

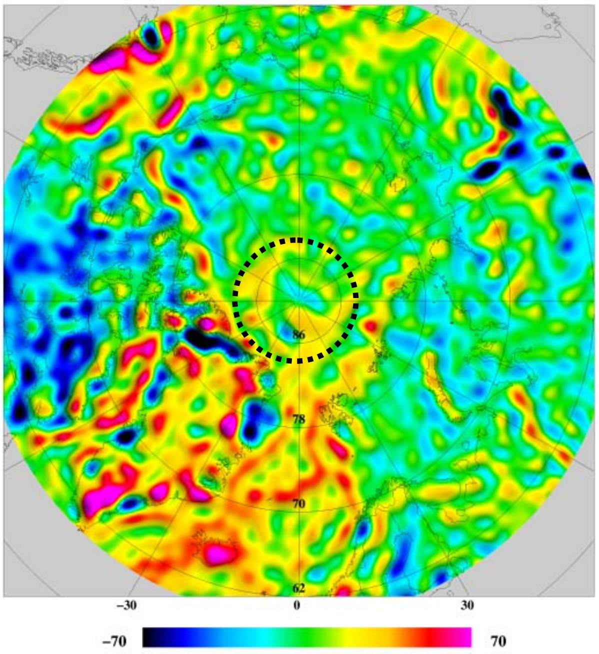

Fig. 1. GOCE gravity field in the Arctic ("Timewise" model to degree 180. Unit mGal. Dotted circle indicate extension of "polar gap".

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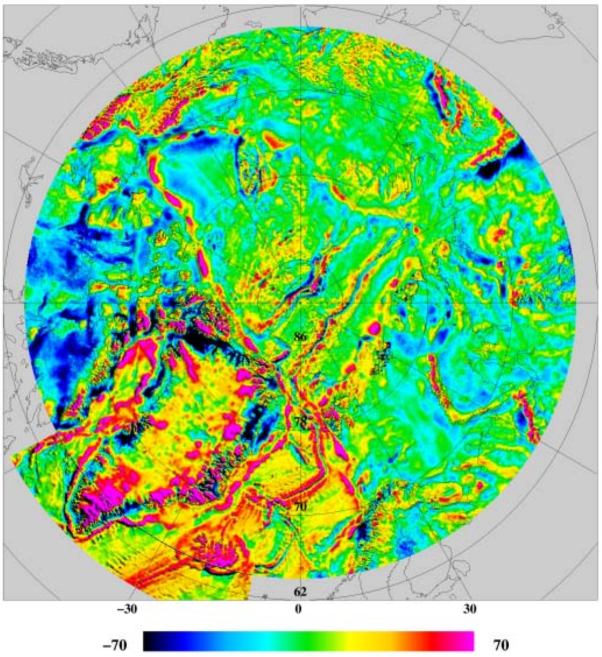

Fig. 2. Arctic Gravity project free-air anomaly grid, mGal. The data is compiled from major airborne surveys, surface, icebreaker and submarine data.

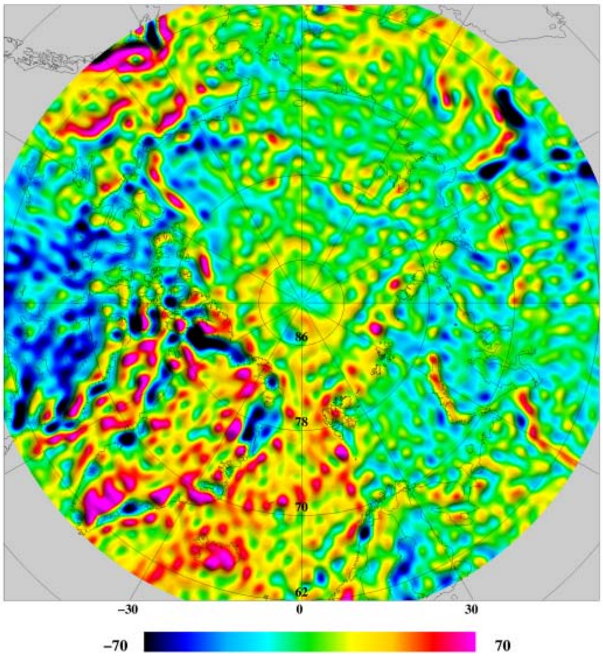

Fig. 3. GOCE timewise solution, to degree 250. Compared to Fig. 1, the noise signal is apparent.

The comparison between the ArcGP grid and GOCE is shown in Table 1. Here we directly compare the ArcGP to GOCE, but also compare only in a comparable spectral band (i.e., by filtering the ArcGP grid equivalent to spherical harmonic degree 180 prior to comparison). The comparison is done in two areas: The total ArcGP area in a band 64-86N, and the smaller "western sector" (76-86N,180W-30E) where the ArcGP data is dominated by recent airborne gravimetry. It is seen that a remarkably good bias fit is obtained, and that comparing in a similar spectally band gives an error at the 10 mGal level, quite satisfactory giving the large downward continuation errors from GOCE. It is also seen that the "timewise" method seems to be marginally better in this region.

Table 1. Comparison of ArcGP to GOCE

	Original ArcGP		ArcGP - GOCE		Filtered deg 180 r.m.s.
	Mean	St.dev.	Mean	St.dev.	
Timewise: All area	3.5	28.3	0.2	17.9	8.5
West sector	8.5	31.8	0.0	21.6	9.9
Direct: All area	3.5	28.3	0.3	18.7	10.0
West sector	8.5	31.8	0.2	23.1	12.9

3. ARCTIC COMPARISON - GEOID

The geoid of the Arctic region has major applications e.g. for determination of sea ice thickness by ICESat and CryoSat, as well as the determination of dynamic topography. A pre-GOCE "ArcGP geoid" model has been determined by 1-D spherical FFT methods, in a remove-restore technique using the GRACE GGM02 model as reference field. The method use a modified Stokes' function kernel allowing the ArcGP data to only have influence for spherical harmonics above degree 80, for details see [6].

The ArcGP geoid has been used as "ground thruth" for comparison to the GOCE-derived geoids. Fig. 4. and 5 shows the differences to the GOCE geoids for both the "timewise" and "direct" solutions. The polar gap effect is seen clearly in both models, highlighting the need for combination solutions of GOCE and GRACE plus local data in the polar gaps.

The mean dynamic topography (MDT) of the Arctic Ocean using GOCE for the period 2002-8 is shown is shown in Fig. 6, derived by

$$MDT = MSS + N \quad (1)$$

where MSS is the an average means sea surface derived from a combination of ICESat and ERS satellite altimetry [6], and N the GOCE geoid. An oceanographic model of MDT for the same period, provided by University of Washington (M. Steele, pers.comm.) is shown in Fig. 7 for comparison. It is again seen that the polar gap causes problems, but that the overall features of the MDT is resolved better in the areas away from the polar gap, compared to the earlier GRACE/ArcGP results, for details see the ESA ArcGICE report [6].

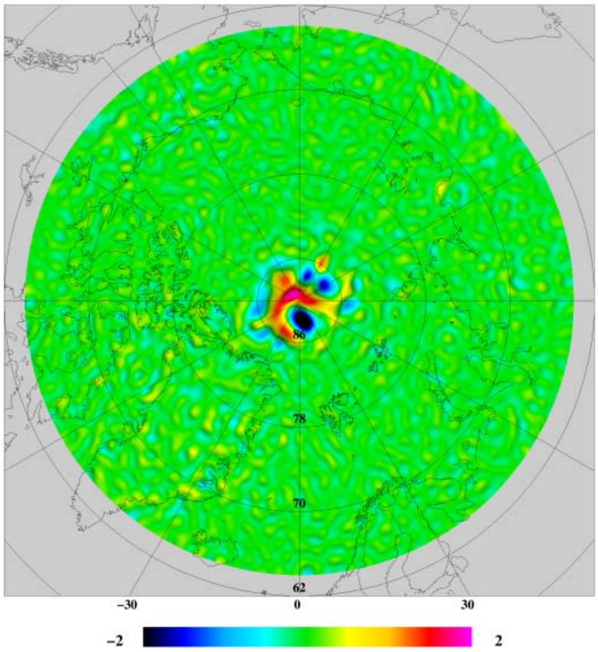

Fig. 4. Comparison of the GOCE "timewise" geoid (to degree 150) to the GRACE-based ArcGP geoid. Unit m.

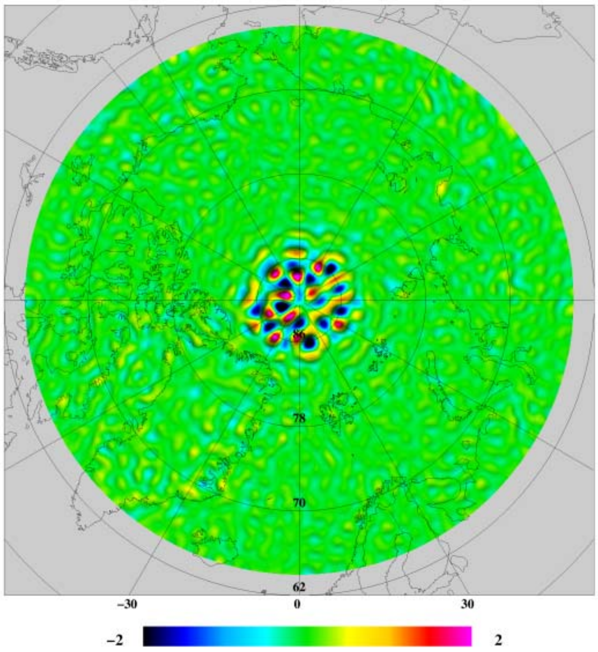

Fig. 4. Comparison of the GOCE "direct" geoid to degree 150 to the GRACE-based ArcGP geoid. Unit m.

3. ANTARCTICA - GRAVITY

Compared to the Arctic, the gravity coverage in Antarctica is much more sparse. Only limited areas have been covered with gravity data, although major ongoing airborne projects by groups like AWI, BAS, NASA-IceBridge, University of Texas and DTU-Space in later years has slowly been covering larger and larger areas.

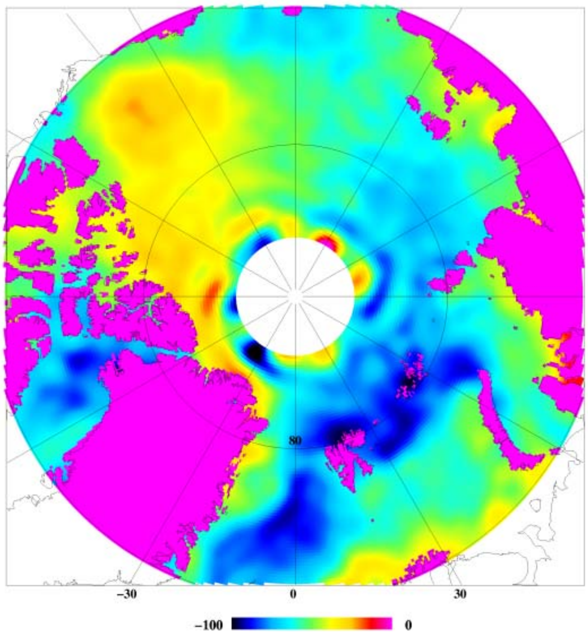

Fig.7. MDT of the Arctic Ocean from GOCE. Unit cm.

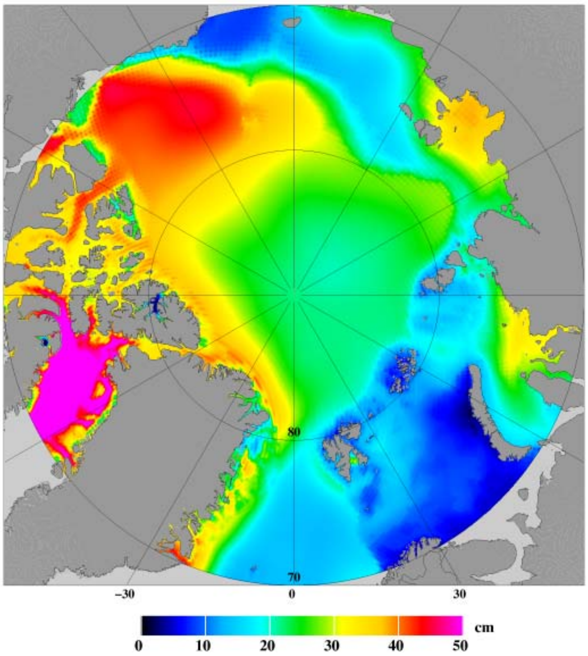

Fig. 8. MDT of the Arctic Ocean for the period 2002-8 derived from oceanographic model (Univ. Washington)

Fig. 9 shows the gravity coverage in the IAG/SCAR "Antarctic Geoid Project", and highlight the lack of data in many regions (AntGP has so far mainly collected AWI and Russian data, still lacking many newer IPY data sources). Fig. 10 shows the recent combined survey efforts of University of Texas and DTU-Space, sharing a common long-range turbo DC3 aircraft. It shows how relatively large ares can be covered in short time.

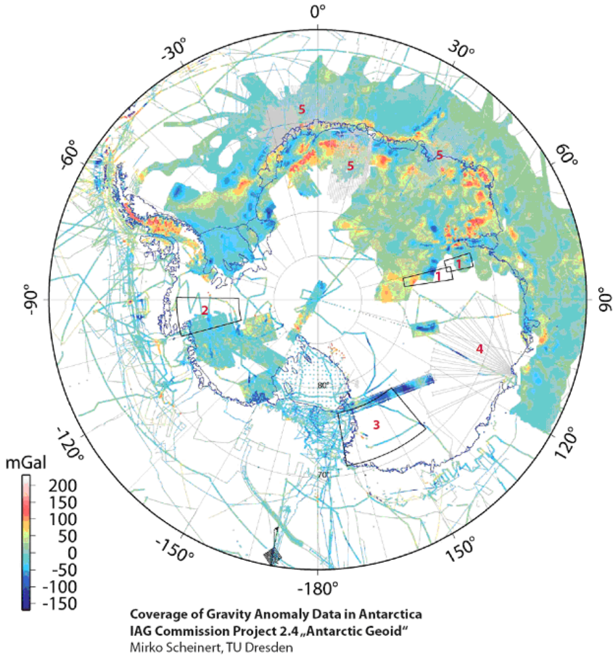

Fig. 9. Gravity coverage of the "Antarctic Geoid Project". Numbers indicate some additional recent surveys. Figure courtesy of M. Scheinert, TU Dresden.

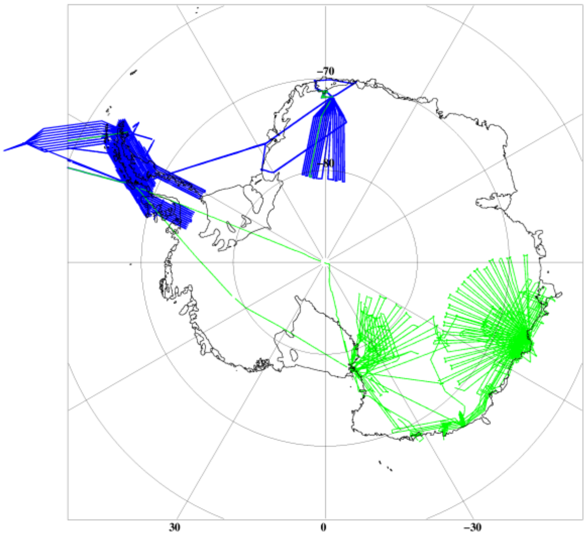

Fig 10. Example of coverage of airborne gravity from recent aerogeophyscical surveys by DTU-Space (blue, 2010-11), and University of Texas at Austin (green, 2008-11; data courtesy J. Greenbaum/D. Blankenship).

The GOCE gravity field for Antarctica is shown in Fig. 11, and the difference between the "timewise" and "direct" models shown in Fig. 12. Again it is evident that there is a polar gap problem in the current GOCE models.

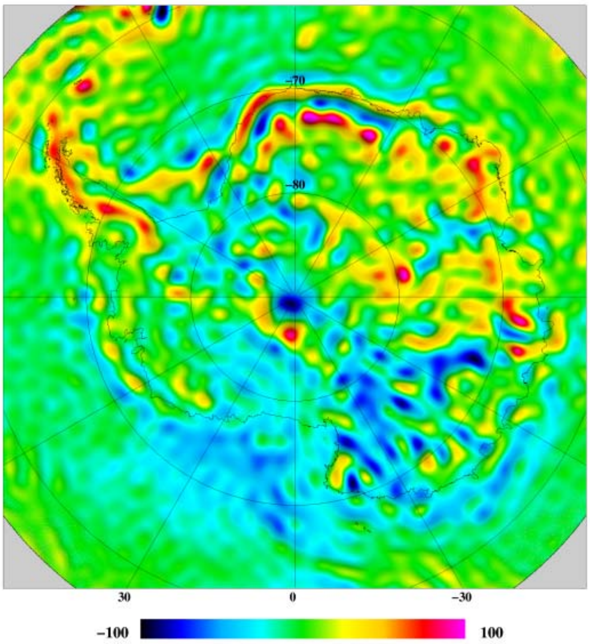

Fig. 11. GOCE timewise gravity field in Antarctica. Unit mGal. Major geological features are clearly seen.

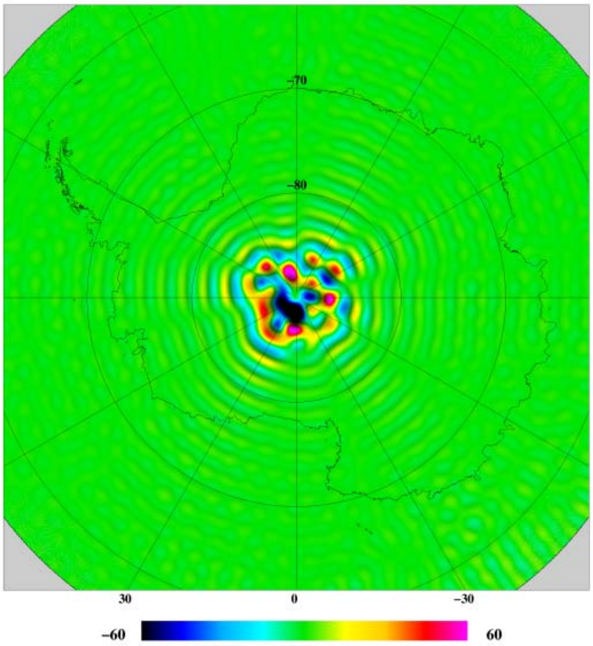

Fig. 12. Difference between GOCE "timewise" and "direct" models in Antarctica. Unit mGal.

Very preliminary partial results of the airborne surveys of DTU-Space (completed March 2011) are shown overlain on the GOCE data in Fig. 13. The comparison of the data illustrates the general agreement between GOCE and the airborne data, except for the spatial resolution.

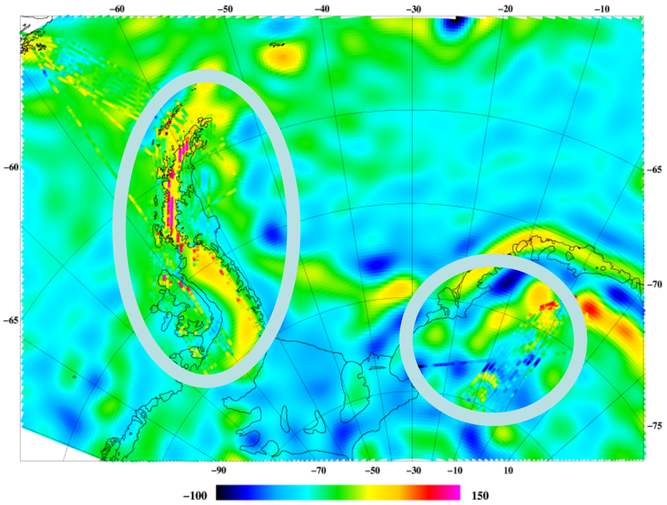

Fig. 13. Details of the GOCE field of the Antarctic Pensinula / East Antarctic sectors, with preliminary DTU-Space airborne gravity overlay (inside grey circle areas).Only parts of data processed. Unit: mGal.

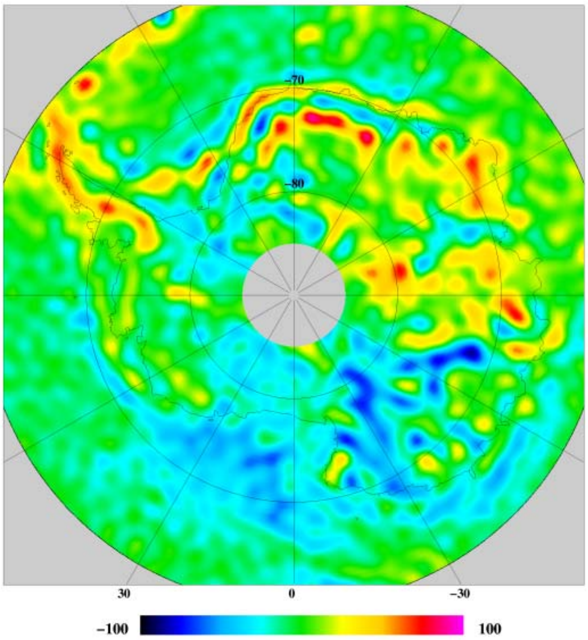

Fig. 14. GOCE gravity field for Antarctica, made from Txx and Tzz gradients by least-squares collocation.

To investigate if a higher accuracy or resolution could be obtained by the direct use of GOCE satellite gradients at orbit altitude, Fig. 14 shows the result of the computation of a gravity grid data using GOCE Txx and Tzz TRF gradients. The solution was run by GEOCOL, selecting gradients in bins prior to running the Antarctic solution in two blocks, each containing about 20.000 observations. Covariance functions used were estimated from empirical T_{zz} gradient covariances at altitude. Compared to Fig. 11 it appears that the collocation solution has slightly less amplitude than the new spherical harmonic models, as expected since selection/thinning of gradients were needed, but otherwise the agreement of features is excellent. The estimated errors of predicted gravity at the surface was around 20 mGal r.m.s., in reasonable agreement with both the Arctic comparisons, as well as the comparison between the preliminary airborne DTU-Space gravity data and GOCE, shown in Table 2.

Table 2. Comparison of preliminary DTU-Space IceGrav-2011airborne gravity data to GOCE (mGal)

GOCE method	Original data		Data - GOCE		Filtered deg 180 r.m.s.
	Mean	St.dev.	Mean	St.dev.	
Timewise	23.4	38.2	2.8	28.7	16.2
Direct	-	-	2.9	28.8	16.5
Collocation	-	-	2.1	30.2	17.1

4 ANTARCTICA – A GEOID EXAMPLE

The advantages of combining airborne gravity and GOCE is illustrated by an example in lower latitudes – using the airborne gravity data collected during the Drake Strait crossings of the DTU-Space 2010-11 IceGrav campaigns. Fig 14 shows the ocean mean dynamic topography (MDT) obtained from GOCE only, using the DNSC08 mean sea surface heights.

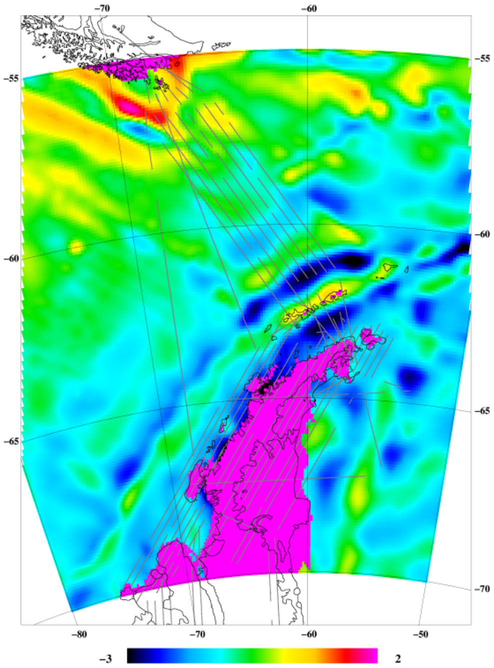

Fig. 15. MDT over the Drake Passage from GOCE (m)

Fig. 15 shows that some of the tectonic features, such as the large negative trench anomalies north of the Antarctic Peninsula, are showing up in the MDT due to lack of resolution. Fig. 16 shows the same area, with a revised geoid combining GOCE and the airborne data in a FFT solution with Stokes modified kernels, allowing local data only to affect the harmonic degrees beyond 150. It is seen how the improved geoid in the area of the airborne data seems to eliminate the imprint of the trench anomaly, and seems so sharpen the gradient of the MDT across the Antarctic polar ocean front in the middle of the Drake Passage.

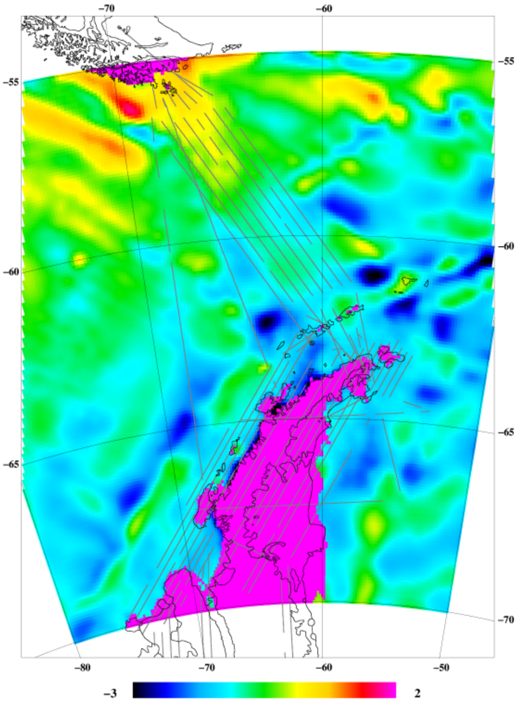

Fig. 16. Drake Passage MDT from a geoid with GOCE and the airborne data. Flight tracks shown in grey. Unit: meter.

4. CONCLUSIONS

It is evident that GOCE provides unique new data for the polar regions, except for the areas of the polar gaps beyond latitude 83.3º. Comparisons to the Arctic Gravity Project show an excellent bias-free agreement, and new airborne gravity data from Antarctica supports this. For geoid applications, e.g. for Mean Dynamic Topography estimation, the current GOCE models do not handle the polar gaps good enough for Arctic applications, and it will be important to use combination models including ideally both surface data and GRACE. Such data are readily available for the Arctic.

For the southern polar gap, only a coordinated international effort can make a realistic effort to cover this gap with airborne gravity data, as such a survey would need to use the South Pole station operated by the US National Science Foundation. Fig. 17 shows a possible flight pattern for a survey using either a DC3 or a smaller Twin-Otter (with ferry tank). Such a survey would require 40 flight-days, and thus could easily be done in one season, and thus provide high-accuracy data for both GOCE and future high-resolution combination solutions such as EGM08.

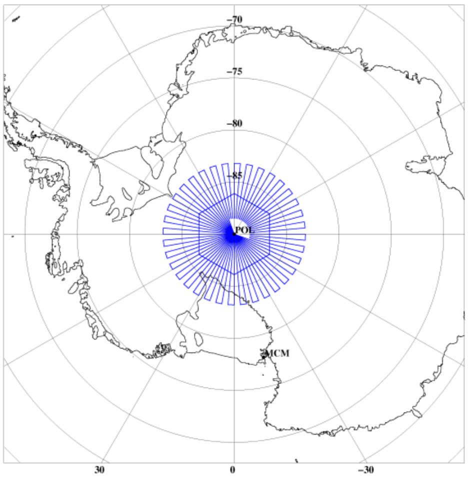

Fig. 17. Flight tracks of a proposed international Antarctic polar gap airborne gravity survey. The survey could be done in one season from South Pole station.

References

1. Forsberg, R. and A. V. Olesen: *Airborne gravimetry.* In: Gouchang Xu (Ed.): Sciences of Geodesy-I, Monograph, Spinger Verlag, pp. 83-104, 2010.
2. Brozena, J. M., R. Salman: *Arctic airborne gravity measurement program.* In: Segawa et al., eds.: Gravity, Geoid and Marine Geodesy, IAG series 117, Springer Verlag, pp. 131-139, 1996.
3. Forsberg, R. and S. Kenyon*: Gravity And Geoid in The Arctic Region – The Northern Polar Gap Now Filled.* 6 pp., Proc. GOCE Workshop, ESA-ESRIN, March 2004.
4. Pail R., Goiginger H., Mayrhofer R., Schuh W.-D., Brockmann J.M., Krasbutter I., Höck E., Fecher T. (2010) *Global gravity field model derived from orbit and gradiometry data applying the time-wise method.* Proceedings of ESA Living Planet Symposium, 28 June – 2 July 2010, Bergen, Norway, ESA SP-686.
5. Bruinsma S.L., Marty J.C., Balmino G., Biancale R., Boerste C., Abrikosov O. and Neumayer H: *GOCE Gravity Field Recovery by Means of the Direct Numerical Method*, presented at the ESA Living Planet Symposium, 27th June - 2nd July, 2010, Bergen, Norway; See also: earth.esa.int/GOCE.
6. Forsberg, R, H Skourup, O B Andersen, P Knudsen, S W Laxon, A. Ridout, J Johannesen, F Siegismund, H Drange, C C Tscherning, D Arabelos, A Braun, V Renganathan: *Combination of Spaceborne, Airborne and In-situ Gravity Measurements in Support of Arctic Sea Ice Thickness Mapping.* Danish National Space Center, Technical Report no. 7, 136 pp, 2007 (also as ESA special report)