
The DTU17 Global Marine Gravity Field: First Validation Results

O. B. Andersen and P. Knudsen

Abstract

The most recent released global marine gravity field from DTU Space takes into account the new SARAL/AltiKa geodetic mission initiated in 2016 along with new improved Arctic processing of the Cryosat-2 mission. With its 369 days repeat cycle, Cryosat-2 provides one repeat of geodetic mission data with 8 km global resolution each year since its launch in 2010. Together with the Jason-1 end-of-life geodetic mission in 2012 and 2013, we now have more than five times as many geodetic missions sea surface height observations compared with the old ERS-1 and Geosat geodetic missions.

The DTU17 has been derived focusing on improving the coastal and Arctic gravity field, enhancing the shorter wavelength of the gravity field (10–15 km). For DTU17, we find a substantial improvement in marine gravity mapping as shown through comparison with high quality airborne data flown north of Greenland in 2009.

Keywords

Arctic Ocean · Free air gravity · Satellite altimetry

1 Gravity Field Update

Since the release of the DTU15 global marine gravity field in 2015 (Andersen et al. 2017) a number of additional data have become available to marine gravity field mapping. This means, that data from the first generation altimeters like ERS-1 and Geosat are now retired and not used anymore for marine gravity field modelling and only data from the new second generation altimeters are used.

Cryosat-2 continues to provide data along its 369 day near repeat since 2010 completing 7 full geodetic cycles for the derivation of DTU17. During the period from May 2012 to June 2013 the Jason-1 satellite operated in a 406 days geodetic mission as part its end of life mission. Jason-1 is particularly valuable for both global high resolution gravityfield modelling and bathymetry modelling at low

to mid latitude (Sandwell et al. 2014). However, the 66° inclination of Jason-1 prevents it providing data at high latitude. Cryosat-2 has an inclination of 88° providing data throughout the Arctic Ocean up to 88°N or 220 km from the North Pole.

Since early 2016, a third geodetic mission by the SARAL/AltiKa satellite has accidently become available. Due to technical issues with the reaction wheels the operators decided to pursue this mission with a new phase named “SARAL-DOP” for SARAL-Drifting Orbit phase. By not maintaining the 35-day repetitive ground track the natural decay of the orbit creates a so-called uncontrolled geodetic orbit and provides data up to 82°N. Such uncontrolled orbit is similar to the way Geosat operated.

The SARAL/AltiKa operates at Ka-band at a pulse repetition frequency of 4,000 Hz were all altimetric satellites operates at Ku band, typically with a pulse repetitions frequency of 2,000 Hz. SARAL provides two important improvements to altimetric gravity field modelling. Firstly, the higher pulse repetition frequency generate higher number of (“independent”) observations, which can be averaged to

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lower the range precision. Secondly, the Ka-band altimeter has a significantly smaller footprint on the sea surface. The smaller footprint is particularly important for coastal and sea ice contaminated regions, as less sea surface height observations are corrupted by the presence of land or ice inside the footprint (Fu and Cazenave 2001). The footprint size is a function of the altitude of the spacecraft and the significant wave-height (Fu and Cazenave 2001; Chelton et al. 1989) and is given below for a 2-m wave-height. ERS-1/2, Envisat and Geosat all had a footprint around 70 km²; Jason-1/2/3 have a footprint size of 95 km² as it flies at nearly twice the altitude. However, the SARAL Ka-band altimeter has a footprint size of 40 km².

For Cryosat-2 the footprint is similar to ERS-1 when the satellite operates in conventional or low resolution mode (LRM). However, when the satellite operates in SAR mode (Raney 1998), the footprint is sliced up in 300 m beams across the flight direction reducing the footprint to less than 5 km². Cryosat-2 occasionally operates in SARin where the secondary receiving antenna is activated. The Cryosat-2 mode mask (<https://earth.esa.int/web/guest/-/geographical-mode-mask-7107>) dictates which mode is active where. This mode mask is updated regularly to accommodate user request. The mode-mask is a consequence of bandwidth and the limited ability to transfer the high resolution SAR and SARin data to the ground.

The Arctic Ocean has been measured in SAR or SARin mode throughout the mission and, from an altimetric gravity point of view, the Cryosat-2 SAR and SARin data are processed identically.

SAR (and SARin) altimetry has a further advantage to conventional LRM altimetry enabling an improved recovery of shorter wavelength of the gravity field. This stems from the fact, that SAR altimetry does not suffer from correlated noise in the sea surface height observations in the 10–50 km wavelength seen for conventional altimetry (Dibarboure et al. 2014). Various ways have been employed to mitigate this for conventional altimetry (i.e., two-step retracking by Sandwell et al. 2013). However, this is not needed for SAR altimetry (Sandwell et al. 2014).

In order to exploit the full potential of Cryosat-2 SAR and SARin data, we have retracked the Cryosat-2 Level 1B waveform data from the recently updated Baseline-C using the narrow peak retracker (Jain et al. 2015). This empirical retracker is very robust and is able to provide accurate heights even when the waveform is moderately contaminated by the presence of sea ice (Stenseng and Andersen 2012). Hence, this retracker is able to retrieve sea level from leads which are significantly smaller than the footprint and which can be as small as 10–20 m.

The geodetic mission sea-surface heights are corrected for range corrections (Andersen and Scharroo 2011) and processed to extract the residual geoid information following the methods described in Andersen et al. (2010b). Similar remove-restore technique relative to EGM2008 (Pavlis et al. 2012) used for previous DTU marine gravity fields was applied, and the data were processed in global mesh of tiles of 1° by 3° latitude by longitude.

For DTU15 global marine gravity field, the Goddard Ocean tide (GOT4.8, Stammer et al. 2014) global ocean tide model was preferred. However, in some coastal regions, this model limits the data with ocean tide correction due to its coarse resolution of 0.5° compared with more recent ocean tide models like FES2014 (Carrere et al. 2015), which has a resolution of 0.125°. One of the regions where the coarse resolution of the GOT4.8 ocean tide model results in a large number of the Cryosat-2 observations being rejected, due to missing ocean tide correction is the south coast of Australia close to Adelaide. Figure 1 illustrates the problem around Adelaide. The number of valid Cryosat-2 observations with the GOT4.8 ocean tide correction is shown in the left figure and the number of valid Cryosat-2 observations with valid ocean tide correction using the FES2014 ocean tide model is illustrated in the right figure. Global testing showed that FES2014 seems to provide similar accuracy to the GOT4.8 ocean tide model and hence, we updated the ocean tide correction to FES2014 for DTU17 to retrain more data close to the coast.

To complete the DTU17 global marine gravity then north of 88°N and on land the DTU17 marine gravity field was augmented with EGM2008 free-air gravity ensuring global coverage. This somewhat older global marine gravity field was chosen to be consistent with the geoid used for the remove/restore process in deriving the gravity field.

2 Evaluation with Marine Gravity Observations

The standard evaluation with more than 1.4 million high quality edited un-classified marine gravity observations from the National Geospatial-intelligence Agency (NGA) was used to evaluate the various available global marine gravity fields in the northwest part of the Atlantic Ocean between 20°N and 45°N and 270°E and 330°E with statistics shown in Table 1. For comparison the Sandwell and Smith marine gravity field release 23.1 and 24.1 (Sandwell et al. 2013), available from http://topex.ucsd.edu/marine_grav/mar_grav.html, were also included.

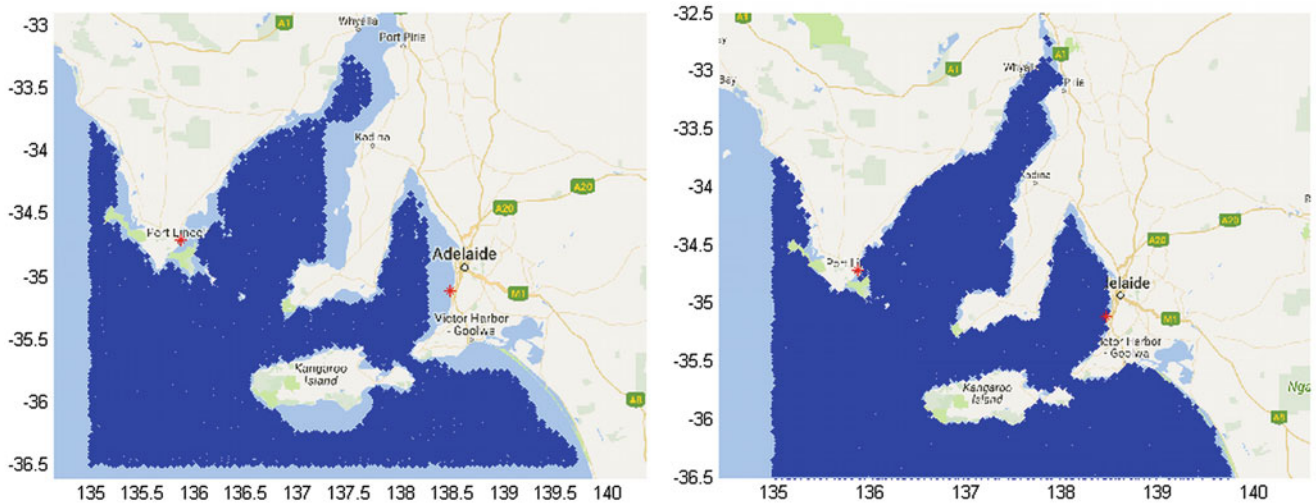


Fig. 1 The location of Cryosat-2 observations around Adelaide with the GOT4.8 ocean tide correction (left) and the FES2014 ocean tide model (right) applied

Table 1 Comparison with more than 1.4 million quality controlled marine gravity field observations in the northwest Atlantic Ocean

	Std. dev. (mGal)	Mean (mGal)	Max (mGal)
DTU17	2.51	0.5	32.4
DTU15	2.51	0.5	32.3
DTU13	2.83	0.5	32.2
DTU10	3.16	0.5	44.1
SS 23.1	3.13	0.7	43.4
SS 24.1	3.11	0.7	41.9

The comparison between altimetry and marine gravity also includes errors in the marine gravity observations. The accuracy of the marine gravity field observations is quoted by NGA to be around 1.5–2 mGal. With an observed standard deviation of 2.5 mGal between DTU15/DTU17 and the marine gravity field observations, this means that the accuracy of the altimetric gravity field must be around 2 mGal in this region.

The inclusion of additional data and application of slightly less spatial filtering does not improve the global statistics with marine gravity field observations for DTU17 vs the older DTU15. To investigate the DTU17 improvement a bit further, we have split the comparison with the NGA marine data into sub-comparisons by depth. From these sub-comparisons shown in Table 2, it is evident, that the largest improvement is seen in coastal regions where the impact of the SARAL/AltiKa can be seen.

On the contrary, the slightly less filtering applied in DTU17 has the effect of degrading the gravity field estimation in the depth range of 500–2,000 m. This is generally where the Gulf Stream is found in the northwest Atlantic Ocean and where the sea surface height variability is the highest (Andersen et al. 2010a).

Table 2 Sub-comparison by depth with the NGA data used in Table 1

	DTU17-DTU15		
	DTU17	DTU15	improvement
Depth (0–25 m)	2.25	2.32	4
Depth (25–50 m)	2.35	2.38	2
Depth (50–100 m)	2.48	2.54	3
Depth (100–500 m)	2.70	2.77	3
Depth (500–1,000 m)	2.55	2.52	–2
Depth (1,000–2,000 m)	2.57	2.52	–3
Depth (2,000–5,000 m)	2.55	2.55	0

Each depth interval has more than 40,000 marine observations for the comparison. The table presents the standard deviation (in mGal) for DTU17 and DTU15 as well as the improvement in percent

3 Marine Gravity Comparison in the Arctic Ocean

Due to the presence of sea ice, the number of ship-surveys is very limited in the Arctic Ocean, so we have performed a comparison with an international airborne survey called LomGrav. The survey was flown and conducted in 2009 by the DTU airborne system (Olesen 2003) in the mostly densely ice-covered part of the Arctic Ocean between Greenland and the North Pole. A little more than 55,000 high quality airborne observations were recorded within the region north of Greenland bounded by 80°N–90°N latitude and by 240°E–360°E longitude. Due to favorable flight conditions, the internal error at crossing points was less than 2 mGal on average (Olesen, personal communication, 2018). In this following analysis, the Sandwell and Smith gravity fields could not be included as the spatial coverage is limited to 80°N for these fields.

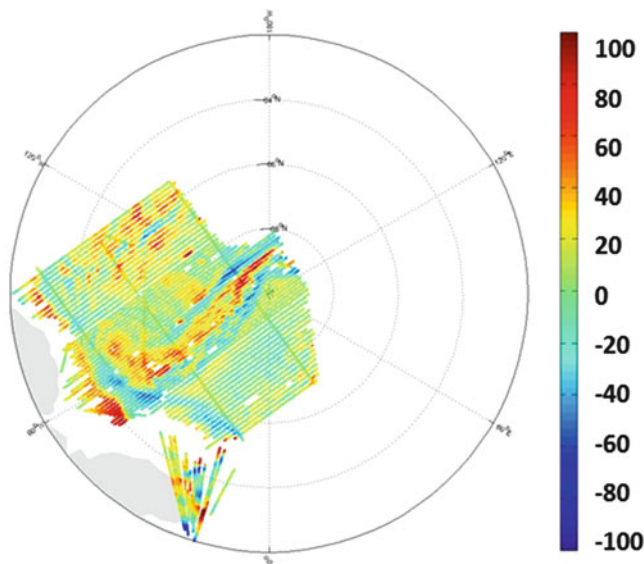


Fig. 2 The LomGrav2009 airborne marine gravity survey north of Greenland in the Arctic Ocean. Free-air gravity ranges from -100 to 100 mGal. The northern tip of Greenland is seen in grey

Table 3 Comparison with the roughly 55,000 airborne gravity observations in the LomGrav 2009 survey north of Greenland in the Arctic Ocean

All in mGal	EGM 2008	DTU10	DTU13	DTU15	DTU17
DTU17	9.82	8.81	5.91	5.45	3.78

The standard deviation of the Free-air gravity differences are shown in mGal

The LomGrav 2009 airborne gravity data are shown in Fig. 2. We compared the altimetric gravity with the airborne marine gravity by means of spline interpolation in the altimetric grid to the location of the airborne observations. The standard deviation of the differences for the various gravity fields are presented in Table 3.

Improvement of more than 50% in terms of standard deviation from pre to post Cryosat-2 launch in 2010 is evident. For the pre Cryosat-2 marine gravity fields, we found standard deviations of differences of 9.8 and 8.8 mGal for EGM2008 and DTU10, respectively. For the gravity field including the Cryosat-2, we found values of 5.9 mGal for DTU13 (1 year of C2 data), 5.45 mGal for DTU15 (4 years of C2 data), and 3.8 mGal for DTU17 (6 years of C2 data).

Even though the improvement is substantial, the comparison is somewhat larger than the 2 mGal quoted in the comparison with the NGA marine gravity data in the Atlantic and the 2 mGal internal consistency on the airborne gravity observations. This is very much expected, as the Arctic Ocean north of Greenland is among the most heavily sea ice covered regions of the world and we are only able to determine the sea surface height in sparse leads within the ice, when ice-movements cause it to crack open for a while.

The nearly permanent sea ice covered regions are among the toughest regions for gravity field recovery from satellite altimetry.

4 Conclusion

With three geodetic missions, all providing data with higher range precision than the older ERS-1 and Geosat geodetic mission, altimetric gravity field accuracy is still increasing. The mapping of spatial wavelength within the 10–15 km range has increased dramatically revealing both new gravity field structures (Stenseng and Andersen 2012) but equally important revealed related bathymetric signals (Sandwell et al. 2014). Even though DTU15 and DTU17 have similar standard deviation with marine gravity in the northwest Atlantic Ocean, DTU17 offers improvement in the coastal zone due to the use of an improved ocean tide model. DTU17 also offers significant improvement in the Arctic Ocean due to longer time-series and improved data processing.

In the Arctic Ocean, this significant development in accuracy of the altimetric marine gravity is shown through comparison with high quality airborne data flown north of Greenland in 2009. An improvement of more than 50% in terms of standard deviation with the airborne data was seen in comparison with older gravity fields like DTU10 and EGM08, which are the only available global marine gravity field available within the region between Greenland and the North Pole.

Several interesting developments from these new data are still to come in the near future. In July 2017, the Jason-2 satellite initiated a 3-year Extension-of-Life (EoL) geodetic mission. The EoL will initially consist of two interleaved geodetic orbits of around 400 days repeat. This should decrease the cross-track difference for geodetic missions below 8 km for the first time, and bring the cross-track difference all the way down to 4 km in 2019. This will enable modelling of shorter wavelength in the gravity field to be mapped. If the Jason EoL last beyond this, another 2 interleaved geodetic orbits can bring the cross-track density down to 2 km by year 2021.

5 Data Availability

The DTU17 Global 1 min marine gravity field along with the DTU suite of related geophysical products like bathymetry and mean sea surface is available for research purposes from <ftp.space.dtu.dk/pub/DTU17/> or by email request to the author at oa@space.dtu.dk.

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