ASEG-PESA-AIG 2016
25TH GEOPHYSICAL
CONFERENCE & EXHIBITION
Interpreting the Past, Discovering the Future

Comparison of Satellite Altimetric Gravity and Ship-borne Gravity - Offshore Western Australia

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SUMMARY

Since 2010 several new satellite altimetry missions have commenced delivering altimetry-derived gravity data with a global offshore coverage and with a quality in many regions nearing that of ship-borne gravity observations. This is resulting in greatly improved global offshore high resolution gravity fields.
The DTU13 and Sandwell and Smith's v23.1 grids of altimetric gravity anomalies from offshore Western Australia are compared with ship-track gravity anomalies computed from the Geoscience Australia marine gravity database. The standard deviation of the difference between the ship-borne gravity data and the satellite altimetric gravity data is 3.1mGal for the DTU13 data and 3.3 mGal for Sandwell and Smith's v23.1 grid. In water depths less than 20m we observed significant differences between ship-borne gravity and altimetric gravity. Over the sampled wavelengths, the DTU13 altimetric gravity data appears to have the best resemblance to the reference marine gravity data, exhibiting the overall least difference amplitude over most wavelengths.

Key words: satellite gravity, marine gravity, offshore Western Australia

INTRODUCTION

A number of new satellite altimetry missions have been executed in the past few years: the GOCE mission delivers unprecedented accurate geoid/gravity field data in the 200-400 km wavelength range, whilst Cryosat-2 delivers new high resolution sea surface height observations. In addition the Jason-1 satellite completed a full geodetic mission as part its end-of-life cycle in 2012. As a result, the amount of altimetry data available to marine gravity field determination has tripled in recent years, with the quality of the altimetric gravity field nearing that of marine gravity observations in many regions (Christensen and Andersen, 2015).

Geoscience Australia maintains a public data base of ship-borne gravity data from offshore Australia. These data sets provide the opportunity to ground-truth and assess the accuracy of the new satellite altimetric gravity data. Figure 1a shows the ship-tracks of a total of 1,141,732 marine gravity observations from offshore Western Australia. This study covers data from 105^{o} to 118^{o} longitude and from -36^{o} to -19^{o} latitude. Figure 1b shows the bathymetry in the region, as derived from the AUSBATH09 model. The ship-borne free-air gravity is shown in Figure 1d. The ship-borne free-air gravity data has been levelled by Geoscience Australia to minimise intersection mismatches. Note that despite containing more than 1.1 million ship-borne gravity observations, there are still vast areas that have not been mapped by ship-borne gravity.

There are currently two publically available satellite altimetry-derived gravity datasets that include the new mission data from Jason-1 and Cryosat-2: those from the Danish Technical University (DTU) and those provided from the Scripps Institute of Oceanography. Figure 1e shows the satellite-altimetry-derived free-air gravity from Sandwell et al., (2013 and 2014) – version 23.1 – hereafter referred as "*SSv23p1*". Figure 1f shows the satellite altimetry-derived free-air gravity from the DTU13 data set (Andersen et al., 2014). Note the complete offshore coverage provided by the satellite altimetric gravity data sets. Onshore free-air gravity data are from the EGM2008 global gravity model (Pavlis et al, 2012).

ANALYSIS OF SATELLITE GRAVITY DATA USING REFERENCE MARINE GRAVITY DATA

The satellite altimetric free-air gravity data sets were sampled along the ship-tracks and the difference between the ship-borne gravity and the satellite altimetric free-air gravity data was computed. Table 1 lists the key statistical findings from statistical analysis of the difference data.

Satellite Gravity Data Set	Mean	Standard Deviation	Minimum Difference	Maximum Difference
Difference: ship-borne free-air gravity – SSv23p1	**-1.21**	**3.29**	**-51.54**	**28.93**
Difference: ship-borne free-air gravity – DTU13	**-1.38**	**3.12**	**-48.63**	**30.32**

Table 1: Key statistical parameters from the difference between the reference ship-borne free-air gravity data and the DTU13 and the SSv23p1 satellite altimetric free-air gravity data, respectively. Number of observations = 1,141,732. Units are mGal.

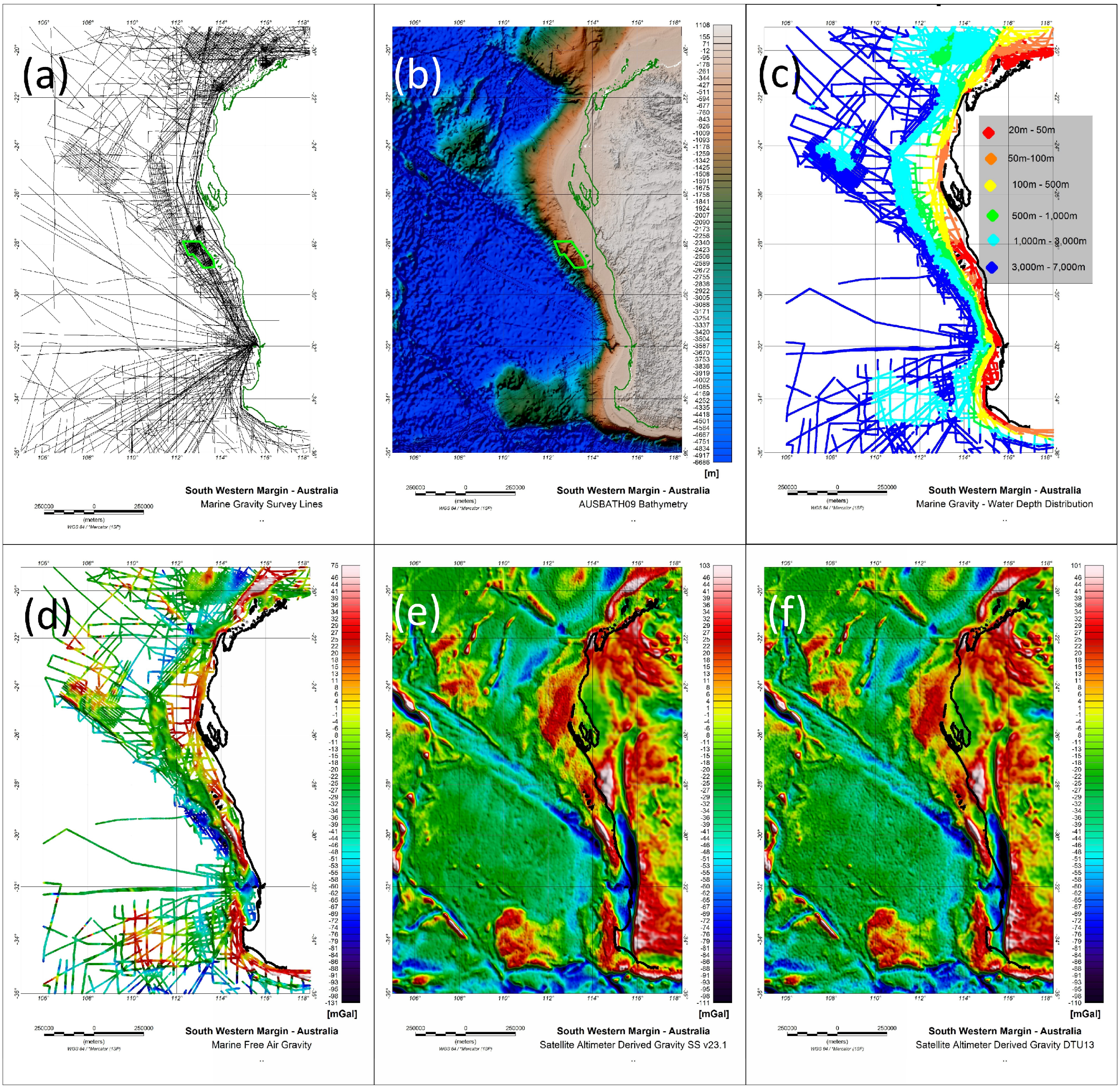

Figure 1: (a) Ship track marine gravity used in the study. (b) Bathymetry (AUSBATH09). (c) Spatial distribution of depth intervals. (d) Ship-borne free-air gravity data. (e) SSv23p1 free-air gravity. (f) DTU 13 free-air gravity.

The standard deviation of the difference between the ship-borne gravity data and the satellite altimetric gravity data is in the [3.1mGal, 3.3 mGal] range. This is a measure of the sum of the noise in the ship-borne gravity data and the noise in the satellite altimetric gravity data sets. This noise measure has been reduced by 45% since Featherstone (2003) reported standard deviation differences between Australian ship-borne gravity data and early-2000 vintage satellite altimetric gravity data in the [5.6mGal, 6.1mGal] range. The improvement in noise is primarily due to the recent inclusion of the Jason-1 and Cryosat-2 satellite altimeter data.

The mean difference between the ship-borne gravity data and satellite altimetric gravity data should be zero, but the analysis indicates a constant bias. This suggests that the ship-borne gravity data has not been fully levelled.

The quality of satellite altimetric gravity data is known to deteriorate in shallow water. This is primarily due to higher sea surface variability, poor near-shore tidal models, and loss of altimeter tracking caused by onshore reflector interference. In order to estimate the effects of water depths on the quality of the of satellite altimetric gravity data, the data was binned into seven water-depth ranges and the statistical analysis of the difference between the ship-borne gravity data and the satellite altimetric gravity data was repeated for each bin. Figure 2 shows the standard deviation of the difference between the ship-borne gravity data and the satellite altimetric gravity data for each of the water-depth intervals.

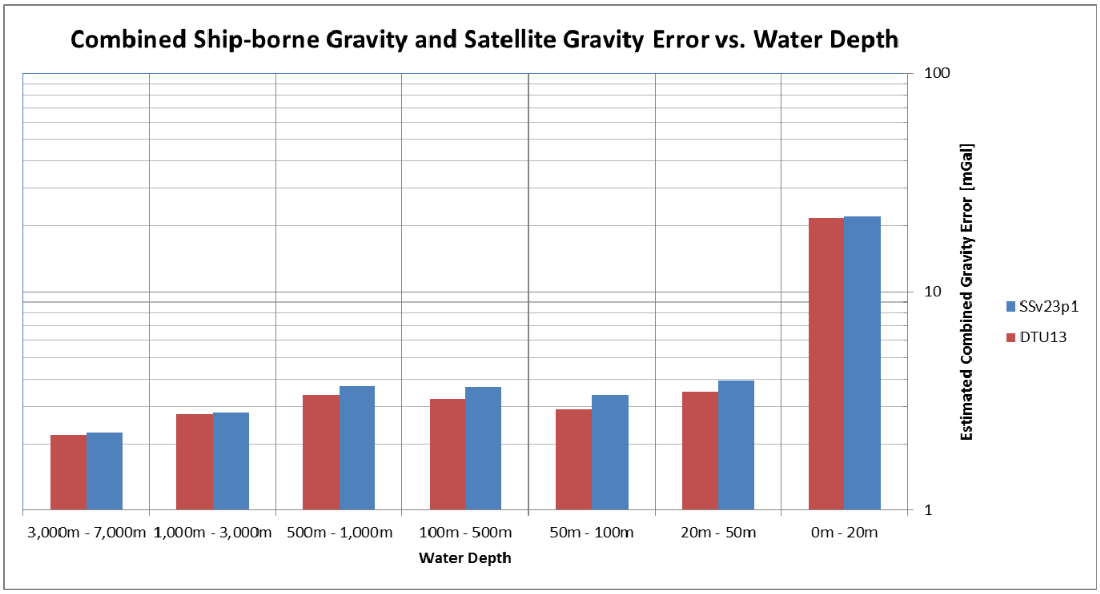

Figure 2: The standard deviations of the differences between the offshore West Australia ship-borne gravity data and the DTU13 (red) and the SSv23p1 (blue) respectively as a function of water depths. The standard deviation of the difference is a measure of the sum of the noise in the ship-borne gravity data and the noise in the satellite altimetric gravity data sets.

For water depths exceeding 1,000m the combined noise in the ship-borne gravity and the satellite altimetric gravity is in the [2.1mGal,2.6 mGal] range, and there is little difference in the quality of the DTU13 and the SSv23p1 satellite altimetric gravity data sets.

For water depths in the [50m, 1,000m] range the combined noise in the ship-borne gravity and the satellite altimetric gravity is in the [3.0mGal,4.0 mGal] range, and the DTU13 gravity data generally exhibit 10% less standard deviation difference with the ship-borne gravity data than the SSv23p1 gravity data.

For water depths in the [0m, 20m] range we note a sharp increase in the standard deviation of the difference between the ship-borne gravity and the satellite altimetric gravity, exceeding 20mGal for both satellite altimetric data sets. This partly due to the inherent near-shore limitations in altimetric gravity data, listed above, but is also be due to apparent levelling difficulties of the near-shore marine gravity data due to sub-parallel profiles and fewer intersection points.

SPECTRAL ANALYSIS RESULTS

In order to investigate the error of the satellite altimetric gravity as a function of spectral wavelengths we consider the differences between the ship-borne gravity data and the satellite altimetric gravity data in a region covered by a recent marine gravity survey, located on the continental slope in the western part of the Perth basin. The location of the survey is marked on Figures 1a and 1b. Figure 3a shows the ship-borne free-air gravity data and the ship track lines used in the study. The survey area is approximately 50km by 120km in size. The typical line spacing is 4km. Hence the smallest wavelength fully sampled by the ship-borne gravity survey is of the order of 8 km (twice the typical line spacing). The longest wavelength sampled by the ship-borne survey is 120km.

Figure 3b shows the bathymetry in the survey area – ranging from a few tens of meters water depth on the continental shelf in the eastern part of the survey area to water depths exceeding 4,000m on the outer continental slope to the west of the survey area. Note the incised canyon system traversing the outer continental shelf.

Figure 3c shows the SSv23p1 free-air gravity. The difference between the ship-borne and the SSv23p1 free-air gravity is shown in figure 3d. Likewise figure 3e shows the DTU13 free-air gravity, and the difference between the ship-borne and the DTU13 free-air gravity is shown in figure 3f.

The standard deviation of the difference between the ship-borne free-air gravity data and the SSv23p1 free-air gravity data is 2.40mGal. The standard deviation of the difference between the ship-borne free-air gravity data and the DTU13 free-air gravity data is only 2.21mGal. Hence the DTU13 gravity data in the survey area exhibit 8% less RMS difference with the ship-borne gravity data than the SSv23.1 gravity data.

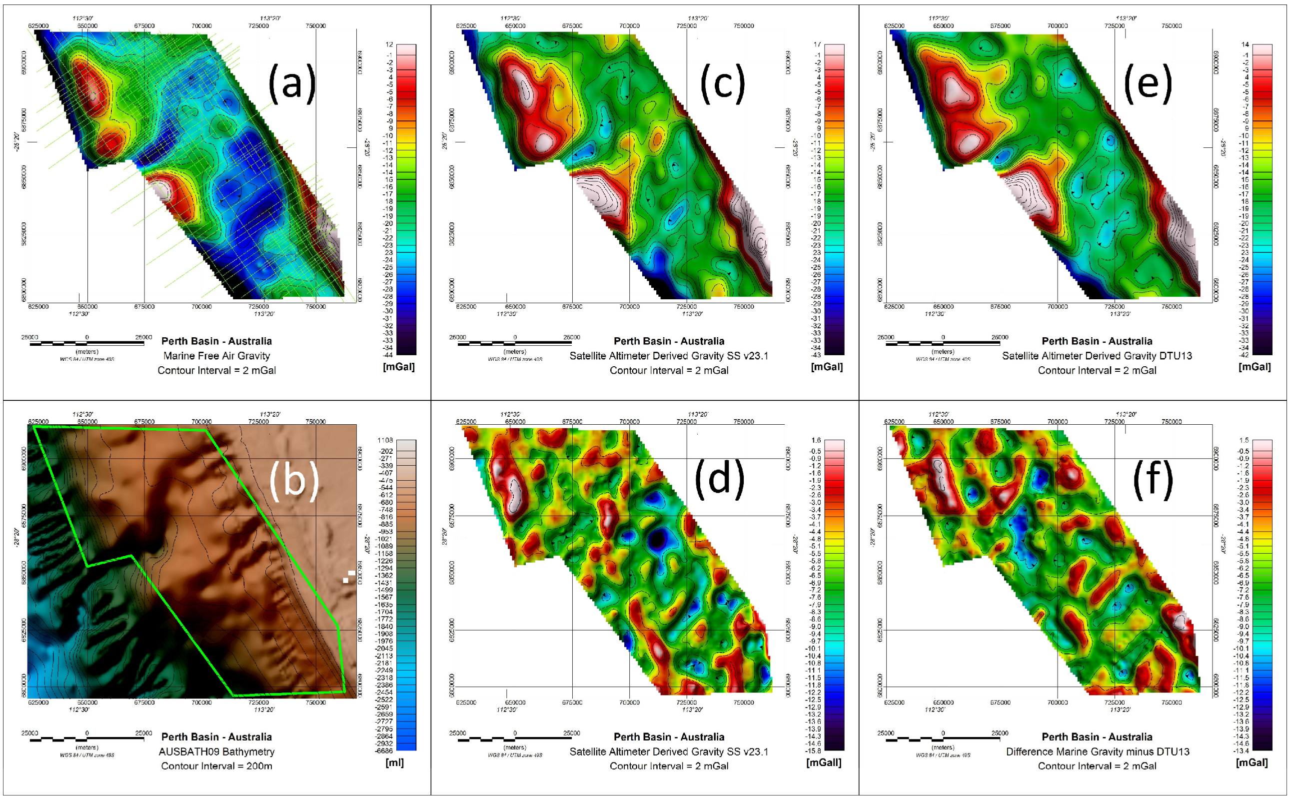

Figure 3: (a) Perth Basin ship-borne free-air gravity and ship tracks. (b) Bathymetry (AUSBATH09), (c) SSv23p1 free-air gravity. (d) Difference between ship-borne and SSv23p1 free-air gravity. (e) DTU13 free-air gravity. (f) Difference between ship-borne and DTU13 free-air gravity.

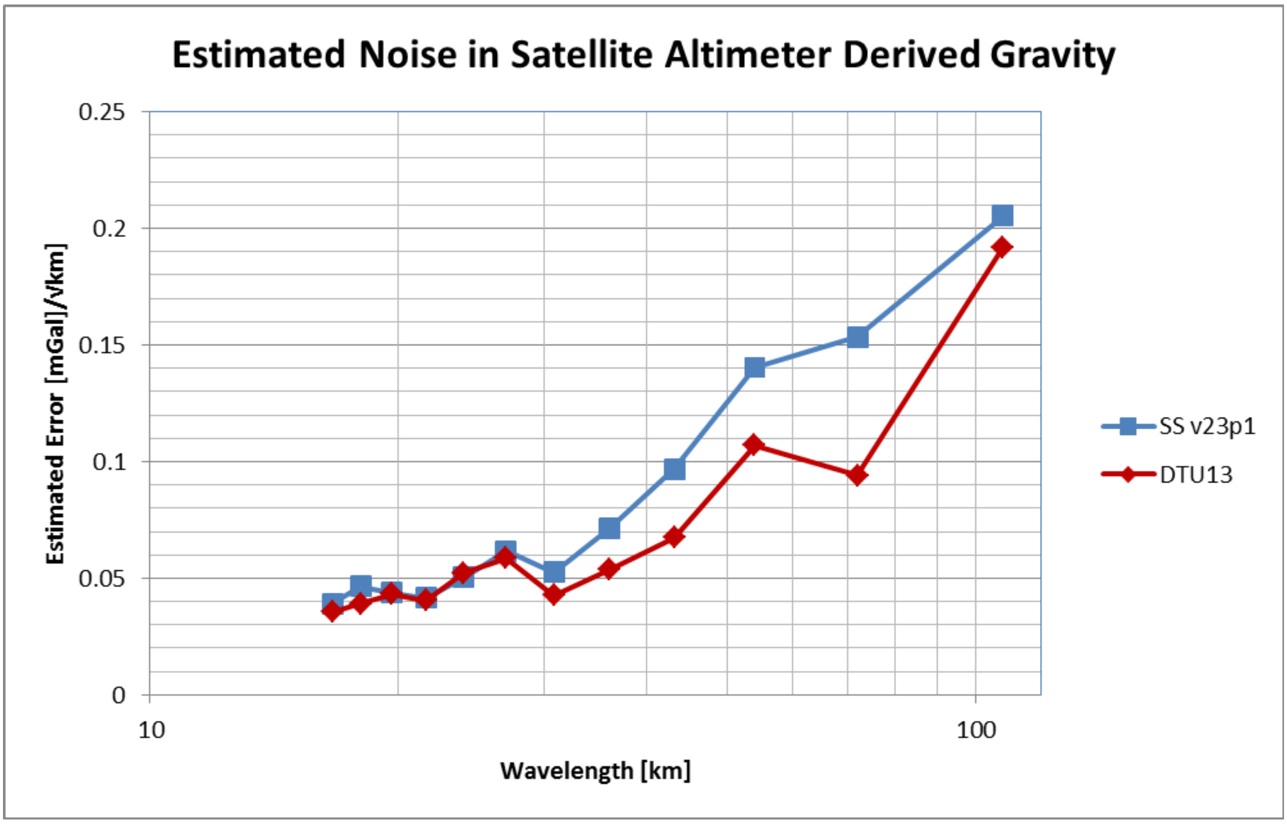

Figure 4: Radially averaged amplitude spectra of the estimated noise in the satellite gravity data sets. The noise was estimated by differencing the satellite gravity data from the marine gravity data. The spectra have been clipped to wavelengths shared by the reference marine gravity data and the satellite altimetric gravity data (16km to 106km).

For each of the satellite-altimeter derived data sets we have computed power spectra of the differences between the reference marine free-air gravity data and the satellite altimeter-derived free-air gravity data. The resultant 2-D power spectral densities were radially averaged and translated into a single dimension, to indicate the contribution to the variance of the error grids as a function of wavelength only (Christensen and Andersen, 2015). The results are shown in Figure 4. The spectral analysis of the difference grids shows that for wavelengths in the 26km-106km range the DTU13 free-air gravity data have less noise than the SSv23p1free-air gravity data. For wavelengths in the 16km-26km range there appears to be little difference between the DTU13 and the SSv23.1 gravity data. Over all the sampled wavelengths, the DTU13 gravity data appears to have the best resemblance to the reference marine gravity data, exhibiting the overall least difference amplitude over most wavelengths.

CONCLUSIONS

The overall standard deviation of the difference between the ship-borne gravity data and the satellite altimetric gravity data offshore Western Australia is in the [3.1mGal, 3.3 mGal] range. The 45% improvement in noise over previous comparisons is primarily due to the recent inclusion of the Jason-1 and Cryosat-2 satellite altimeter data.

The analysis indicates a constant bias in the mean difference between the ship-borne gravity data and satellite altimetric gravity data. This suggests that the ship-borne gravity data has not been fully levelled.

When taking water depths into consideration whilst comparing between ship-borne gravity and satellite altimetric gravity in offshore Western Australia we find that the satellite altimetric gravity is not reliable in water depths shallower than 20m. This is primarily due to higher sea surface variability, poor near-shore tidal models, and loss of altimeter tracking caused by onshore reflector interference.

In water depths between 20m and 1,000m in offshore Western Australia there is generally good agreement between the ship-borne gravity and the satellite altimetric gravity grids, with RMS differences in the [3mGal, 4mGal] range. In these water depths the DTU13 gravity data generally exhibit 10% less RMS difference than the SSv23.1 gravity data, when compared with the ship-borne gravity data,.

In water depths exceeding 1,000m there is very good agreement between ship-borne gravity tracks and both satellite altimetric gravity data sets with RMS differences in the [2.2mGal, 2.8mGal] range. In these water depths there is little difference between the DTU13 and the SSv23.1 gravity data.

Comparison with a recent ship-borne gravity survey from the continental slope in the western part of the Perth Basin show good agreement between ship-borne gravity tracks and both satellite altimetric gravity data sets with RMS differences in the [2.3mGal, 2.4mGal] range.

The spectral analysis of the difference grids in the western part of the Perth Basin shows that for longer wavelengths in the [26km, 106km] range the DTU13 gravity data have less noise than the SSv23p1data. For shorter wavelengths in the [16km, 26km] range there appears to be little difference between the DTU13 and the SSv23.1 gravity data. Over all the sampled wavelengths, the DTU13 gravity data appears to have the best resemblance to the reference marine gravity data, exhibiting the overall least difference amplitude over most wavelengths.

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