Using satellite altimetry data for regional marine gravity field modeling

Introduction

Measurements from radar altimetry missions are the primary source for high resolution marine gravity field modeling. Particularly, the geodetic mission phases with its dense ground track pattern can provide valuable information. In addition to the older data from GEOSAT and ERS-1, new measurements are available today: Jason-1 was flying on a geodetic orbit between May 2012 and February 2013; CryoSat-2 was launched in 2010 with a long repeat cycle of 369 days. The modeling approach presented here directly uses absolute sea surface height measurements along the ground tracks of these missions instead of the commonly used relative or gridded products.

Modeling Approach

The model is set up as a series expansion in spherical basis functions, i.e. spherical scaling functions $\phi_{l,j}$ (Schauss et al. 2007) whose unknown coefficients $d_{l,j}$ are estimated in an adjustment procedure. In order to get rid of the low-frequency signal parts which cannot be determined from regional data—signal differences to a given background model (e.g. GOCO03S) are computed. Within the adjustment process a variance component estimation (VCE) is used to ensure an appropriate relative weighting between the different altimeter missions and the other model types, if desired. The estimation of the gravitational potential $V$ enables deriving not only geoid undulations $\Delta$ but any functional of interest, e.g. gravity anomalies $\Delta g$ or gravity gradients $\nabla^2 \Delta g$. Figure 3 shows the gravity anomalies (a) and its formal errors (b). The model parameters are set to level 20 with basis $l \geq 6$ km, see Tab. 1 as this resolution fits best to the observation distribution. For this resolution $d_{\text{max}} = 9853$ model coefficients are estimated.

Comparison to EGM2008

To get a first impression on the model accuracy differences to EGM2008 are build. The choice of the level defines the spatial model resolution and influences the consistency to EGM2008 (which is developed up to $l = 2393$). The smallest differences to EGM can be reached with $l = 18$ (b=1545), since the resolution ($l_{\text{max}} = 2500$) of the models is akin in this case (keeping in mind the spatial smoothing characteristics of Blackman functions). The differences to EGM reach 3.8 mGal RMS for this model (see Fig. 5).

Input Data

In our modeling approach we use 1 Hz absolute sea surface height (SSH) measurements from various altimetry missions (see Tab. 2) together with instantaneous dynamic ocean topography DIT (Bosch et al. 2013) to estimate perturbation potential $T$ in ocean areas with high spatial resolution. The consistency of the different altimeter missions is obtained by a pre-processing crossover analysis (Dettinger & Bosch 2013) which also ensures that long-wavelength errors such as orbit errors are eliminated beforehand. Moreover, a background model (GOCO03S up to $d / b = 180$) is used for providing the low-frequency signals $T_{\text{back}}$ and to ensure stability of the adjustment system.

$$ T = N \cdot T = \text{SSHI} - \text{DIT} $$

$T$ normal gravity.

Validation

For model validation ship-borne free-air gravity anomalies from NOAA’s NGDC are used. In the study area, 12 different surveys provide measurements. As the data has not been pre-processed and harmonized, model differences (RMS) and correlation coefficients $\rho$ are computed for each campaign independently.

It seems that the actual model resolution of about 6 km is not sufficient to describe all high-frequency signals available in the study area. However, the 1Hz data distribution is too sparse in some regions of the study area to reliably estimate higher levels.

Conclusions

The presented approach provides high-quality regional gravity models comparable to EGM2008. In order to further improve the model resolution the spatial distribution of input observations should be increased, e.g. by using preprocessed high-frequency altimeter data and data from GEOSAT geodetic mission phase.

References:


Fig. 3: Gravity anomalies in mGal for level $l = 20 (b = 1.5)$ estimated from altimetric SSH.

Fig. 4: Differences to EGM2008 (d/o 2190). The model differences ($r = 20, b = 1.5$) are randomly distributed with an RMS of 4.3 mGal and a maximum of 35 mGal. The consistency is better in the central part of the area: 3.6 mGal RMS and 15 mGal maximum.

Fig. 5: Influence of model Resolution on differences to EGM2008. The smallest differences to EGM can be reached using a similar spatial resolution.

Tab. 1: Parameter of scaling functions and resulting model resolution

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Fig. 5: Influence of model Resolution on differences to EGM2008. The smallest differences to EGM can be reached using a similar spatial resolution.

Fig. 6: Ship tracks used for model validation. Each black dot indicates one ship-borne measurement. In the study area the 56,600 measurements from 12 different campaigns are available.

As it can be seen from Fig. 7, the quality of the model depends on the model resolution. In some areas the gravity signal cannot be described by model resolutions around 10 km (such as $l = 11, b = 2$ in cyan). The model with higher resolution (e.g. $l = 12, b = 2, r = 5$ in blue) performs better. However, this is different in other model areas where the data distribution is sometimes too sparse for a reliable estimation of higher levels. The black curve ($r = 20, b = 1.5, r = 6$ km) is a compromise and performs best taking into account the whole study area.

The quality of the ship-borne data is different for the campaigns. Comparing the model to the most reliable survey (BMRG/SM5 with about 15,000 observations) provides an RMS of about 4 mGal. This is in good coincidence with the estimated formal errors of about 3 mGal.

Fig. 7: Gravity anomalies for part of campaign BMRG/SM5 (8625 obs.). Plots shows the ship-borne data (in red) and 4 different model realizations. In plot (b) the model difference to the ship-borne data can be seen.