MODELING MARINE GRAVITY POTENTIAL WITH SATELLITE ALTIMETRY DATA

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ABSTRACT

This contribution introduces a regional model approach for estimating marine gravitational information from satellite altimeter measurements. The approach allows an optimal combination of different input data types to estimate scaling coefficients from a series expansion based on spherical scaling functions. The derivation of different gravitational functionals and a multi-scale representation is easily possible with this approach. Using 1 Hz along-track sea surface height (SSH) measurements (without any retracking) from three different altimetry missions accuracies around 4 mGal can be reached in a study area south of Australia.

Key words: marine geoid; satellite altimetry; regional gravity modeling; spherical basis functions.

1. INTRODUCTION

Sea surface height (SSH) measurements from radar altimetry missions are the primary source of information for marine gravity field modeling. In contrast to other satellite based gravity measurements the data are directly related to the ground and no downward continuation from orbit height is necessary. Consequently, much higher spatial resolution can be reached compared to dedicated gravity missions (GRACE, GOCE). Particularly, the geodetic mission phases of GEOSAT, ERS-1, and Jason-1 as well as the long repeat-cycle mission Cryosat-2 can provide valuable information for high resolution marine gravity field modeling.
In this contribution, some results of our approach for regional marine gravity modeling using spherical scaling functions are presented. As test region a 5° by 5° area south of Australia is chosen. The estimated gravity anomalies for this region are compared to other models (i.e. EGM2008 and SS_V20.1) as well as to ship-borne gravity measurements.

2. MODELING APPROACH

In our work we do not follow the traditional Stokes or Vening Meinesz approach. Instead we use absolute SSH profiles of different altimeter missions to compute high resolution regional gravity field models over the ocean. In combination with sea surface topography information, the SSH is used as input data for the estimation of the unknown coefficients of our model, which is set up as a series expansion in spherical basis functions, i.e. spherical scaling functions [Schmidt et al., 2007], in order to estimate differences to a given background model (e.g. GOCO03S). The approach has several advantages over the inversion of Stokes or Vening Meinesz integrals: A combination with other input data types such as GOCE gravity gradients is possible in order to stabilize the results in the medium frequency band. Moreover the estimation of the gravity potential allows deriving not only geoid undulations but any functional of interest, e.g. gravity anomalies or gravity gradients.
We use the series expansion to describe disturbing potential differences ΔT with respect to a given background model T_{back} in order to avoid the necessity to determine low-frequency signal parts which cannot be determined from regional data. As background model we use GOCO03S up to degree 180 [Mayer-Guerr et al., 2012].

$$T = T_{back} + \Delta T = T_{back} + \sum_{q=1}^{q_{max}} d_{b,j,q}\phi_{b,j,q} \quad (1)$$

$$\phi_{b,j,q} = \sum_{l=0}^{l_{max}} \frac{2l+1}{4\pi}\left(\frac{R}{r}\right)^{l+1} \Phi_{b,l}P_l(cos\psi) \quad (2)$$

The model is set up as a series expansion in spherical basis functions, i.e. spherical scaling functions $\phi_{b,j,q}$ whose unknown coefficients $d_{b,j,q}$ are estimated in an adjustment procedure. Within the adjustment process a variance component estimation (VCE) is used to ensure an appropriate relative weighting between the different altimetry missions and other input data types (if available).
Each scaling function is located on a fixed position on the sphere. We use a Reuter grid with q_{max} grid points for defining the distribution of the functions. The scaling functions are defined by its level j and a base b whose relation to the maximum degree l_{max} is given by Eq. (3). The higher j the sharper is the scaling function, the more grid points are necessary, and the higher is the spatial resolution of the model.

$$l_{max} = int[b^j - 1] \quad (3)$$

The introduction of different bases $b \leq 2$ (in contrast to using a fixed base $b = 2$) is introduced to allow for

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closer frequency bands in the higher frequency parts. Detailed information on the model approach and the theory behind can be found in Schmidt et al. [2007] and [Lieb et al., in preparation].

3. INPUT DATA

We use 1 Hz data from three different altimetry missions, namely ERS-1 (geodetic mission phases E and F, Apr. 1994 to Mar. 1995), Cryosat-2 (LRM and Pseudo-LRM data from RADS, July 2010 to Dec. 2012), and Jason-1 (geodetic mission phase, May 2012 to Feb. 2013). The SSH data are directly introduced along the satellite ground tracks and no further gridding, retracking or smoothing is performed. The consistency of the different altimetry missions is reached by a preprocessing crossover analysis [Dettmering and Bosch, 2013] which also ensures that long-wavelength errors such as orbit errors are eliminated beforehand.
For converting the SSH measurements to geoid information a correction by the sea surface topography also known as dynamic ocean topography (DOT) is necessary. The derived quantity, the geoid undulation N can easily be converted to disturbing potential T using normal gravity γ.

$$T = \gamma \cdot N = \gamma \cdot (SSH - DOT) \tag{4}$$

The DOT is derived from multi-mission altimetry and a satellite only gravity model (GOCO03S). It is important to note, that no mean dynamic topography (MDT) is used but instantaneous DOT on the satellite profiles, so-called iDOTs with spatial resolution of about 70 km. For more details on the derivation of these quantities see Bosch et al. [2013].

4. ESTIMATED GRAVITY ANOMALIES AND COMPARISON TO OTHER MODELS

The estimation of the gravitational potential enables deriving not only geoid undulations but any functional of interest, e.g. gravity gradients T_{rr} or gravity anomalies Δg. In the following we focus on free-air gravity anomalies as these quantities can easily be compared to other models and validation data sets. The left upper plot of Fig. 1 shows free-air anomalies computed using Blackman scaling functions. The model parameters are set to level $j = 20$ and base $b = 1.5$ as this resolution (approx. 6 km) fits best to the observation distribution. The other three plots in the figure show the estimated formal errors (top right) and the differences to two external models: EGM2008 [Pavlis et al., 2012] and SS_V20.1 [Sandwell and Smith, 2009].
The full error propagation gives model precisions of about 2.6 mGal (mean standard deviation of the estimated gravity anomalies) in the central part of the test area with up to 10 mGal standard deviations at the margins (which are not visible in the plot due to the chosen colorbar). The differences with respect to the two models give RMS values of 3.88 mGal (EGM2008) and 3.90 mGal (SS_V20.1) and show no systematic effects.

5. COMPARISON TO SHIPBORNE DATA

For model validation, ship-borne free-air gravity anomalies from NOAA's National Geophysical Data Center (NGDC) are used which are freely available via http://www.ngdc.noaa.gov/mgg/geodas/geodas.html. In the study area, 12 different research cruises are available. Since the data has not been preprocessed and harmonized, model differences are computed for each campaign independently.
The RMS of the differences vary between 3.4 mGal and 14.4 mGal, depending strongly on the campaign. Older cruises show less consistency to our model than more recent campaigns. The mean of all RMS values reaches 6.9 mGal in the central part of the test area. The differences are in the same order of magnitude as the differences between ship-borne data and EGM2008 (6.3 mGal) and a little worse than the differences between ship-borne data and SS_V20.1 (5.8 mGal).
It is important to keep in mind that these numbers not only reflect the accuracies of the tested models but also include measurement errors from the ship-borne data.

6. CONCLUSIONS AND OUTLOOK

This paper gives an overview on an approach for model regional gravity potential using spherical basis functions. The model can handle and combine different types of input data and provides different gravitational functionals. In this contribution, along-track SSH measurement from different altimetry missions are combined to estimate high-resolution marine gravity anomalies. The results show differences of about 3.9 mGal with respect to other models and minimal differences of 3.4 mGal with respect to ship-borne data sets. The reached accuracy is similar to EGM2008 but further improvements are possible to reach the same level of accuracies than other models, e.g. SS_V20.1. Nevertheless, keeping in mind that we use the original 1 Hz SSH measurements without dedicated data preprocessing (i.e. retracking of altimeter waveforms), the results are quite promising. In the future we will investigate the use of 20 Hz altimeter data to improve the spatial model resolution. Moreover we will deal with data preprocessing in order to improve the data quality and the model results.

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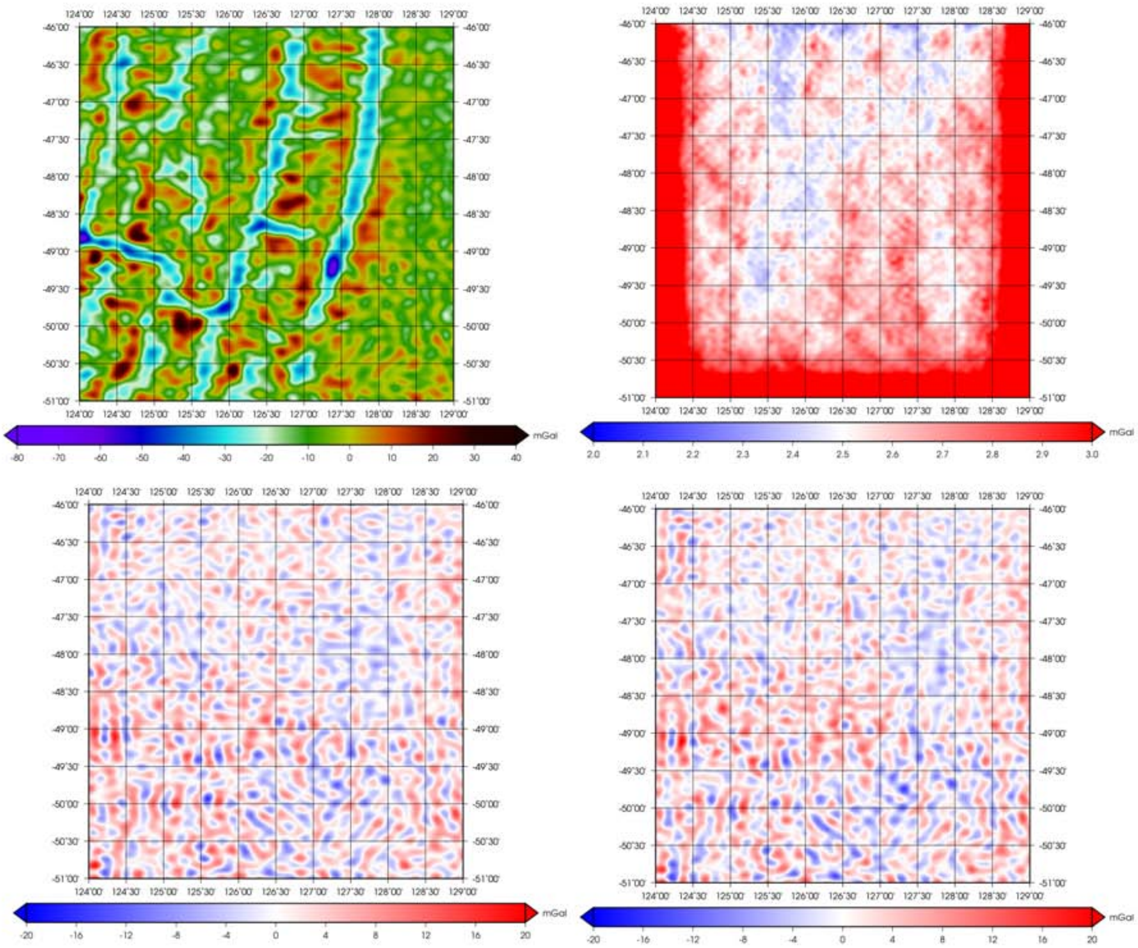

Figure 1. Estimated gravity anomalies in the study area (top plot on the left hand side) together with the formal errors (top right) and differences to two external models in the bottom line: EGM2008 (left) and SS_V20.1 (right).

altimeter mission operations and data distribution (ESA, CNES/NASA, AVISO, and RADS).

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