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Evaluation of satellite altimetry-derived gravity field models with shipborne gravity data in the Mediterranean Sea

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Abstract

Marine gravity field models can be used in a wide range of applications such as improving marine geoid and the height system, monitoring ocean circulation, tides, the greenhouse effect and climate change and can benefit various Earth sciences such as geodesy, geophysics and oceanography. Satellite altimetry-derived gravity field models provide uniform global coverage compared to shipborne gravity data. Studies conducted about the quality assessment of the latest satellite altimetry-derived gravity field models in Turkish seas are deficient. Therefore, in this study, selected satellite altimetry-derived gravity field models (SSv29.1, DTU21, DTU17, DTU15, DTU13 and DTU10) were validated with shipborne gravity data in the Mediterranean Sea. In comparison with shipborne free-air gravity anomalies, SSV29.1 model has the lowest standard deviation with 24.096 mGal followed by DTU21, DTU17, DTU15, DTU13 and DTU10 models with standard deviations of 24.169, 24.371, 24.396, 24.416 and 24.444 mGal, respectively. It is concluded that there are no statistically significant differences between the models for the study area.

1. Introduction

Gravity field models offer valuable information about the Earth, its interior and its fluid envelope for all geosciences such as geodesy, geophysics and oceanography (Barthelmes, 2014). Gravity field models can be used in geoid modelling, defining the reference height system, determining ocean circulation models and dynamics, monitoring tides, greenhouse effect and climate change, marine transportation and fishing, weather forecasting and prediction of natural disasters, exploration of natural resources like oil and gas, and mining.

Marine gravity fields can be generated from different data sources which consist of shipborne, airborne and land measurements, satellite gravity missions and satellite altimetry. Terrestrial measurements such as shipborne gravity data have high accuracy, however, these datasets are mostly sparse, the data derivation process is costly and time-consuming, temporal variations of the gravity field cannot be determined and also systematic errors can occur. Although satellite altimetry might not provide as accurate data as shipborne gravimetry, satellite altimetry data have global and uniform coverage and can be accessed free of charge.

Satellite altimetry provides sea surface heights by measuring the time between a radar signal transmitted to the Earth's surface and reflected back to the satellite. Marine geoids generated from the sea surface height measurements enable to develop gravity field models since geoids refer to the equipotential surface of the Earth's gravity field that corresponds closely with the mean sea level (Andersen, 2012; Andersen & Knudsen, 2000). Satellite altimetry is particularly efficient over oceans and open water on land due to the excellent reflective structure of the water (GGOS, n.d.). Coastal areas are not ideal for implementing satellite altimetry. Abulaitijiang et al. (2021) stated that improvements in recent satellite altimeters enable to provide more reliable short-wavelength components of the marine gravity field than traditional altimetry.

Satellite altimetry is confirmed as a valuable observational tool for numerous research areas such as ocean and hydrosphere, due to its achievements and its level of accuracy and precision (Abdalla et al., 2021). The developments in satellite altimetry missions and data processing methods contributed to the enhancement of

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marine gravity models in terms of accuracy and resolution (Guo et al., 2022; Zaki et al., 2018, as cited in Li et al., 2022).

Around the world, several studies were carried out in order to evaluate the accuracy of satellite altimetry-derived marine gravity fields (Kamto, 2022). There are a few related studies conducted in Turkish seas, however, studies that contain the latest satellite altimetry models are inadequate. Therefore, this study aims to fill the gap on this subject by validating satellite altimetry products in the Turkish seas. In this study, selected satellite altimetry-derived gravity field models which also consist of the recent models (SSv29.1, DTU21, DTU17, DTU15, DTU13 and DTU10) were validated with shipborne gravity data in the Mediterranean Sea.

2. Method

Shipborne gravity data were obtained from International Gravimetric Bureau (BGI). 14661 points at the Mediterranean Sea between 33°N to 38°N and 26°E to 36°E were used for the validation (Figure 1).

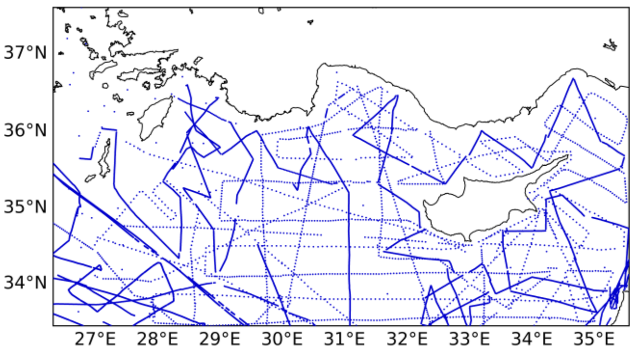

Figure 1. Spatial distribution of 14661 shipborne data points at the Mediterranean Sea

SSv29.1, DTU21, DTU17, DTU15, DTU13 and DTU10 models were selected as satellite altimetry gravity field models (Table 1). S&S series of marine gravity models were presented by the Scripps Institution of Oceanography (SIO) (Abdallah et. al., 2022). SSv29.1 gravity data were extracted from global 1 arc-minute grids from SIO's website (SIO, n.d.).

DTU21 model was obtained from the Technical University of Denmark (DTU). DTU17, DTU15, DTU13 and DTU10 models were acquired from DTU's website (DTU, 2018). All of the DTU models have 1 arc-minute resolution and the same reference gravity field with SSv29.1 which is EGM2008. DTU21 and SSv29.1 models were generated practically from the same available altimetry data. The computation algorithms of these models are different. DTU models use the residual sea surface heights while SSv29.1 model applies the residual slopes of the sea surface heights (Andersen & Knudsen, 2020; Sandwell et al., 2013, as cited in Abdallah et al., 2022).

Before the validation, SSv29.1 and DTU free-air gravity anomalies were interpolated to 14661 shipborne gravity points with a bilinear interpolation method by using Surfer® from Golden Software. Satellite altimetry-derived free-air gravity anomalies were compared with shipborne free-air gravity anomalies by subtracting shipborne gravity anomalies from satellite altimetry-derived gravity anomalies (Equation 1). For each comparison, statistical parameters were calculated and differences were visualized in order to implement both quantitative and qualitative analyses. As statistical parameters, minimum, maximum, mean and standard deviation (SD) values were computed.

$$\Delta g_{residual} = \Delta g_x - \Delta g_y \quad (1)$$

Δg_y : the shipborne-derived gravity anomaly
Δg_x : the satellite altimetry-derived gravity anomaly
$\Delta g_{residual}$: the residual gravity anomaly

Table 1. Characteristics of satellite altimetry gravity field models (Abdallah et al., 2022; Li et al., 2022)

Model	Year	Data	Coverage Range
SSv29.1	2019	T/P + J1 + E2 + En + J2 + C2 + Al + S3A + S3B	85°S ~ 85°N
DTU21	2021	T/P + GFO + E2 + J1 + C2 + J2 + Al + ICESat-1 + S3A + S3B	90°S ~ 90°N
DTU17	2017	T/P + GFO + E2 + J1 + C2 + J2 + Al + ICESat-1	90°S ~ 90°N
DTU15	2015	Ge + E1 + T/P + GFO + E2 + J1 + C2 + ICESat-1	90°S ~ 90°N
DTU13	2013	Ge + E1 + T/P + GFO + E2 + J1 + C2 + ICESat-1	90°S ~ 90°N
DTU10	2010	Ge + E1 + T/P + GFO + E2 + J1+ ICESat-1	90°S ~ 90°N

(Ge: Geosat, E1: ERS-1, T/P: Topex/Poseidon, J1: Jason-1, E2: ERS-2, En: Envisat, C2: Cryosat-2, Al: Saral/Altika, J2: Jason-2, S3A: Sentinel-3A, S3B: Sentinel-3B)

3. Results

In comparison with shipborne free-air gravity anomalies, SSv29.1 model has the lowest standard deviation with 24.096 mGal followed by DTU21, DTU17, DTU15, DTU13 and DTU10 models with standard deviations of 24.169, 24.371, 24.396, 24.416 and 24.444 mGal, respectively. SSv29.1 model also has the lowest mean value with -1.635 mGal followed by DTU21 with the mean value of -2.714 mGal (Table 2).

A similarity can be seen among the difference maps (Figures 2, 3, 4, 5, 6 and 7). In the difference map of the SSv29.1 model, the difference values are slightly lower near the coasts of Israel compared to the other models. For all models, the largest discrepancies with shipborne data belong to two tracks of the ship surveys. This could be due to some errors in shipborne data along these survey tracks.

Table 2. Statistics of the differences between satellite altimetry-derived free-air gravity anomalies and shipborne free-air gravity anomalies

Model	Minimum	Maximum	Mean	SD
SSv29.1	-94.880	163.931	-1.635	24.096
DTU21	-89.267	165.453	-2.714	24.169
DTU17	-92.523	163.977	-2.913	24.371
DTU15	-92.641	164.545	-2.968	24.396
DTU13	-91.563	164.407	-2.974	24.416
DTU10	-92.726	163.367	-2.908	24.444

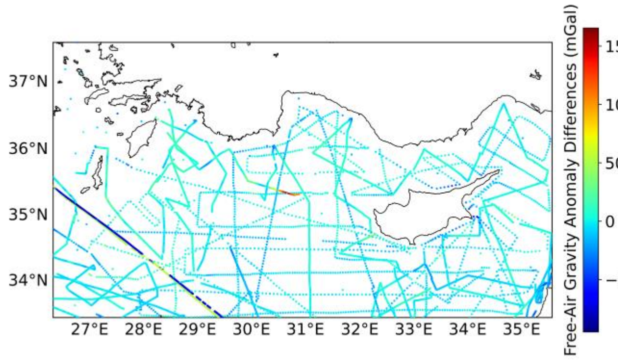

Figure 2. Differences between SSv29.1 free-air gravity anomalies and shipborne free-air gravity anomalies

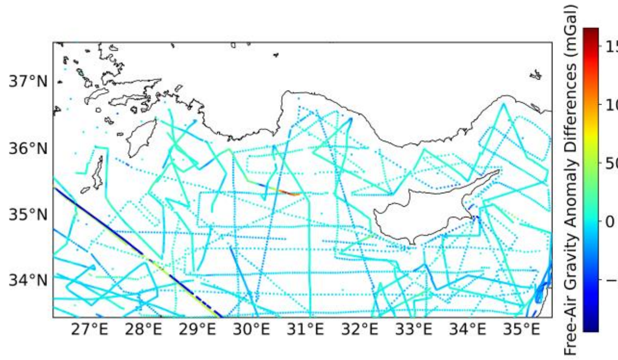

Figure 3. Differences between DTU21 free-air gravity anomalies and shipborne free-air gravity anomalies

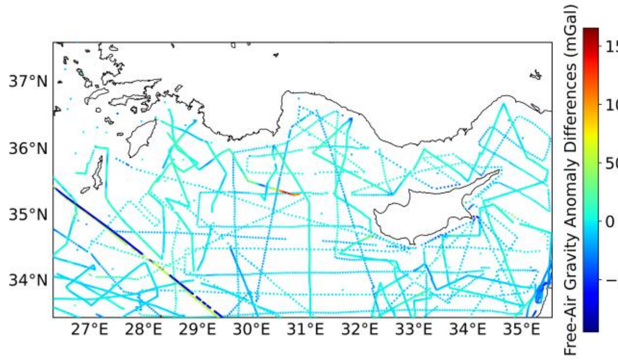

Figure 4. Differences between DTU17 free-air gravity anomalies and shipborne free-air gravity anomalies

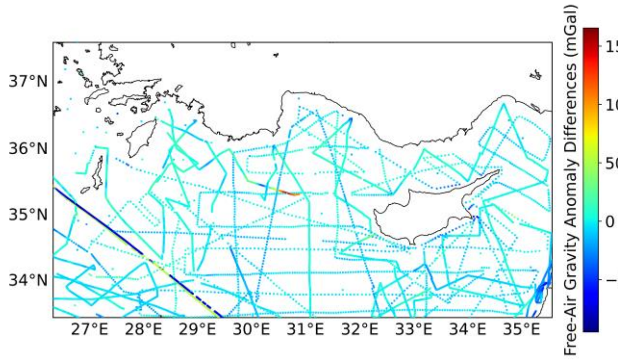

Figure 5. Differences between DTU15 free-air gravity anomalies and shipborne free-air gravity anomalies

In Figure 8, it can be seen that SSv29.1 and DTU21 model differences in comparison with the shipborne gravity data differ from each other mostly in the coastal areas.

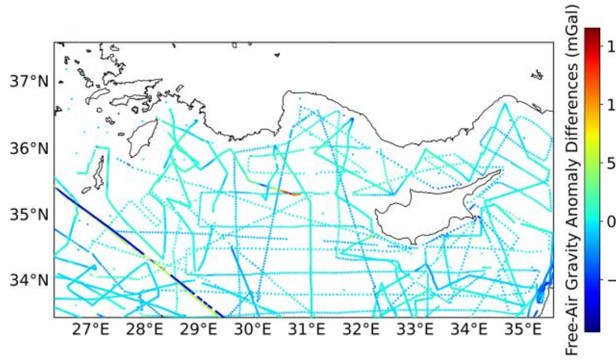

Figure 6. Differences between DTU13 free-air gravity anomalies and shipborne free-air gravity anomalies

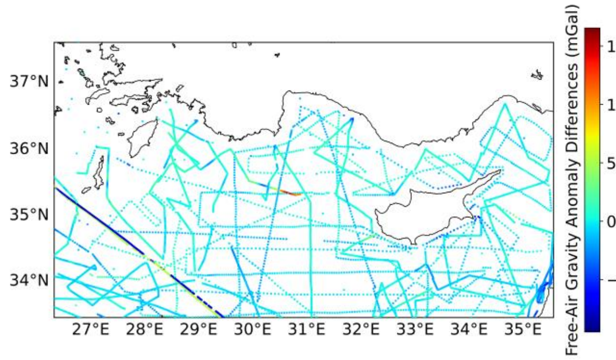

Figure 7. Differences between DTU10 free-air gravity anomalies and shipborne free-air gravity anomalies

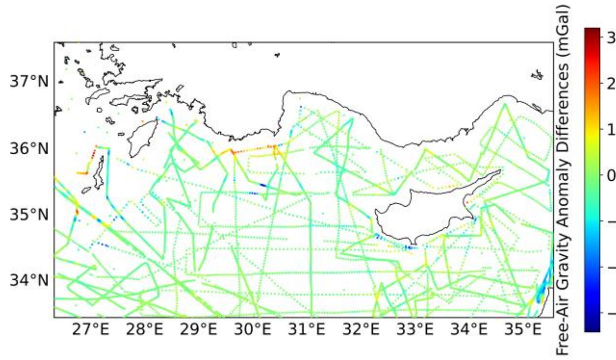

Figure 8. Differences between SSv29.1 and DTU21 models in comparison with shipborne free-air gravity anomalies

4. Discussion and Conclusion

Satellite altimetry is essential for gathering marine data for all geosciences including geodesy and oceanography. Therefore, evaluating the accuracy of satellite altimetry data is important. This study provides information about the performances of SSv29.1, DTU21, DTU17, DTU15, DTU13 and DTU10 satellite altimetry gravity models in the Mediterranean Sea. By comparing six different satellite altimetry-derived free-air gravity anomalies with shipborne free-air gravity anomalies, it is concluded that there are no statistically significant differences between the models for the study area. The reason for this can be that the models were generated from data obtained from mainly the same satellite altimetry missions.

The results of this study are preliminary for future studies and will be supported by further analyses. In future studies, it is planned to use the outputs of this study to enhance marine geoid in coastal areas and improve the height system. Moreover, dynamic ocean topography will be modelled with satellite altimetry data. Furthermore, it is aimed to generate a combined marine geoid with shipborne gravity and satellite altimetry data in order to increase spatial resolution. Increased resolution and accuracy of the marine geoid will improve the forecasting of ocean circulation, tides, greenhouse effect and climate change, since ocean currents can be observed from sea surface heights.

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