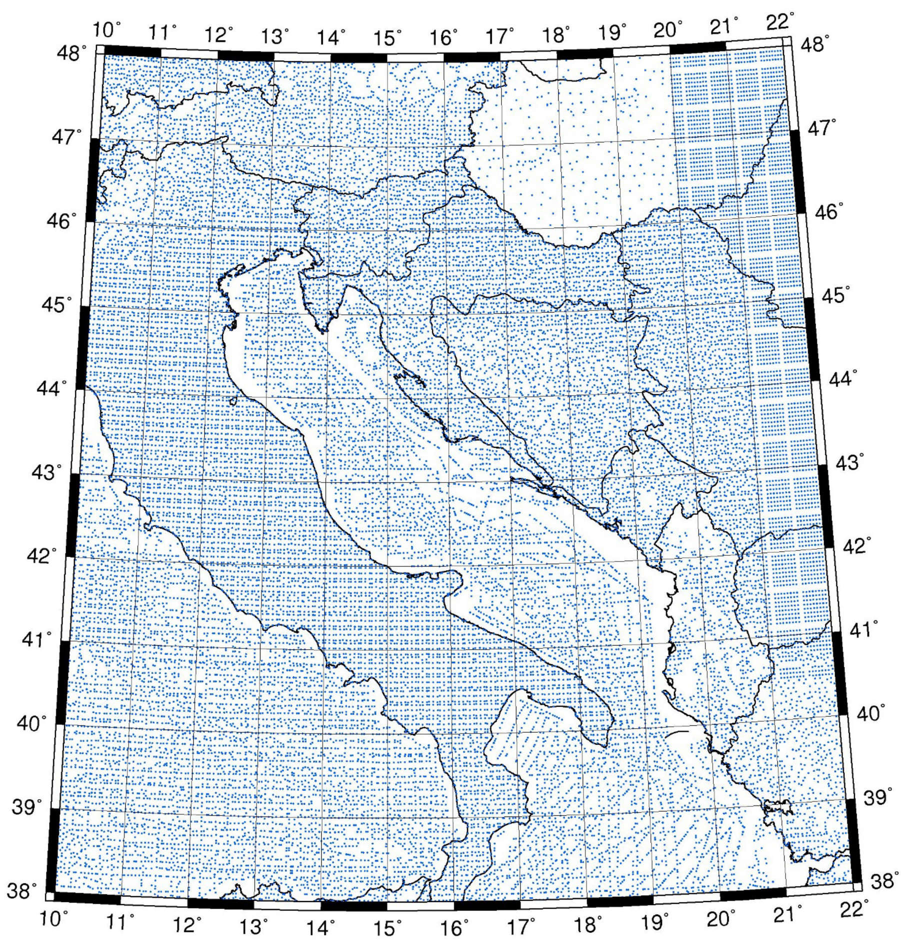
Investigation of the contribution of topographic effects on regional geoid modeling within the Geomed2 project

Riccardo Barzaghi[1], Georgios Vergos[5], Alberta Albertella[1], Daniela Carrion[1], Noemi Emanuela Cazzaniga[1], Ilias N. Tziavos[5], Vassilios Grigoriadis[5], Dimitrios Natsiopoulos[5], Sean Bruinsma[2], Sylvain Bonvalot[2], Lucia Seoane[2], Franck Reinquin[2], Marie-Françoise Lequentrec-Lalancette[3], Corinne Salaun[3], Pascal Bonnefond[4], Per Knudsen[6], Ole Baltazar Andersen[6], Mehmet Simav[8], Hasan Yildiz[8], Tomislav Basic[9], Matej Varga[9], Olga Bjelotomic[9] and Antonio J. Gil[10]

[1]Politecnico di Milano, Italy (Polimi); [2]GET UMR 5563, Toulouse, France (GET); [3]SHOM, Brest, France (SHOM); [4]OCA/Géoazur, Sophia--Antipolis, France (OCA); [5]University of Thessaloniki, Greece (AUTh); [6]DTU Space, Kopenhagen, Denmark (DTU); [8]General Command of Mapping, Ankara, Turkey (GCM); [9]University of Zagreb, Zagreb, CroaKa (UZ); [10]University of Jaén, Jaén, Spain (UJA)

Introduction

With nowadays high resolution Global Geopotential Models (GGMs), traditional geoid approximation with the Remove-Compute-Restore (RCR) procedure needs revisiting both in terms of the numerical and the methodological steps followed. This becomes evident if one considers the high degree of expansion of the latest combined GGMs, corresponding to frequencies as short as 9.2 km for a maximum degree of expansion equal to 2160, and the limited spatial resolution of bathymetry models, being 30 arcsec (~1 km) for the SRTM15_PLUS model. In the above schema, if a high-resolution GGM is used to reduce the available surface gravity data, then the bathymetry model used for the terrain reduction should be able to represent adequately the spatial frequencies between 10 and 1 km, so that the corresponding gravity signal presents in the reduced gravity anomalies can be removed. This step is quite significant since depending on the correctness, resolution and accuracy of the bathymetry model, the resulting residual gravity anomalies can be either useful for geoid determination, or can introduce biases, noise exaggeration and aliasing in the predicted gravimetric geoid model. Within the GEOMED 2 project, which aims at a high resolution and accuracy geoid determination for the entire Mediterranean basin, in situ gravity anomalies are used within the RCR procedure employing DIR-R5 and EIGEN6c4 as reference geopotential models and various bathymetry/topography models (DTU10, EMODNET and SRTM15_PLUS) in order to investigate the influence of the used terrain representation on the gravity and geoid signal. The used Digital Terrain and Bathymetry Models (DTBMs) are of various resolutions, smoothness, and accuracy, while some of them are directly derived from satellite data and some of them from in situ echo sounding observations. In this work the Residual Terrain Model (RTM) reduction is used to model the contribution of topography/bathymetry to gravity and the geoid, while the contribution of each model and its appropriateness for use in geoid modelling are investigated both in the frequency and the space domain.



Data considered for the test: 29804 points in the displayed area

Digital Terrain and Bathymetry Models (DTBMs)

Over land the SRTM3 has been used. Over sea the following models have been considered.

DTU10 (1'x1'): Bathymetry derived from satellite ERS-1 data, mapped with a resolution of 1 minute by 1 minute corresponding to 2 minute by 2 minute resolution at Equator (Andersen et al., 2008).

EMODNET (7.5"x7.5"): The EMODnet-Bathymetry portal (http://www.emodnet-bathymetry.eu) is being developed in the framework of the European Marine Observation and Data Network (EMODnet) as initiated by the European Commission. There are 4 types of organisations (Hydrographic Offices, Authorities, Research institutes, Industry) that perform bathymetric surveys, thereby partly overlapping and mostly complementing their geographical coverages. Data are collected at different frequencies and even date back to previous centuries. The partners combine expertise and experiences of collecting, processing, and managing of bathymetric data together with expertise in distributed data infrastructure development and operation and providing OGC services (WMS, WFS, and WCS) for viewing and distribution.

SRTM15_PLUS (15"x15"): Land elevations are based on the best available data from SRTM, ASTER digital elevation models while the ice topography of Greenland and Antarctica is based on CryoSat-2 and IceSat. Ocean bathymetry is based on bathymetric predictions from the latest global gravity model from CryoSat-2 and Jason-1 along with 494 million edited depth soundings at 15 arcsec resolution. Bathymetry of the Arctic seafloor is based on the IBCAO grid with improved resolution in areas of multibeam coverage. This SRTM15_PLUS provides the foundational bathymetry layer for Google Earth and is freely available at the topex.ucsd.edu ftp site (Olson and Sandwell, 2016).

Statistics of the residuals Δg after the Remove phase. Different Geopotential Models (DIR up to d/o 230 and EIGEN-6c4 up to d/o 1000) have been used and Digital Terrain Models including different bathymetries have been considered. Various caps for getting the coarse DTM to be used for the Residual Terrain Correction component have been considered in the computation, to find the one providing the best reduction (highlighted in green).

The best reduction is obtained with a 22' cap for DIR geopotential model and with a 8' cap for EIGEN-6c4. The results are equivalent for the three considered bathymetries.

Statistics of the residuals considering various caps DTU10 Bathymetry DIR and EEIGEN-6C4 geopotential models

DTU10	over 29804 points														
	DIR														
Cap [']	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Mean	0.814	0.739	0.689	0.651	0.614	0.565	0.523	0.465	0.388	0.312	0.245	0.176	0.096	0.016	-0.065	-0.157
StDev	17.421	16.866	16.420	16.138	16.017	16.057	16.204	16.466	16.827	17.278	17.822	18.470	19.206	19.989	20.816	21.691
Max	114.979	112.460	110.475	108.703	107.422	106.037	104.454	103.264	102.761	102.360	102.866	106.429	110.245	114.091	117.819	121.254
Min	-112.680	-106.953	-106.618	-106.992	-107.910	-108.900	-110.295	-112.297	-114.357	-117.216	-120.433	-124.065	-127.480	-130.397	-133.037	-135.486
RMS	17.440	16.882	16.435	16.151	16.028	16.067	16.213	16.473	16.831	17.281	17.824	18.471	19.206	19.989	20.816	21.692
	EIGEN															
Cap [']	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean	0.729	0.826	0.889	0.925	0.943	0.949	0.942	0.929	0.912	0.892	0.872	0.852	0.832	0.812	0.791	0.771
StDev	11.603	10.747	10.285	10.210	10.468	10.985	11.681	12.480	13.330	14.192	15.037	15.852	16.628	17.361	18.048	18.693
Max	95.387	94.538	92.046	91.756	91.696	91.551	91.738	91.495	92.287	95.474	98.791	101.739	104.326	106.040	106.954	107.612
Min	-114.955	-113.645	-112.827	-112.153	-112.528	-116.762	-120.367	-123.487	-126.292	-128.769	-131.188	-133.355	-135.284	-137.101	-138.815	-140.489
RMS	11.626	10.779	10.323	10.252	10.511	11.026	11.719	12.515	13.361	14.220	15.062	15.875	16.648	17.380	18.065	18.709

Statistics of the residuals considering various caps EMODNET Bathymetry DIR and EEIGEN-6C4 geopotential models

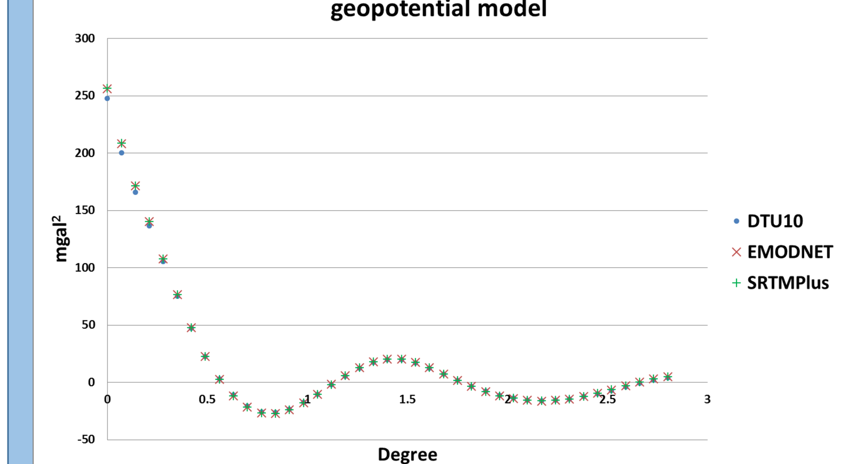
EMODNET	over 29804 points															
	DIR															
Cap [']	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Mean	0.763	0.689	0.643	0.608	0.578	0.532	0.493	0.439	0.364	0.288	0.224	0.161	0.080	0.000	-0.078	-0.171
StDev	17.641	17.096	16.660	16.388	16.275	16.320	16.477	16.750	17.120	17.581	18.133	18.787	19.531	20.325	21.170	22.060
Max	114.183	111.671	109.728	107.907	106.600	106.112	109.712	113.452	116.918	120.275	123.759	127.565	131.515	135.424	139.263	142.802
Min	-112.222	-108.337	-107.908	-108.378	-109.299	-110.305	-111.701	-113.602	-116.614	-119.765	-122.994	-126.624	-130.019	-132.941	-135.529	-137.972
RMS	17.657	17.110	16.672	16.399	16.286	16.328	16.485	16.755	17.124	17.583	18.135	18.788	19.531	20.325	21.170	22.061
	EIGEN															
Cap [']	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean	0.638	0.736	0.802	0.841	0.863	0.872	0.870	0.860	0.847	0.831	0.814	0.796	0.779	0.762	0.744	0.725
StDev	11.543	10.670	10.183	10.074	10.295	10.772	11.429	12.192	13.008	13.839	14.657	15.449	16.204	16.919	17.593	18.226
Max	98.665	96.080	93.815	93.960	93.898	93.122	92.278	91.499	94.399	97.660	100.990	103.959	106.491	108.133	108.994	109.726
Min	-116.624	-115.288	-114.405	-113.736	-112.810	-117.031	-120.628	-123.796	-126.553	-129.034	-131.495	-133.677	-135.688	-137.517	-139.311	-140.992
RMS	11.561	10.695	10.215	10.109	10.331	10.807	11.462	12.222	13.035	13.864	14.680	15.469	16.223	16.937	17.609	18.241

Statistics of the residuals considering various caps SRTM15_PLUS DTM DIR and EEIGEN-6C4 geopotential models

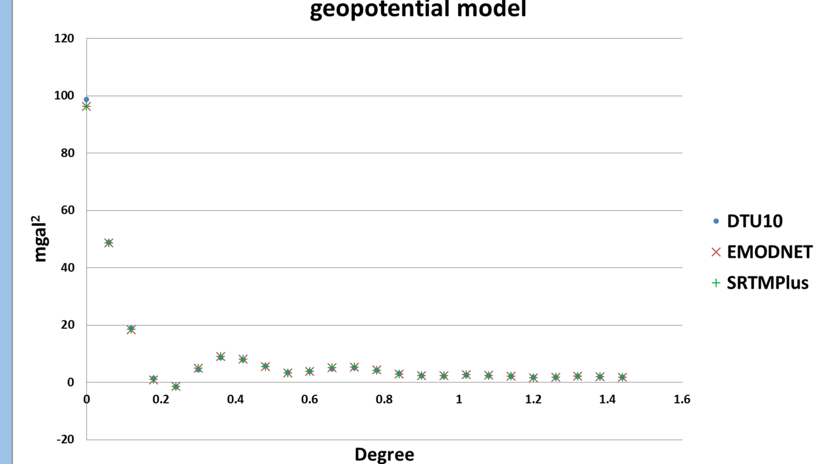
SRTMPlus	over 29804 points															
	DIR															
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Cap [']	0.747	0.673	0.625	0.591	0.561	0.515	0.476	0.422	0.347	0.271	0.207	0.144	0.063	-0.016	-0.095	-0.188
Mean	17.649	17.104	16.669	16.395	16.283	16.326	16.482	16.755	17.125	17.584	18.136	18.789	19.532	20.326	21.169	22.058
StDev	-112.222	-108.337	-107.908	-108.378	-109.299	-110.305	-111.701	-113.602	-116.614	-119.765	-122.994	-126.624	-130.019	-132.941	-135.529	-137.972
Max	114.183	111.671	109.728	107.907	106.600	105.297	107.649	111.433	114.900	118.229	121.747	125.553	129.518	133.514	137.354	140.900
Min	226.405	220.008	217.635	216.285	215.899	215.602	219.350	225.035	231.514	237.993	244.741	252.177	259.537	266.455	272.883	278.873
RMS	17.665	17.117	16.681	16.406	16.292	16.333	16.489	16.760	17.128	17.586	18.137	18.790	19.532	20.325	21.169	22.059
	EIGEN															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cap [']	0.622	0.721	0.786	0.825	0.847	0.856	0.854	0.844	0.831	0.814	0.797	0.780	0.762	0.745	0.727	0.708
Mean	11.544	10.670	10.183	10.073	10.293	10.770	11.426	12.189	13.004	13.836	14.654	15.445	16.200	16.916	17.589	18.222
StDev	-116.624	-115.288	-114.405	-113.736	-112.810	-117.033	-120.630	-123.798	-126.561	-129.045	-131.500	-133.753	-135.708	-137.616	-139.363	-141.085
Max	98.665	96.080	93.815	93.960	93.898	93.122	92.278	91.499	94.399	97.660	100.990	103.959	106.491	108.133	108.994	109.726
Min	215.290	211.368	208.219	207.696	206.707	210.155	212.908	215.296	220.960	226.704	232.491	237.712	242.199	245.750	248.357	250.811
RMS	11.560	10.694	10.213	10.107	10.328	10.803	11.458	12.218	13.031	13.859	14.675	15.465	16.218	16.932	17.604	18.236

Covariance function over the whole area (land and sea) or over sea only, considering different geopotential models (DIR and EIGEN-6c4) and using DTMs based on different bathymetries. It is possible to observe that the behaviour of the covariance function is less regular than expected. The effect does not vary with respect to the considered bathymetry.

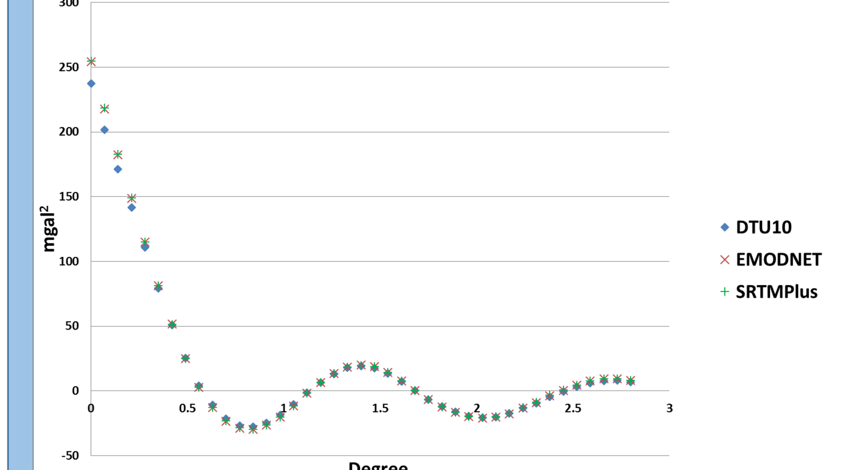
Covariance function over land and sea with DIR geopotential model



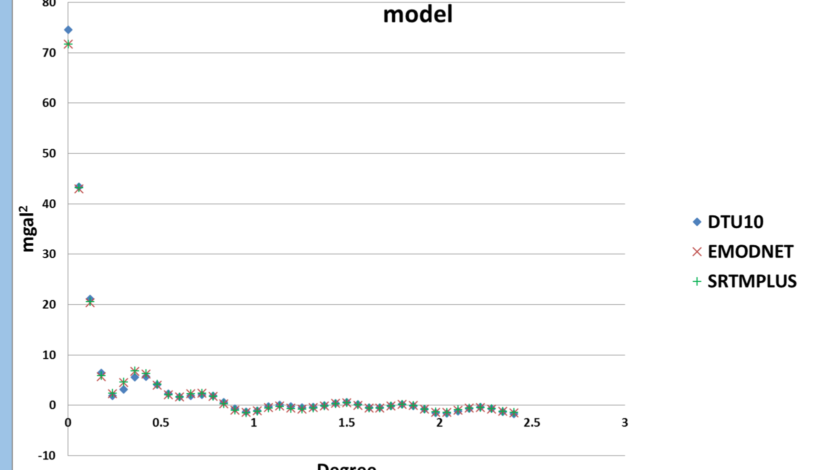
Covariance function over land and sea with EIGEN geopotential model



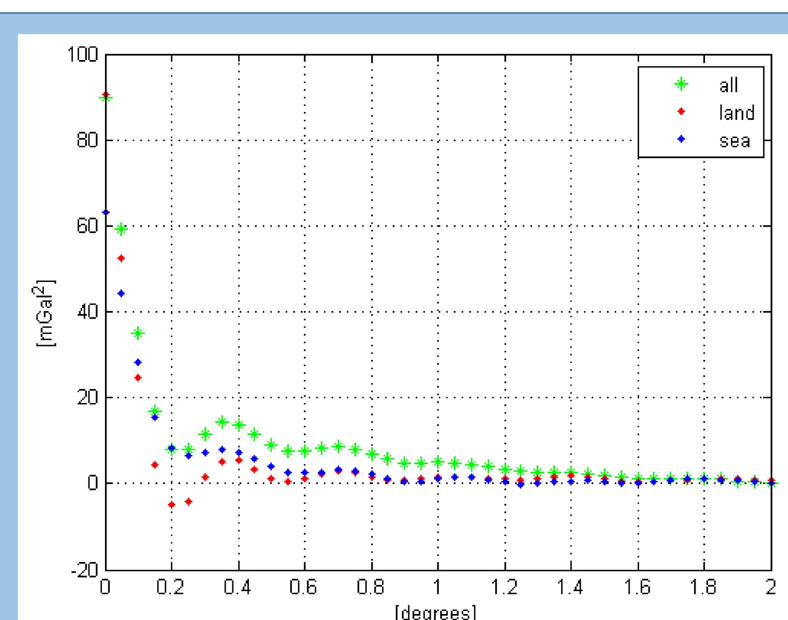
Covariance function over sea with DIR geopotential model



Covariance function over sea with EIGEN geopotential model

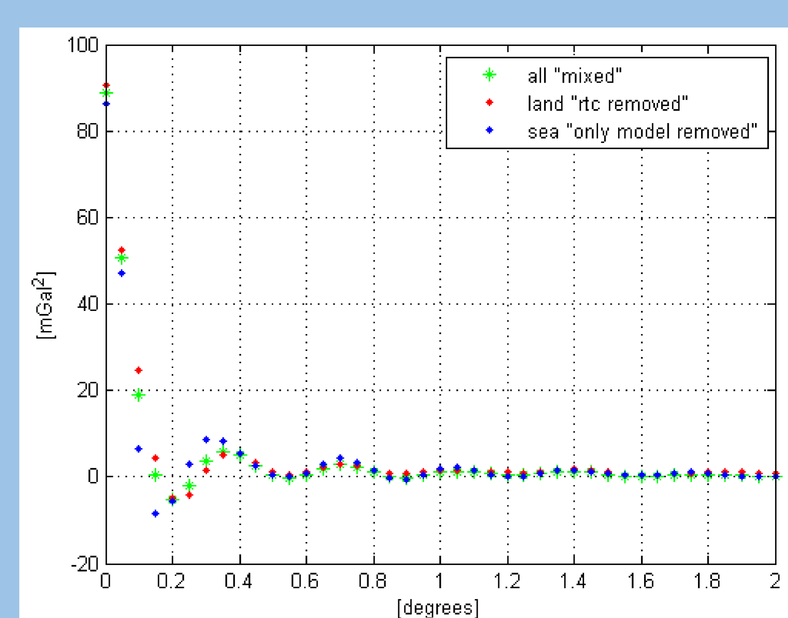


Covariance function over the whole area (land and sea) or over land only or sea only, considering EIEGEN-6c4 geopotential model and the DTM based on EMODNET bathymetry. It is possible to observe that the covariance function over land only has a more regular behaviour.

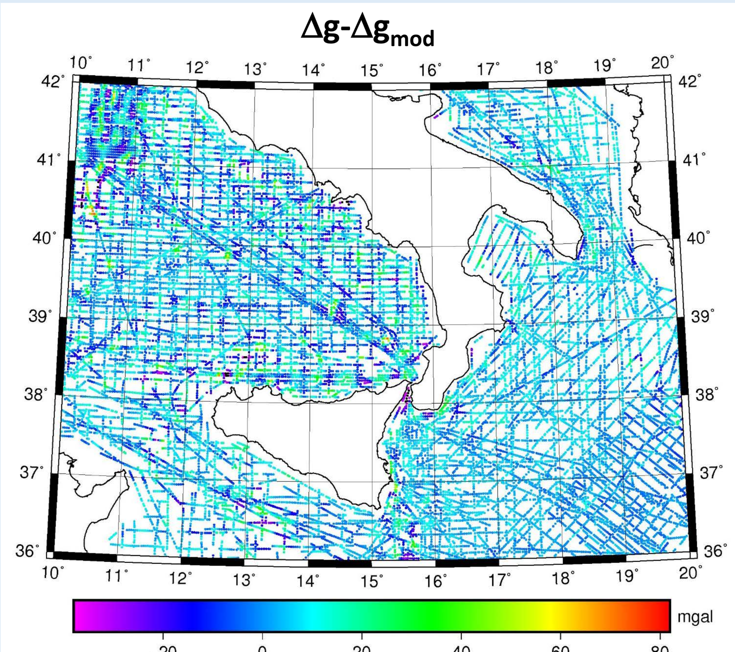


Covariance function over the whole area (land and sea) or over land only or sea only, considering EIEGEN-6c4 geopotential model and the DTM based on EMODNET bathymetry.

In this case the data over land have been completely reduced ($\Delta g - \Delta g_{model} - \Delta g_{RTC}$), while the data over sea have been only partially reduced ($\Delta g - \Delta g_{model}$). It is possible to observe that the behaviour of the covariance function has improved, implying that the matter is to be ascribed to the RTC component over sea.



Δg-Δg_{mod}



Δg-Δg_{mod}-Δg_{mod}

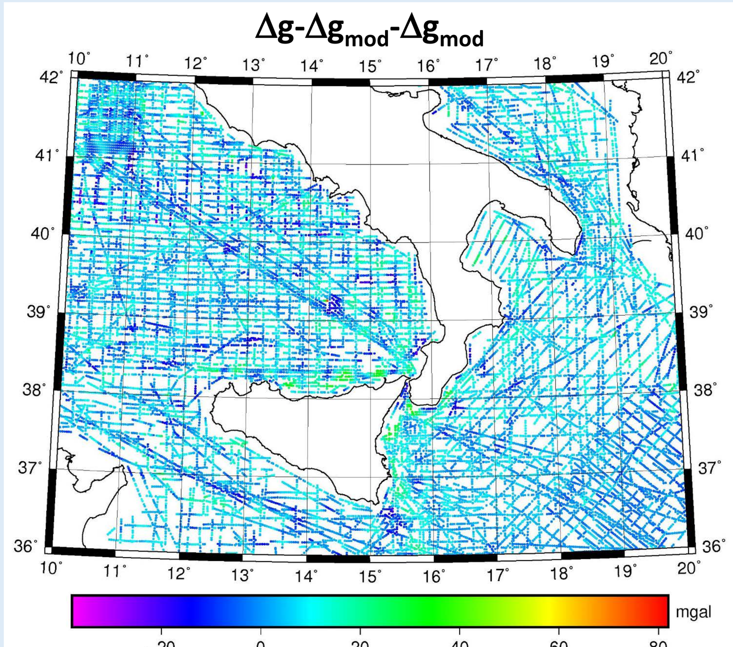


Image and statistics of the residuals partially reduced ($\Delta g - \Delta g_{model}$) and completely reduced ($\Delta g - \Delta g_{model} - \Delta g_{RTC}$), considering EIEGEN-6c4 geopotential model and the DTM based on EMODNET bathymetry.

After removing also the RTC component a high frequency signal is still present in the residuals, suggesting that some of the gravity contribution of the terrain cannot be modelled with the available information.

	$\Delta g - \Delta g_{model}$	$\Delta g - \Delta g_{model} - \Delta g_{RTC}$
# Values	22966	22966
Mean	3.160	3.775
St Dev	9.794	7.280
Min	-53.942	-38.399
Max	84.816	74.946

Conclusions

In view of the new computation of the Mediterranean geoid with the Remove-Compute-Restore technique, a test has been performed to investigate the performance of the reduction of gravity data considering different geopotential models and DTMs based on different bathymetries. The observation of the reduced data, of their statistics and of the covariance functions have shown that there are possible mismatches between marine data and bathymetry.

Bibliography

Andersen et al., 2008. The DTU10 global Mean sea surface and Bathymetry. Presented EGU-2008, Vienna, Austria.

Christopher J. Olson Joseph J. Becker David T. Sandwell (2016). SRTM15_PLUS: Data fusion of Shuttle Radar Topography Mission (SRTM) land topography with measured and estimated seafloor topography (NCEI Accession 0150537). Version 1.1. NOAA National Centers for Environmental Information.