P. Schaeffer[1], S. Bruinsma[2], F. Reinquin[2].
[1]CLS, France,
[2]CNES, France.
Email: pschaeffer@groupcls.com

The new CNES-CLS 2022 marine gravity anomaly model: first validation in the Mediterranean.

ABSTRACT

A new model of marine free-air gravity anomalies (**AG**) has been determined. It is based on the same data set used in the CNES CLS 2022 Mean Sea Surface determination. Particular attention was paid to the shortest wavelengths of less than 30 km. Furthermore, data sampling at 1 Hz (~7km) along track is not sufficient in this context. It is necessary to focus this new determination on the use of high-resolution data that are provided by a new generation of altimeters such as the Cryosat-2 (20 Hz) and SARAL (40 Hz) missions in the geodetic/drifting phase. However, at this rate, observations are too noisy and need application of a dedicated optimal filter.

We will present a validation of this new model based on a comparison with existing models, which were also derived from altimetry data.

Mapping method is based on objective analysis (Bretherton et al., 1976)

The best estimation is given by: $\Delta g(\vec{r}_e) = \sum_G \sum_N \mathbf{C}_{GN} \mathbf{A}_{NN}^{-1} \mathbf{N}_o$

Where : G represent the Gravity Anomaly and N the geoid height,

- C_{GN} is the cross-correlation function of the gauss-markov third order family of function (Jordan, 1972).
- A_{NN} is the covariance matrix between (i,j) observations and their corresponding errors:

$$A_{ij} = \langle \Phi_{obs,i} \cdot \Phi_{obs,j} \rangle = \langle \theta(\vec{\mathbf{r}}_i) \cdot \theta(\vec{\mathbf{r}}_j) \rangle + \langle E(\vec{\mathbf{r}}_i) \cdot E(\vec{\mathbf{r}}_j) \rangle$$

- N_O are the observations above the [first guess],

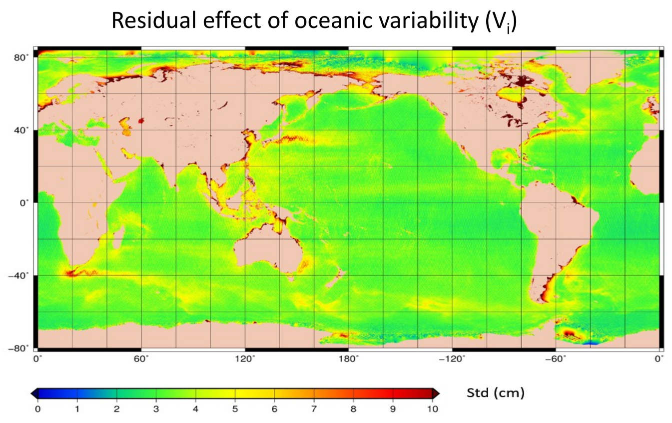
N_O = (SSH- MSLA) – [MDT(CLS20) + N(XGM2019e_SH2159)]

Particularities of this method is to take into account different types of noise

$$\langle E(\vec{\mathbf{r}}_i) \cdot E(\vec{\mathbf{r}}_j) \rangle = \underbrace{\delta_{ij} \langle \varepsilon^2 \rangle}_{\text{White noise}} + \underbrace{\zeta_{ij} \langle B^2 \rangle}_{\text{Long Wavelength Bias}} + \underbrace{\zeta_{ij} \sqrt{\langle V_i^2 \rangle \cdot \langle V_j^2 \rangle}\, exp\left(\frac{(\vec{r}_j - \vec{r}_i)^2}{L_{Var}}\right)}_{\text{Residual effect of oceanic variability}} + \underbrace{\zeta_{ij} A. exp\left(\frac{(\vec{r}_j - \vec{r}_i)^2}{C^{te}}\right)}_{\text{Optimal Filter}}$$

$\zeta_{ij} \Rightarrow$ Same Track, Same Satellite

Residual effect of oceanic variability (V_i)



- Based on the Standard deviation of the average of the Mean Profiles in 5 km boxes

Method

Observation

Mean Profiles(**1Hz**): TPJ1J2J3 – E2ENAl – GFO – TPnJ1nJ2n
High Resolution data: C2(**20Hz**) – Al(**40Hz**)

Preprocessing

Retracking
Environnemental & Instrumental corrections

Data preparation

Analyzes of the homogeneity of observations (MP & HR)
Correction of oceanic variability [SSH – **MSLA_DUACS**]
HR data filtering at 5 Hz (gaussian filter)
Slope correction (Sandwell & Smith, 2014)

Uncertainties analysis

Fine tuning of noise budgets

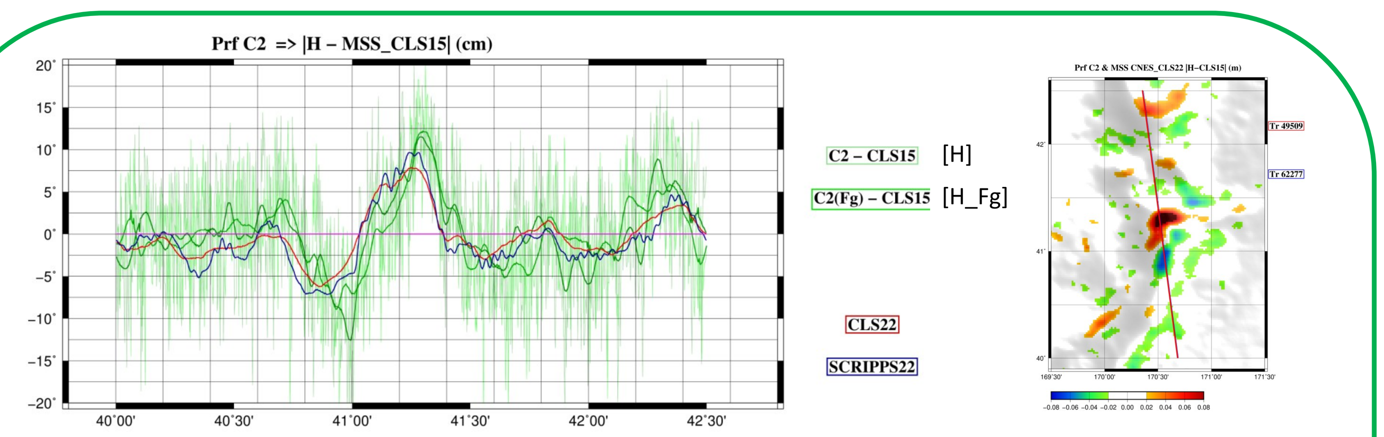
Mapping

Least Square Colocation (Hernandez & Schaeffer, 2000)

Removing of the first guess (XGM2019e & MDT CNES_CLS20)
Determination of the correlation/covariance model
Adjustment of the noise budgets
Optimal filtering

Validation

comparison with other models
comparison with ship data

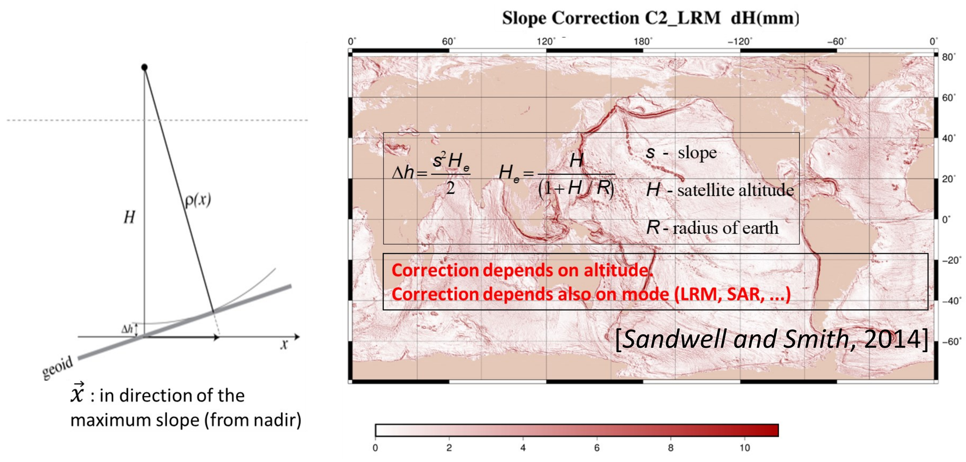


Here is a C2 20 Hz SSH extraction (thin line) that appears too noisy for MSS and moreover for gravity anomaly determination. In order to obtain an adequate signal-to-noise ratio, it is therefore necessary to perform a filtering of these data (bold line). The interpolation of the CNES_CLS22 and SCRIPPS_CLS22 MSS are given for comparison.

Nbr Obs	Average	Std	RMS	dH(m)
C2 PDGS (20 Hz) cycles 17-34				
122 716 126	-0.056	0.039	0.068	H-MSS15
122 716 122	0.000	0.020	0.020	H_Fg-MSS15
C2 PDGS(20Hz) cycles 117-126				
54 177 688	-0.028	0.074	0.079	H-MSS15
54 177 688	0.000	0.022	0.022	H_Fg-MSS15
AltiKa (40Hz)				
371 560 919	-0.007	0.041	0.042	H-MSS15
371 560 632	0.000	0.019	0.019	H_Fg-MSS15

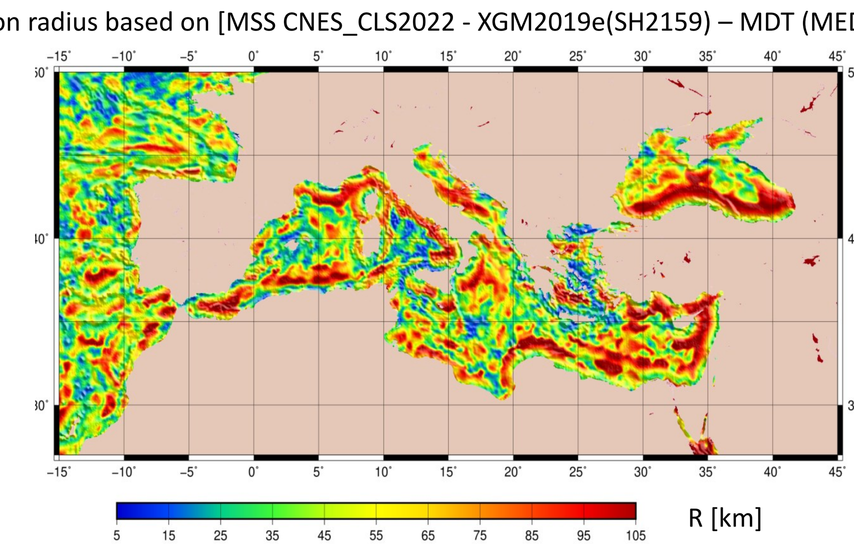
⟹ 5 Hz filtering

- The filtering used allows us to obtain homogeneous data for both the mean and the standard deviation.

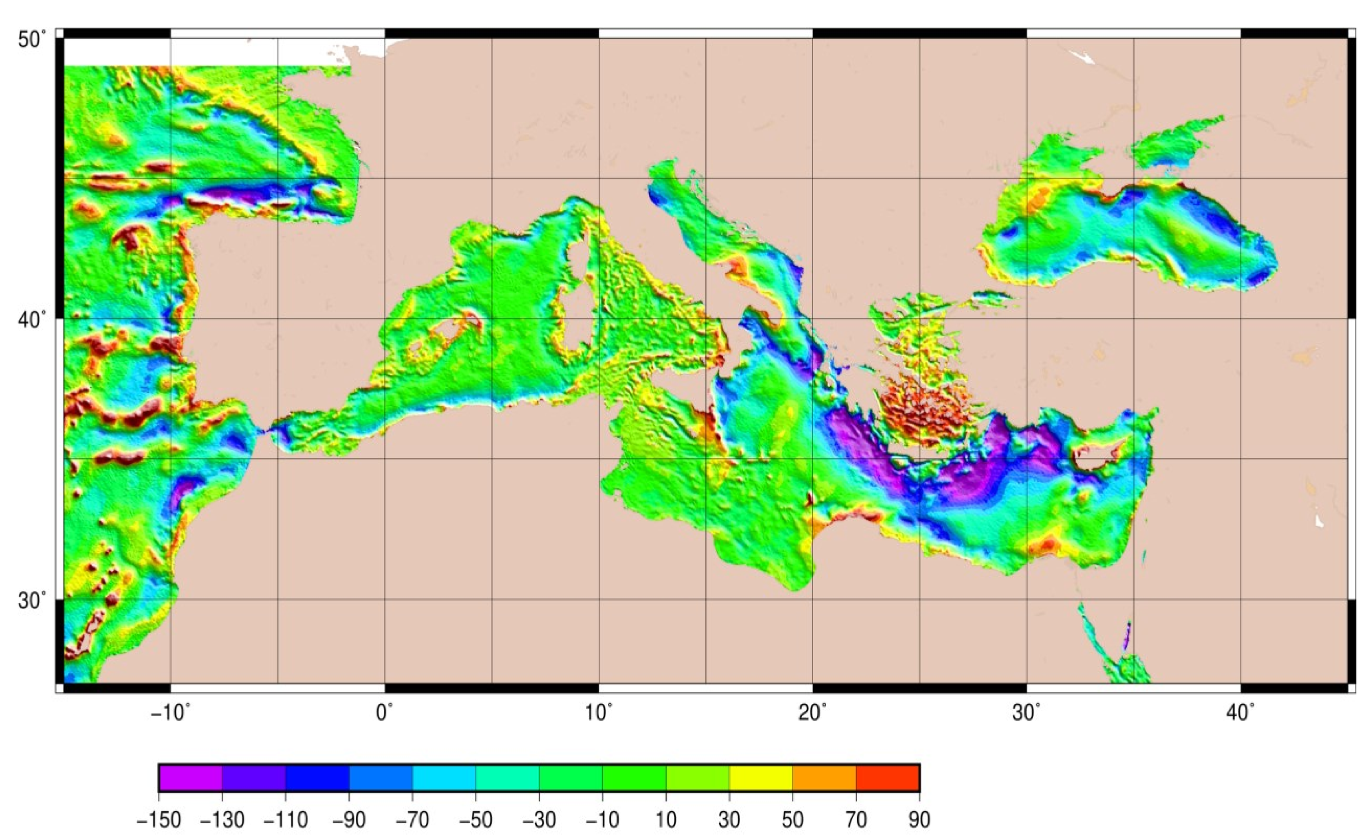


- New AG and MSS will result from a combination of **various altimeter** that are not affected in the same way by the slope of the sea surface.

Isotropic correlation radius based on [MSS CNES_CLS2022 - XGM2019e(SH2159) – MDT (MED) CNES_CLS20]



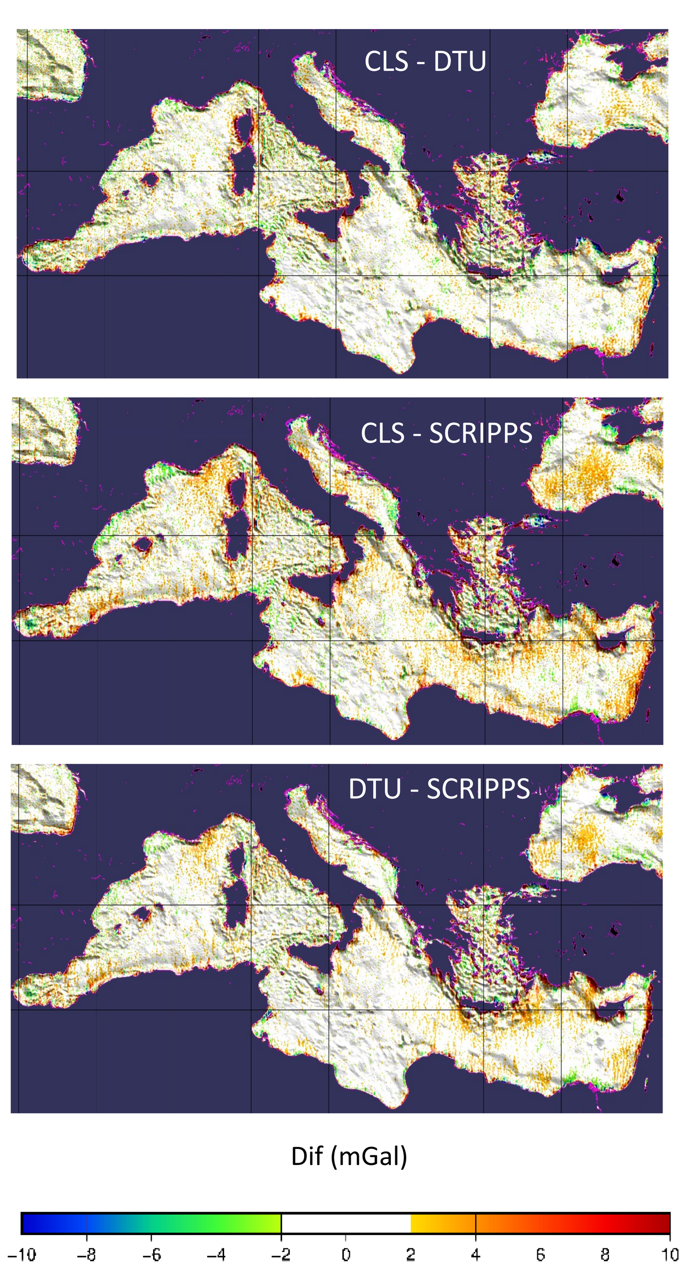
AG CNES_CLS 2022 => Dg (mGal)



The new free air anomalies of gravity CNES_CLS 2022 model is calculated on a 1-minute grid step. A covariance matrix is inverted at three-minute intervals, with observations selected in a 300 km bubble of influence.
It is the result of the combination of Mean Profiles that provide the mean ocean content and also the high-resolution data from C2 and SARAL that allow mapping the shortest wavelengths of the geophysical structures.
The reference period of the ocean mean content is 20 years [1993,2012] but the data used cover the period since 1993 to 2021 (see also Schaeffer et al. 2022 for more details).

Validation & Comparisons

Models: SCRIPPS = UCSD V31.1 , DTU=DTU21 , CLS=CNES_CLS22



- Relatively larger differences can be seen in the area of very high granularity (tyrrhenian sea) where differences greater than +/-2 mGal are visible.
- Note that these differences essentially impact structures smaller than 20 km and that we are probably at the limit of the stability of the methods with respect to the residual noise of the data.

Difference between grid

Distance to coast > 30 km (outliers > 3std excluded)

Diff (mGal)	Nb Pts	% > 3Std	Avg	Std	RMS
CLS - SCRIPPS	611738	0,8	0,8	1,7	1,9
CLS-DTU	611629	0,8	0,2	1,5	1,5
SCRIPPS-DTU	611033	0,9	-0,6	1,4	1,5
CLS – XGM(SH2159)	*607641*	*1,4*	*0,1*	*3,2*	*3,2*

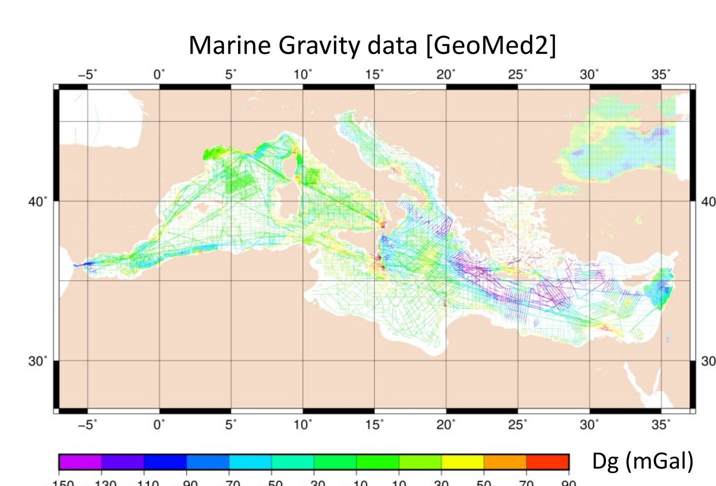
Distance to coast < 30 km

Diff (mGal)	Nb Pts	% > 3Std	Avg	Std	RMS
CLS - SCRIPPS	202524	1,9	1,5	4,3	4,6
CLS-DTU	202805	1,8	0,6	3,7	3,7
SCRIPPS-DTU	202410	2,0	-0,8	3,3	3,4
CLS – XGM(SH2159)	*203657*	*1,4*	*-0,5*	*7,5*	*7,5*

- Globally, the small differences between the standard deviations in the open ocean reveal a very good consistency between these 3 solutions.
- The increase of more than a factor of two concerning the standard deviations near the coast is not systematic, but it is localized over some areas for which further analysis is needed in order to better explain the causes.

Comparisons with ship data

Marine Gravity data [GeoMed2]



- As well as for the differences between the models, the standard deviation of the differences with in-situ data reveals a very high consistency between these 3 solutions in open ocean.
- We also see the increase in std's for statistics near the coast.
- We further observe that the difference between the in-situ data and the models is greater than that between the models themselves.
- More explanation are given in the presentation by Bruinsma et al. 2022.

Distance to coast > 30 km (outliers > 3std excluded)

Diff (mGal)	Nb Pts	% > 3Std	Avg	Std	RMS
GeoMed – CLS	130962	1,4	-0,3	2,5	2,5
GeoMed – SCRIPPS	131095	1,3	0,5	2,5	2,6
GeoMed – DTU	130751	1,6	0,0	2,5	2,5
GeoMed – XGM	*130775*	*1,5*	*-0,2*	*3,3*	*3,3*
Differences interpolated under in-situ data					
CLS – SCRIPPS	*131789*	*0,8*	*0,7*	*1,7*	*1,9*
CLS – DTU	*131813*	*0,8*	*0,2*	*1,6*	*1,6*
SCRIPPS - DTU	*131620*	*0,9*	*-0,5*	*1,4*	*1,5*

Distance to coast < 30 km

Diff (mGal)	Nb Pts	% > 3Std	Avg	Std	RMS
GeoMed – CLS	34734	1,6	-0,4	4,7	4,7
GeoMed – SCRIPPS	34727	1,6	1,0	5,0	5,1
GeoMed – DTU	34742	1,5	0,2	4,2	4,2
GeoMed – XGM	*34914*	*1,1*	*-0,8*	*6,2*	*6,3*
Differences interpolated under in-situ data					
CLS – SCRIPPS	*34632*	*1,8*	*1,5*	*3,9*	*4,1*
CLS – DTU	*34518*	*2,2*	*0,6*	*3,5*	*3,5*
SCRIPPS - DTU	*34537*	*2,1*	*-0,7*	*3,1*	*3,2*

Conclusion & Perspective

This study used on a method developed almost 20 years ago (Lalancette et al, 2002) that had to be updated both from the point of view of the theory (correlation model and noise theory) and in terms of the number of data to be managed, especially with the high-resolution observations of C2 and AltiKa. The results obtained over the Mediterranean show that we have reached a level of accuracy similar to the two reference solutions, USCD and DTU.
These results confirm our intention to go further with a global estimate, and in the nearest future to improve it for use with the upcoming SWOT data.

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