PRELIMINARY ANALYSIS ON GOCE CONTRIBUTION TO THE MEDITERRANEAN SEA CIRCULATION

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ABSTRACT

One of the main objectives of the ESA Gravity field and Ocean Circulation Explorer (GOCE) is to investigate the oceanic circulation by means of high accuracy satellite gravity observations.
In this framework the Mediterranean Sea is certainly a complicated test area and the study of its circulation is particularly tangled and requires the knowledge of a geoid with extremely high resolution and accuracy.
In the present work a combination of the EGM2008 global model and a GOCE-derived solution is used in connection with the CNES-CLS11 mean sea surface (MSS) to estimate the Mediterranean geodetic mean dynamic topography (MDT).
In order to assess the accuracy of the GOCE-derived products for oceanographic purposes, the geostrophic currents computed from geodetic MDT are compared to those obtained with independent drifter observations. It comes out that the GOCE solution well describes the mean circulation patterns and the main dynamical features improving the EGM2008 solution.

1. INTRODUCTION

The GOCE satellite mission was launched with the objective of determining the Earth geoid at a spatial scale of 100 km with an accuracy of 1 cm. This reflects into one of the main applications of this mission, i.e. the global estimation of the ocean geostrophic currents. In fact the availability of such an accurate global geoid makes it possible to directly derive the absolute dynamic topography from satellite altimetric measurements.
The capability of GOCE to improve the results achieved in this research field by previous global geoids has been already proved e.g. in the North Atlantic [1] and in the Southern Ocean [2], but it is still an open question in semi-enclosed seas, where the spatial scale of the oceanic structures is definitely smaller. In particular, the study of the Mediterranean geostrophic circulation is complex and requires the knowledge of a geoid with an extremely high resolution and accuracy [3].
The idea of this work, developed within the ESA STSE project MEGG-C in collaboration with OGS, is to use GOCE data to first improve the EGM2008 global model and then estimate the mean dynamic topography and the corresponding surface geostrophic circulation in the Mediterranean Sea.
While the used GOCE model, i.e. the time-wise R4 model [4], is given along with the full error covariance matrix (which is well approximated by a block-diagonal covariance structure [5]), EGM2008 is delivered with two, not fully consistent, error descriptions: spherical harmonic coefficient variances and a 5´ × 5´ grid of variances [6]. Standard global model combination is based on coefficient errors only, while an alternative solution also exploiting grid variances is here investigated. The geostrophic currents derived from these two combined models are compared to those derived from the EGM2008-only model with the aim of identifying the best solution and showing the GOCE decisive contribution. The reference currents are taken from a combination of drifter data and altimetry products [7].

2. GEOID COMPUTATION

EGM2008 is the most widely used global gravity model, complete to degree and order 2159 corresponding to a resolution of about 10 km. It is basically a combination between the low frequency signal observed by the GRACE mission and a global gravity anomaly database of 5´ × 5´ resolution coming from different sources. Its error is delivered with two sources of information: spherical harmonic coefficient variances and a geographic map of geoid error variances.
A GOCE satellite-only global model (complete to degree and order 250) is used to improve the accuracy of EGM2008 in the low-medium degrees (say between 100 and 200) [8].
The idea is to integrate the information coming from the GOCE geoid into the EGM2008 one by a least squares adjustment. Particular attention is given to the modeling of the error covariance matrices of the two models. The combination is done in two ways:

- by using coefficient covariances (CC) only, i.e. diagonal matrix for EGM2008 and order-wise block-diagonal matrix for GOCE. This model is called GECO_CC;
- by additionally rescaling the latitude dependent EGM2008 geoid error derived from coefficient variances with the available 5´ × 5´ grid of variances. This model is called GECO.

GECO stays for GOCE and EGM2008 COmbined model.

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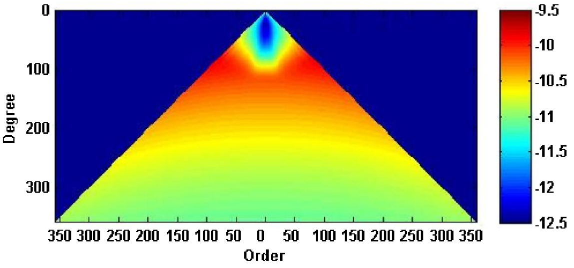

Figure 1. EGM2008 coefficient error standard deviations (log10 scale). GRACE contribution below degree 100

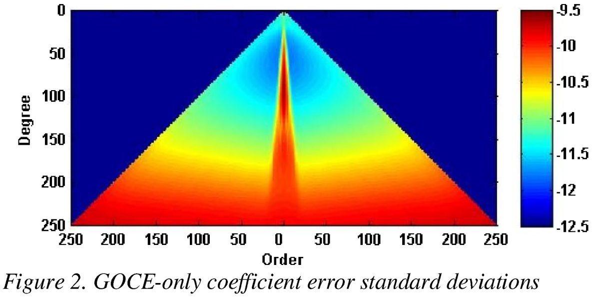

Figure 2. GOCE-only coefficient error standard deviations (log10 scale). Polar gaps effects at low orders

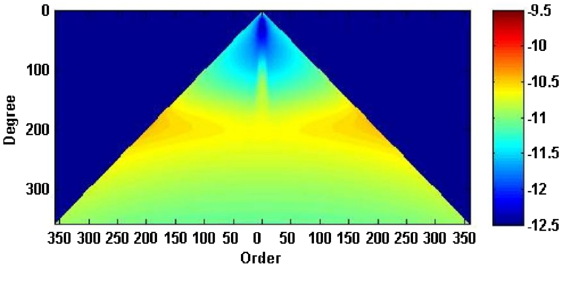

Figure 3. GECO coefficient error standard deviations (log10 scale). GOCE corrections to EGM2008 up to about degree 200

Figs. 1-3 show the improvement in terms of spherical harmonic coefficient standard deviations while Fig. 4 displays the corrections in terms of geoid undulations.

3. MDT ESTIMATION

GECO_CC and GECO are tide-free geoids while the MSS CNES-CLS11 is a mean-tide solution; to compute the MDT a correction is needed [2]:

$$\mathrm{MDT} = \mathrm{MSS} - (\mathrm{Geoid} + \mathrm{Mean\ Tide}). \quad (1)$$

The mean tide consists of a permanent deformation of the Earth leading to a constant high tide at the equator and low tide at the poles which includes both the direct effect of the luni-solar Tide-Generating Potential (TGP) and the indirect effect of the Earth's response to this potential. The mean tide effect ΔN_{MT} to be added to the tide-free geoid undulations is computed from the zonal second degree Love number k_{20}=0.3019 for an anelastic solid Earth from IERS-TN36 Standards [9] as:

$$\Delta N_{MT} = (1 + k_{20}) \frac{\overline{V}_2^{TGP}}{g}, \quad (2)$$

where g is the gravity acceleration on the Earth's surface and $\overline{V}_2^{TGP}$ is the time average of the zonal second degree luni-solar TGP, determined according to [10]. In Fig. 5 the mean tide distribution is displayed over the Mediterranean area. The altimetric MSS used in this work is the CNES-CLS11 (shown in Fig. 6), computed using a 15-year dataset of TOPEX/ POSEIDON, ERS-2, GFO, JASON-1, ENVISAT mean profiles [11]. The estimated MDTs are representative of the MSS for the reference period (1993-1999).
Fig. 7 shows the MDT of the Mediterranean Sea in the period 1993-1999 obtained from GECO.

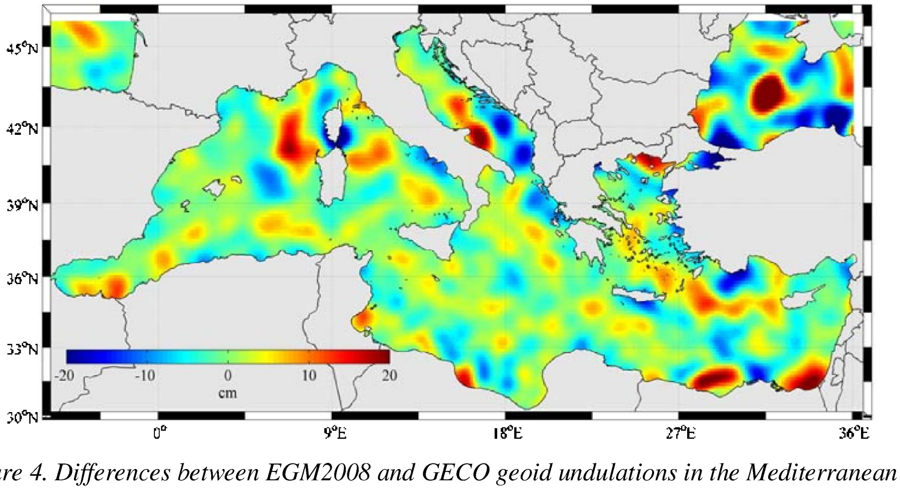

Figure 4. Differences between EGM2008 and GECO geoid undulations in the Mediterranean Sea

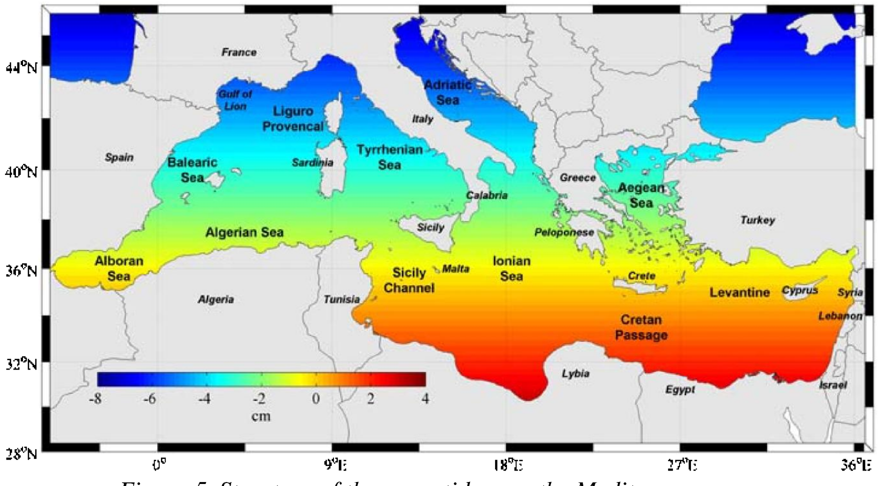

Figure 5. Structure of the mean tide over the Mediterranean area

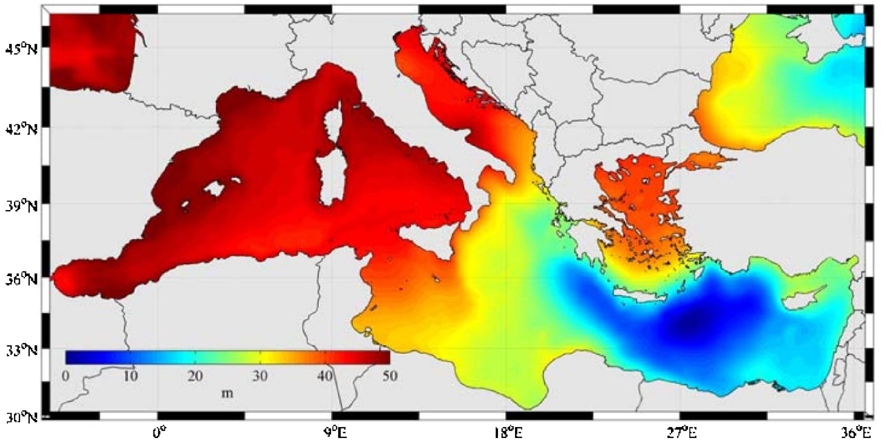

Figure 6. The altimetric CNES-CLS11 MSS in the Mediterranean area (referred to the period 1993-1999)

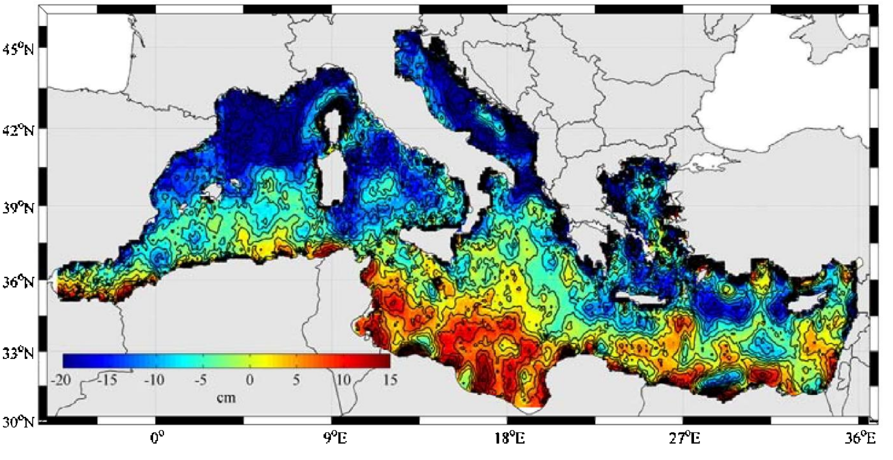

Figure 7. The mean dynamic topography of the Mediterranean Sea obtained from GECO (referred to the period 1993-1999)

4. GEOSTROPHIC CURRENT COMPUTATION

A geostrophic current is an oceanic flow in which the pressure gradient force is balanced by the Coriolis effect due to the Earth's rotation. The geostrophic balance is:

$$fv = \frac{1}{\rho}\frac{\partial p}{\partial x}; \qquad -fu = \frac{1}{\rho}\frac{\partial p}{\partial y} \tag{3}$$

where x and y are the local Cartesian coordinates, u and v are respectively the zonal and meridional currents velocities, ρ is the surface water density, p is the pressure and $f = 2\Omega cos\varphi$ is the Coriolis parameter (Ω is the Earth's angular speed and φ is latitude).
At the surface the pressure is:

$$p = \rho\, g\, \eta \tag{4}$$

where η is the dynamic topography (DT) height. From Eqs. 3 and 4 surface geostrophic currents can be easily derived as:

$$v = \frac{g}{f}\frac{\partial \eta}{dx}; \qquad u = -\frac{g}{f}\frac{\partial \eta}{dy}. \tag{5}$$

5. CIRCULATION STUDY

The geodetic MDTs obtained from the GECO, GECO_CC and EGM2008 solutions in the period 1993-1999 generally reproduce the main characteristics of the large scale circulation in the Mediterranean Sea described in [12]: a large cyclonic cell in the Liguro-Provencal sub-basin, an anticyclonic cell and a central eastward cross-basin current in the Ionian Sea and a cyclonic circulation in the center of the Levantine sub-basins. Fig. 8 shows the geostrophic velocities observed using drifter data [7] while Figs. 9 and 10 the currents obtained considering the EGM2008 and the GECO geoid respectively.
At sub-basin scale, the MDTs and the currents from the combination of EGM2008 model and GOCE time-wise solutions improve the estimates derived using only the EGM2008 solution. However in the semi-enclosed basins like the Adriatic and the Aegean Seas, both the EGM2008 and GOCE/EGM2008-derived circulations are unrealistic.
Looking at Figs. 8-10, some considerations can be done. The narrow Algerian Current is partially resolved by the GECO and GECO_CC solutions, whereas it flows in the wrong direction (westward) using the MDT derived from EGM2008. The cyclonic circulation in the Liguro–Provencal basin is better reproduced by the GECO solution with respect to EGM2008 and GECO_CC solutions (as shown in Fig. 11).
Another visible improvement with respect to EGM2008 solution is in the Levantine basin (Fig. 12) where the multi-scaled eddies are better reconstruct by the GECO solution.
Note that EGM2008 gravity data over the oceans are mainly derived from altimetry inverting Eq. 1 and using an iterative approach [6]; this means that GECO and GECO_CC circulation model are basically a combination of the low frequency GOCE-GRACE derived geostrophic currents and the high frequency EGM2008 a priori information.
In order to asses quantitatively the accuracy of the GOCE-derived products for oceanographic applications, the mean currents obtained from the geoid models are compared with the mean surface geostrophic velocities measured by drifters and satellite altimetry data [7].
Tab. 1 reports the root mean square differences (RMSD) between geostrophic velocities obtained from geodetic MDTs and those derived from drifters (taken as reference). In Tab. 1 the values related to another MDT [13] obtained by altimetric data, in-situ measurements and a general circulation model are also reported.
The statistics regarding the combined solution are similar and they are close to the velocities obtained starting from the synthetic MDT [13]. Nevertheless the minimum RMSD and the best correlation coefficient are achieved using the GECO_CC solution.

Table 1. Root mean square differences (RMSD) and magnitude of the complex correlation coefficient estimated between the geostrophic velocities of [7], taken as reference, and those derived from the geodetic MDTs .Statistics related to [12] are also reported for comparison. The standard deviation (STD) of each dataset is also present.

		EGM2008	EGM2008 and GOCE combined model		Rio et al. 2007	Poulain et al. 2012 (Reference)
			GECO_CC	GECO		
RMSD (cm/s)	u	11.69	4.65	5.50	5.70	/
	v	10.65	4.04	5.21	5.63	/
STD (cm/s)		10.01	8.07	9.32	6.09	7.25
Correlation coefficient		0.21	0.61	0.57	0.67	1

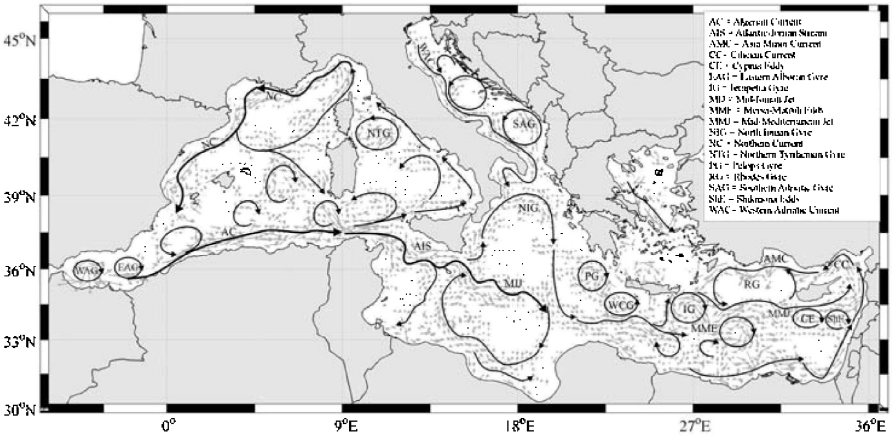

Figure 8. Mean surface geostrophic circulation in the Mediterranean Sea in the period 1993-1999 (bright grey) organized in bins of 0.25° x 0.25°. Black lines emphasize the main currents and sub-basin eddies (adapted from [7])

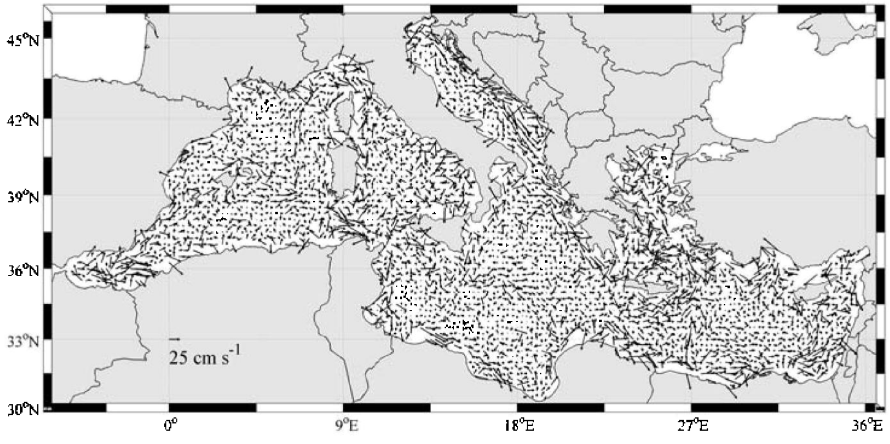

Figure 9. Mean surface geostrophic circulation in the Mediterranean Sea from EGM2008

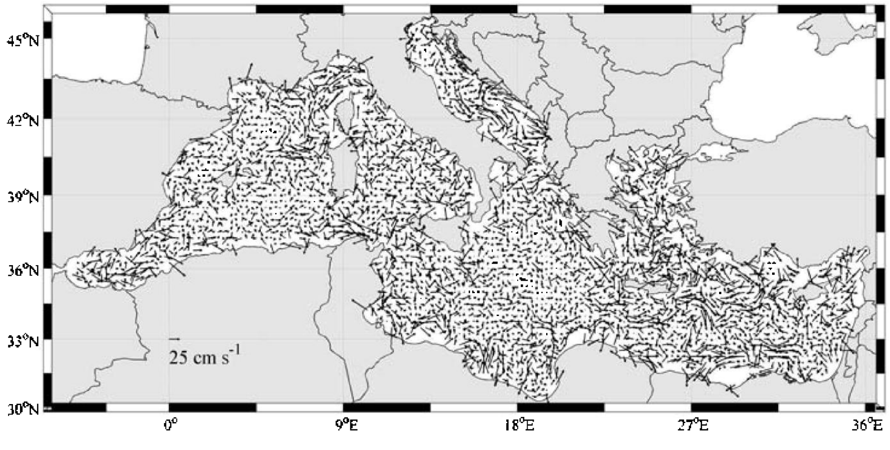

Figure 10. Mean surface geostrophic circulation in the Mediterranean Sea from GECO

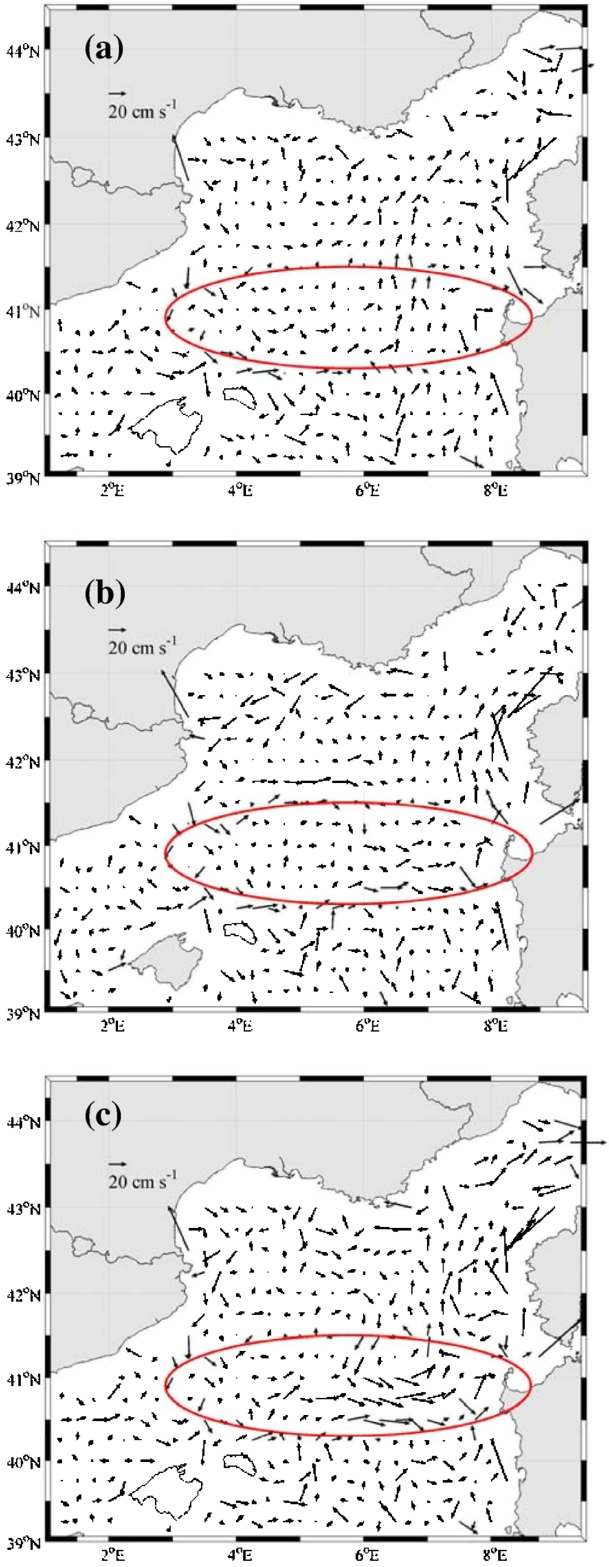

Figure 11. Mean surface geostrophic circulation in the Liguro-Provencal sub-basin from:
EGM2008 (a), GECO_CC (b) and GECO (c)

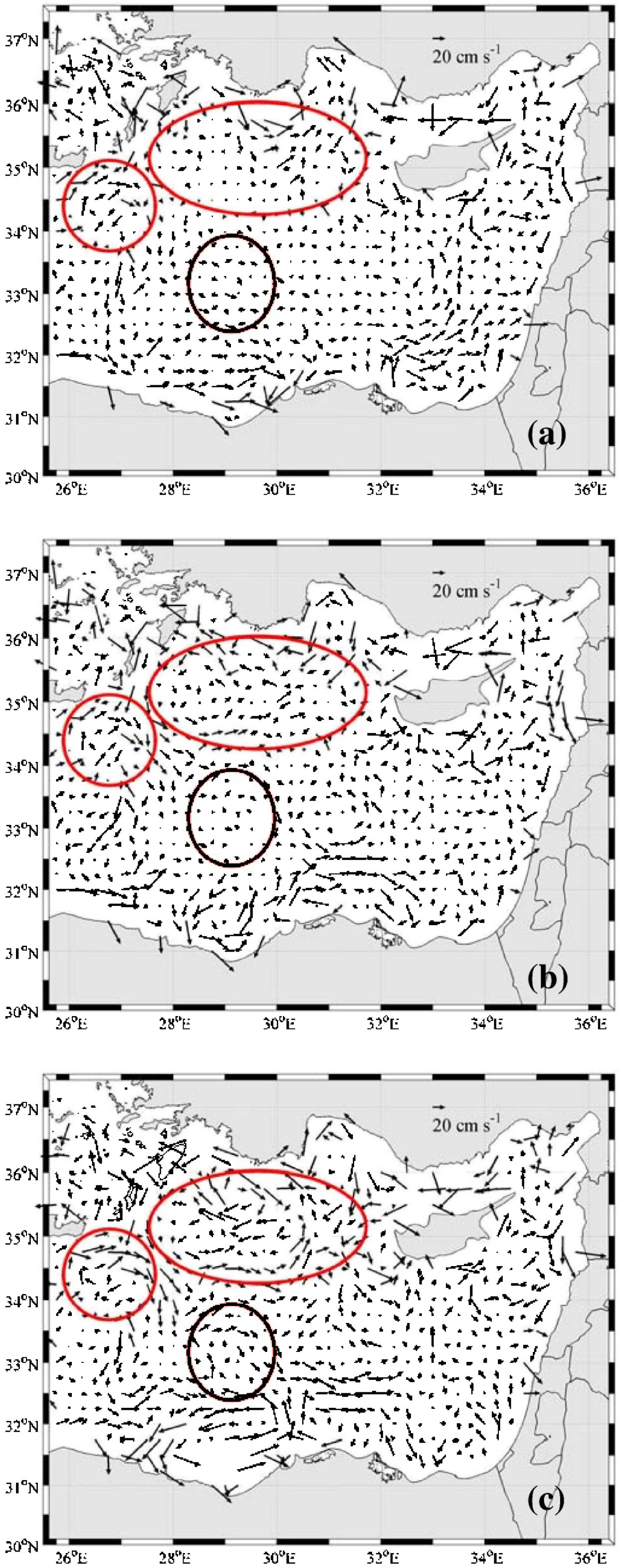

Figure 12. Mean surface geostrophic circulation in the Levantin sub-basin from:
EGM2008 (a), GECO_CC (b) and GECO (c)

6. CONCLUSIONS

The incorporation of GOCE data into existing geoid models and in particular into EGM2008 enhances the quality of the description of the Mediterranean Sea circulation based on geodetic and altimetry data, especially for the sub-basin scale features and for the along–slope currents. The agreement with respect to the drifter solution is of the order of 5 cm/s for both zonal and meridional component. There is also an improvement with respect to experiments using previous releases of the GOCE solution.

The two proposed geoid combinations with and without the additional information of the EGM2008 error map are very similar from the oceanographic point of view, even though the GECO_CC solution shows slightly better statistics. On the other hand, the GECO solution seems to better highlight some well known circulation patterns.

7. ACKNOWLEDGEMENTS

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