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Multi-Satellite Altimetry and GOCE Geoid Based Surface and Subsurface Currents in the Mediterranean Sea

Juan Jose Benjamin[1], Chi-Hung Chang[2], Chung-Yen Kuo[2], C.K. Shum[3], Yuchan Yi[3]

[1]Department of Geotechnical Engineering and Geosciences, Technical University of Catalonia, jj.benjamin@upc.edu
[2]Department of Geomatics, National Cheng Kung University, jack7989@gmail.com, kuo70@mail.ncku.edu.tw
[3]Division of Geodetic Science, School of Earth Sciences, The Ohio State University, ckshum@osu.edu, yi.3@osu.edu

Abstract

The Mediterranean Sea (MS) is a semi-enclosed "true" ocean bordering European nations from the Western Europe to the near-, middle-East and Africa. MS's tremendous resources could be influenced by global climate change. MS is connected with the North Atlantic Ocean through the Strait of Gibraltar, where an upper layer of Atlantic Water flows eastward into MS and a lower layer of Mediterranean water outflows westward. The salty outflow water from MS may alter water patterns in the Atlantic Ocean and influence the meridional overturning circulation, which are important for heat transports from lower to higher latitudes. Therefore, accurately continuous monitoring of the current velocities and the circulation patterns could help us to understand the mechanism of the circulation and transport. In the study, we focus on the use of contemporary multi-mission satellite altimetry data and objectively analyzed MBT/XBT/Argo hydrographic data to calculate surface and subsurface geostrophic current velocities by referencing to contemporary accurate geoid models, include the GOCE and/or GRACE geoid models. The estimated current velocities are validated with *in-situ* observations to evaluate the performance of different geoid models used for the calculation of geostrophic currents.

Introduction

Since Mediterranean Sea (MS) is characterized by a very active Thermohaline Circulation (THC) strongly resembling the global conveyor belt, it is very suitable to be used as a scaled-down model for studying the mechanism and variation of global overturning circulation and predicting how ocean responds to climate changes, and has been highlighted as one of the most vulnerable regions [IPCC, 2007]. Multiple climate-change-induced transients may lead to the variations and the shift of conveyor belt and therefore affect the characteristic intermediate and deep water masses of the whole basin [Roether *et al*., 1996; Klein *et al*., 1999]. Recent observational studies demonstrated that THC in MS represents a very high spatiotemporal variability driven by anthropogenic environmental changes [Bethoux and Gentili, 1999]. Due to the importance of MS, the study will focus on the use of contemporary multi-satellite altimetry data combining with latest GOCE and GRACE gravity field models (GOCET-TIM5 and ITG-GRACE2010S) and *in-situ* T/S profile to calculate surface and subsurface geostrophic current velocities to analyze their performance and also the temporal variation of currents at different layers.

Data

Along-track TOPEX, JASON-1, JASON-2, ERS-2 and ENVISAT Sea Surface Height (SSH) data provided by Radar Altimetry Database System (RADS) were used to generate along-track Absolute Dynamic Topography (ADT) by using geoid calculated from GOCE-TIM5 (up to 280 degree) [Pail *et al*., 2011] and ITG-GRACE2010S (up to 180 degree) [Mayer-Gürr *et al*., 2010] gravity field models as reference datum. Afterwards, the along-track ADT were used to calculate the geostrophic currents after gridding. The quality of the results is evaluated by comparing with *in-situ* surface current velocities collaborated, processed and distributed by the Global Drifter Program (GDP) [V2.07, Lumpkin and Johnson, 2013]. Monthly T/S profile data (GLOBAL_REP_PHYS_001_013), derived from Argo profiling floats, XBT, CTD and moorings measurements, are provided by MyOcean on a 0.25° regular grid covering latitude 82°S to 90°N and 0°~360°E with 33 layers of 0 ~ 5500 *m* depths during the time span of 1993 to 2011. With T/S profiles, we are able to derive Relative Dynamic Topography (RDT) and then to calculate absolute geostrophic currents at different layers when combining with ADT. In the study, data covering 1996~2011 are used for analysis.

Methodology

ADT ($\boldsymbol{\eta_{abs}}$) on sea surface can be calculated from the following equation and filtered which is called Pointwise approach:

$$\boldsymbol{\eta_{abs} = 2\mathrm{D}[\,SSH - N\,]} \qquad \textbf{(1)}$$

Relative dynamic topography ($\boldsymbol{\eta_{rel}}$) at certain depth can be computed by the following equation: [Cadden *et al*., 2009]

$$\boldsymbol{\eta_{rel} = \int_{P_R}^{0} \frac{dp}{\rho}} \qquad \textbf{(2)}$$

$\boldsymbol{p}$ means pressure, $\boldsymbol{P_R}$ is reference pressure at certain depth under sea surface ; $\boldsymbol{\rho}$ is density which can be calculated from sea water temperature and salinity data.

Absolute geostrophic current velocities at different layers can be derived by the combination of the use of $\boldsymbol{\eta_{abs}}$ and $\boldsymbol{\eta_{rel}}$ [Wunsch and Gaposchkin, 1980; Cadden *et al*., 2009]

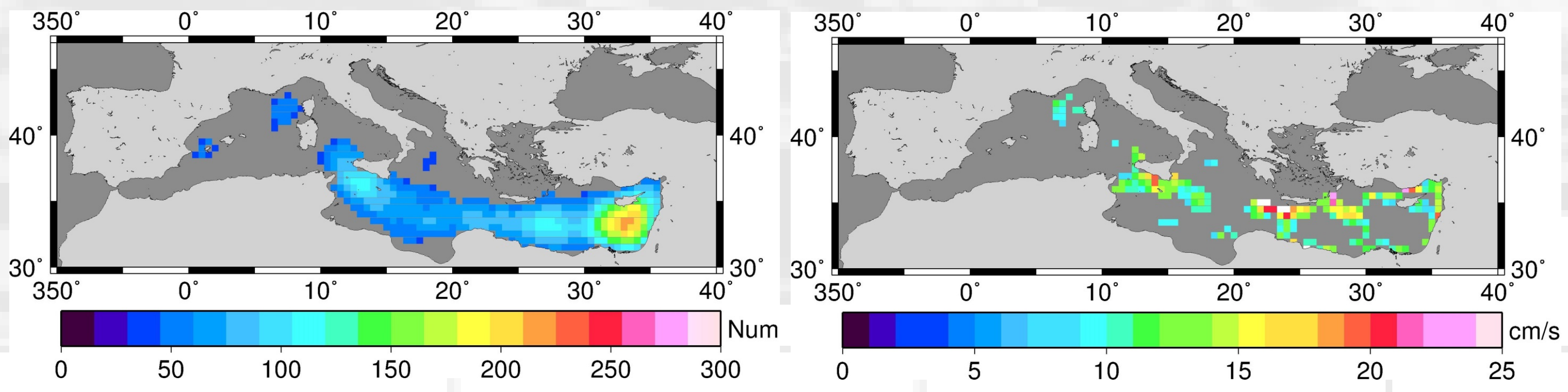
$$\boldsymbol{u_R = -[\frac{g}{f}\frac{\partial\eta_{abs}}{\partial y} + \frac{g}{f}\frac{\partial\eta_{rel}}{\partial y}]} \qquad \textbf{(3)}$$

$$\boldsymbol{v_R = \quad [\frac{g}{f}\frac{\partial\eta_{abs}}{\partial x} - \frac{g}{f}\frac{\partial\eta_{rel}}{\partial x}]} \qquad \textbf{(4)}$$

$\boldsymbol{g}$ is gravitational acceleration, $\boldsymbol{f}$ is Coriolis parameter, $\boldsymbol{u}$, and $\boldsymbol{v}$ means east-west, and north-south component of sea surface geostrophic velocities, respectively. $\boldsymbol{u_R}$, and $\boldsymbol{v_R}$ means geostrophic velocities at certain depth.

Results

To analyze the performance of GOCE and GRACE gravity field models on the determination of geostrophic currents, estimated mean surface geostrophic currents (MSG) were compared to *in-situ* data from GDP. In the MS, locations with the largest 50% number of drifter-days per square degree (over 43.53 days) *in-situ* data from GDP were chosen (See Fig.1-a). Among these selected locations, we further chose the locations with current velocity larger than the average (> 8.65 *cm/s*) for the comparison (See Fig. 1-b).



(a) (b)

Fig. 1 Locations with the largest 50% number of drifter-days per square degree (a) and current velocity is larger than the average (b).

Along-track ADT based on geoid undulations derived from GOCE-TIM5 and ITG-GRACE2010S gravity field models were both smoothed using a Gaussian filter with different half-weights at half-maximum (HWHM). Root Mean Square (RMS) of current velocities at the locations shown in Fig. 1-b is plotted as a function of HWHM (See Fig.2), while the values are listed in Table 1. Fig.2 shows that ADT based on GOCE-TIM5 has smaller RMS and faster convergence of RMS than ITG-GRACE2010S does. Clearly, applying wider HWHM is necessary for ITG-GRACE2010S.

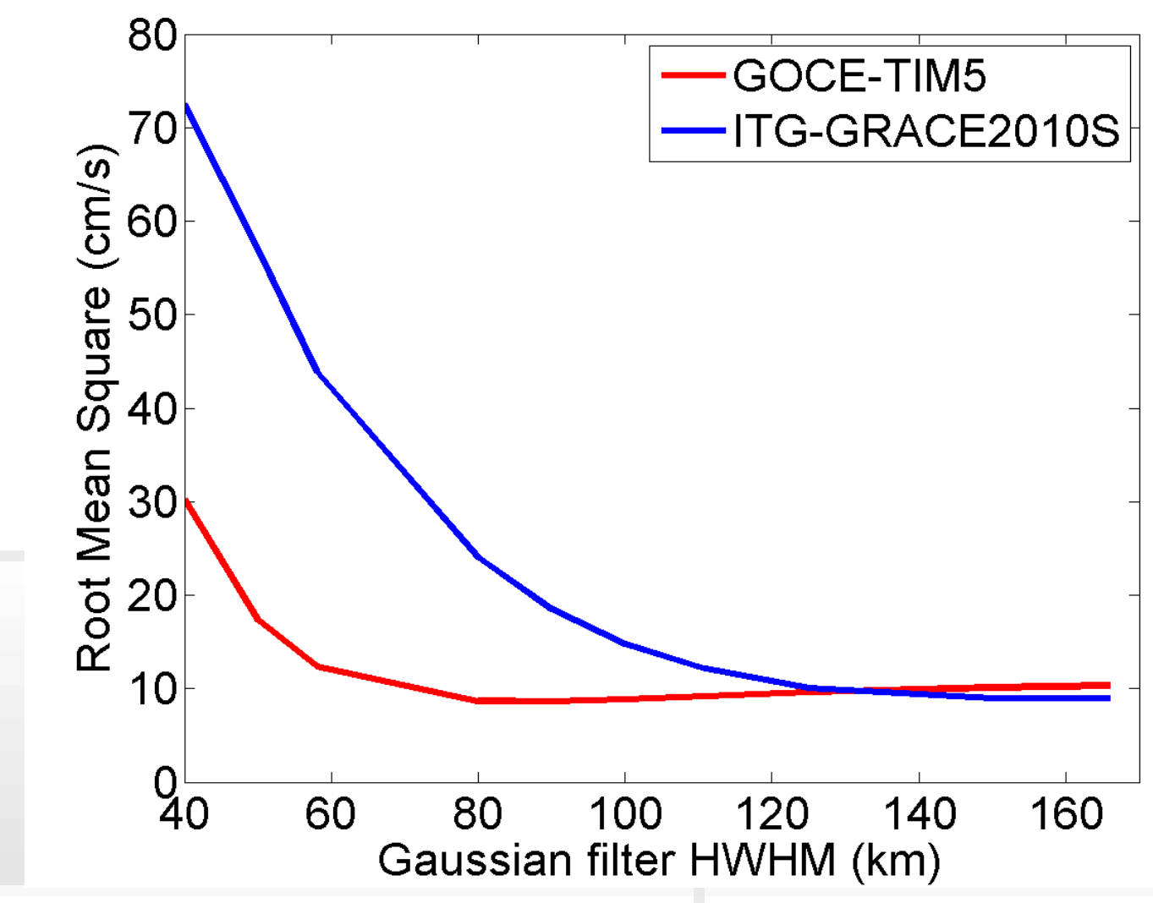
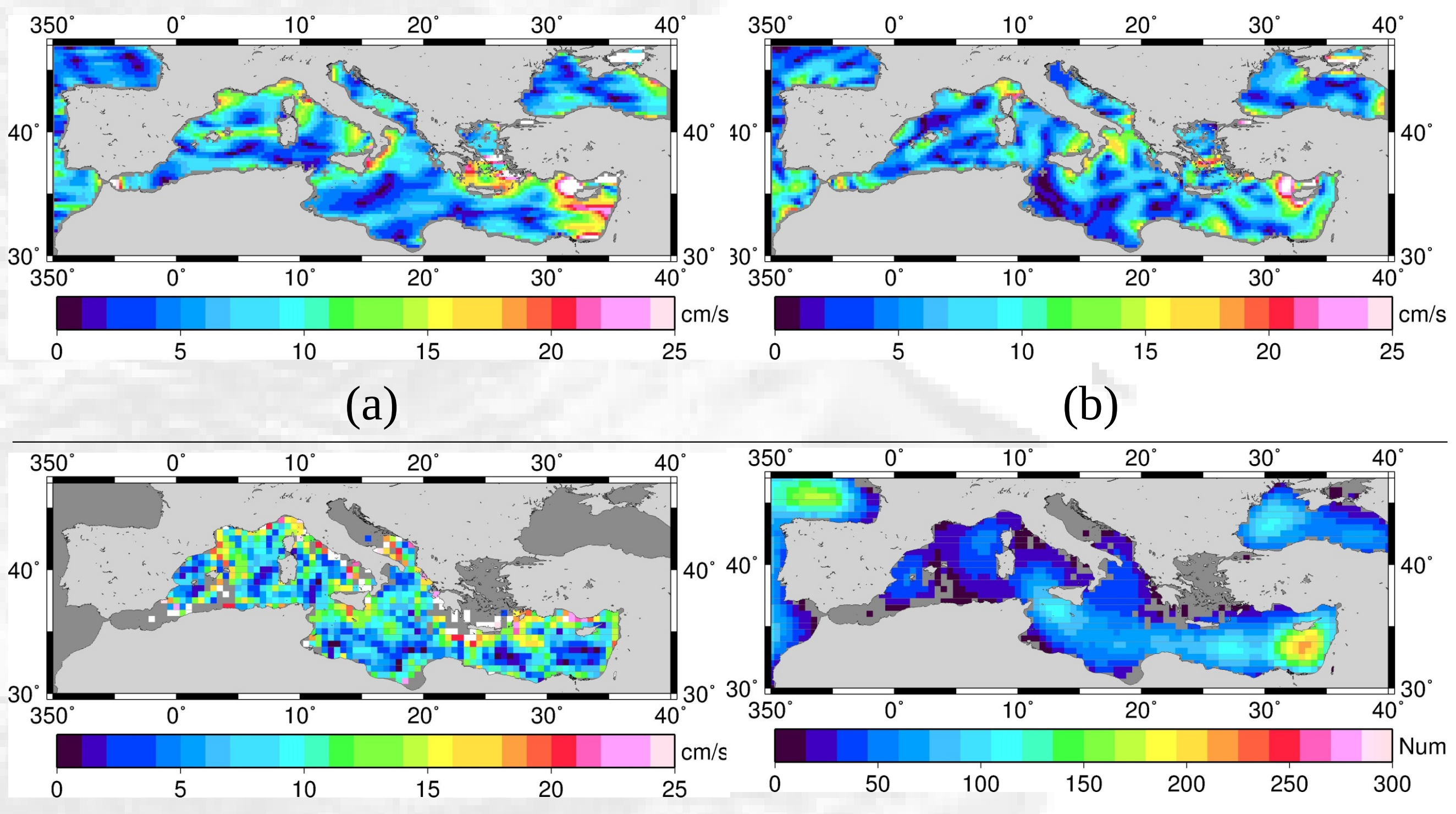


Fig. 2 RMS differences of altimetry-derived geostrophic current velocities and *in-situ* data from GDP as a function of HWHM.

HWHM (*km*)	**RMS (*cm/s*)**	
	GOCE-TIM5	GRACE2010S
40	30.23	72.47
50	17.35	56.95
58	12.39	43.93
80	8.66	24.01
90	**8.65**	18.49
100	8.87	14.82
111	9.20	12.10
125	9.61	10.04
150	10.12	**8.95**
166	10.35	8.96

Table 1. RMS values between altimetry-derived geostrophic current velocity and *in-situ* data from GDP. Spatial resolution of GOCE-TIM5 and GRACE2010S is 71 *km* and 111 *km*, respectively.



(a) (b)

(c) (d)

Fig. 3 Geostrophic current velocity based on (a) ITG-GRACE2010S and (b) GOCE-TIM5 with filter HWHM equals 150 *km* and 90 *km*, respectively. (c) *In-situ* current speed from GDP and (d) number of drifter-day over MS.

Table 1 indicates that RMS converges to 8.65 *cm/s* with the HWHM of 90 *km* using GOCE-TIM5, while ITG-GRACE2010S takes the HWHM of 150 *km* for giving the convergence to 8.95 *cm/s*. Fig. 3 shows the mean current velocity in the MS. With the narrower filter HWHM, results from GOCE-TIM5 reserve more detail signals than ITG-GRACE2010S. Following analysis were based on GOCE-TIM5.

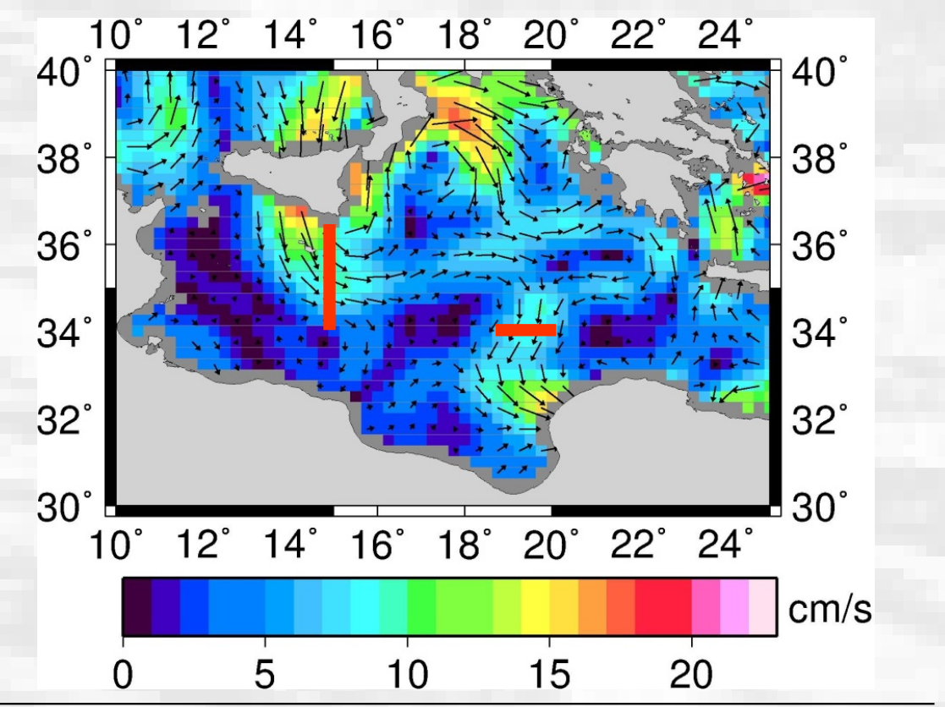


Fig. 4 Current velocities with directions and selected sections for time-depth plots in the southern MS.

Fig. 4 shows the current velocities and corresponding directions in the southern MS. Sections marked in red in the south of (1) Sicilia Island and (2) Ionian Basin showing a eastward and southward pattern with speed at around 10 *cm/s*, respectively, are picked for time-depth transect plot in Fig. 5 and 6.

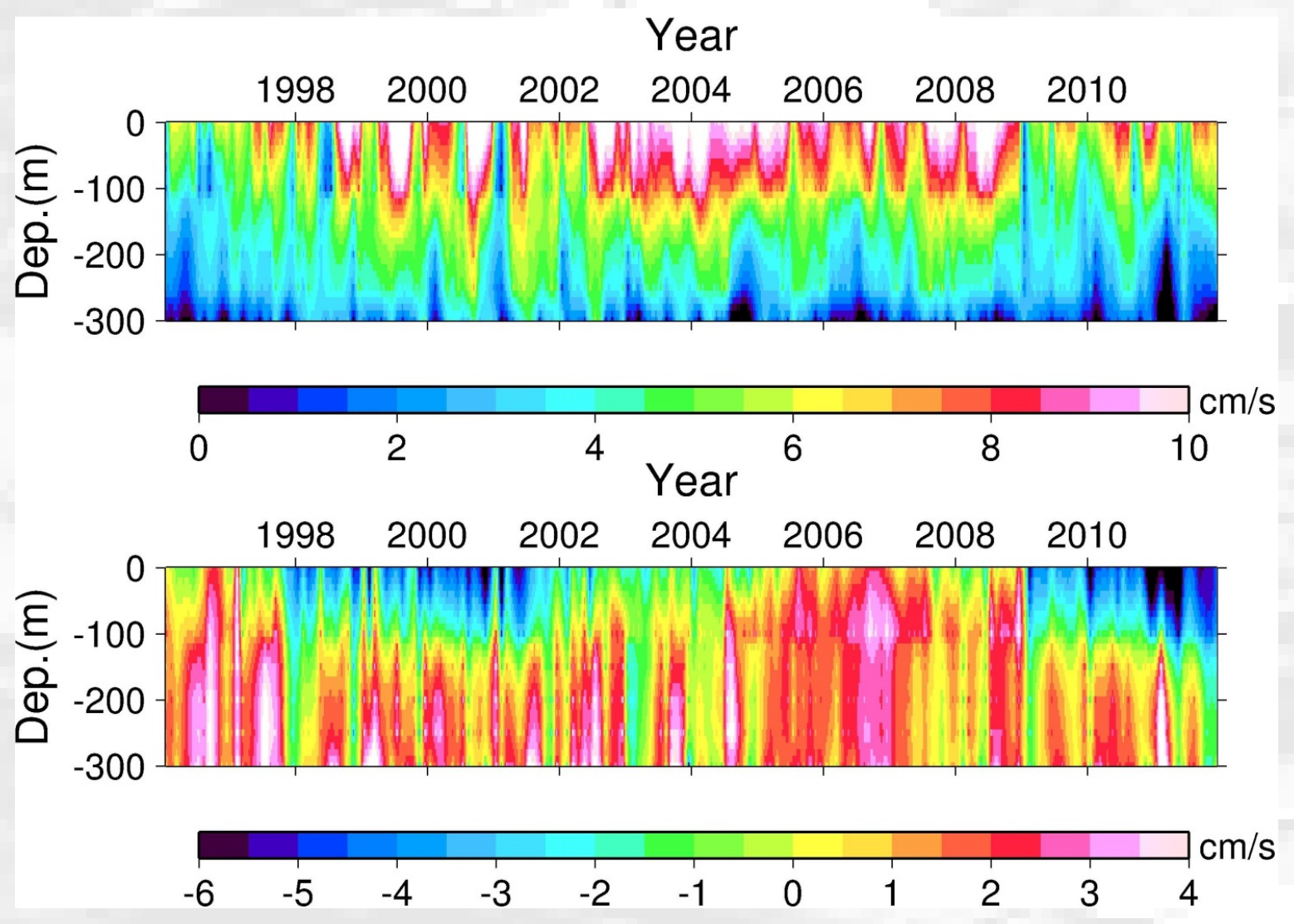


Fig. 5 Time-depth current velocities transect in the south of Sicilia Island.

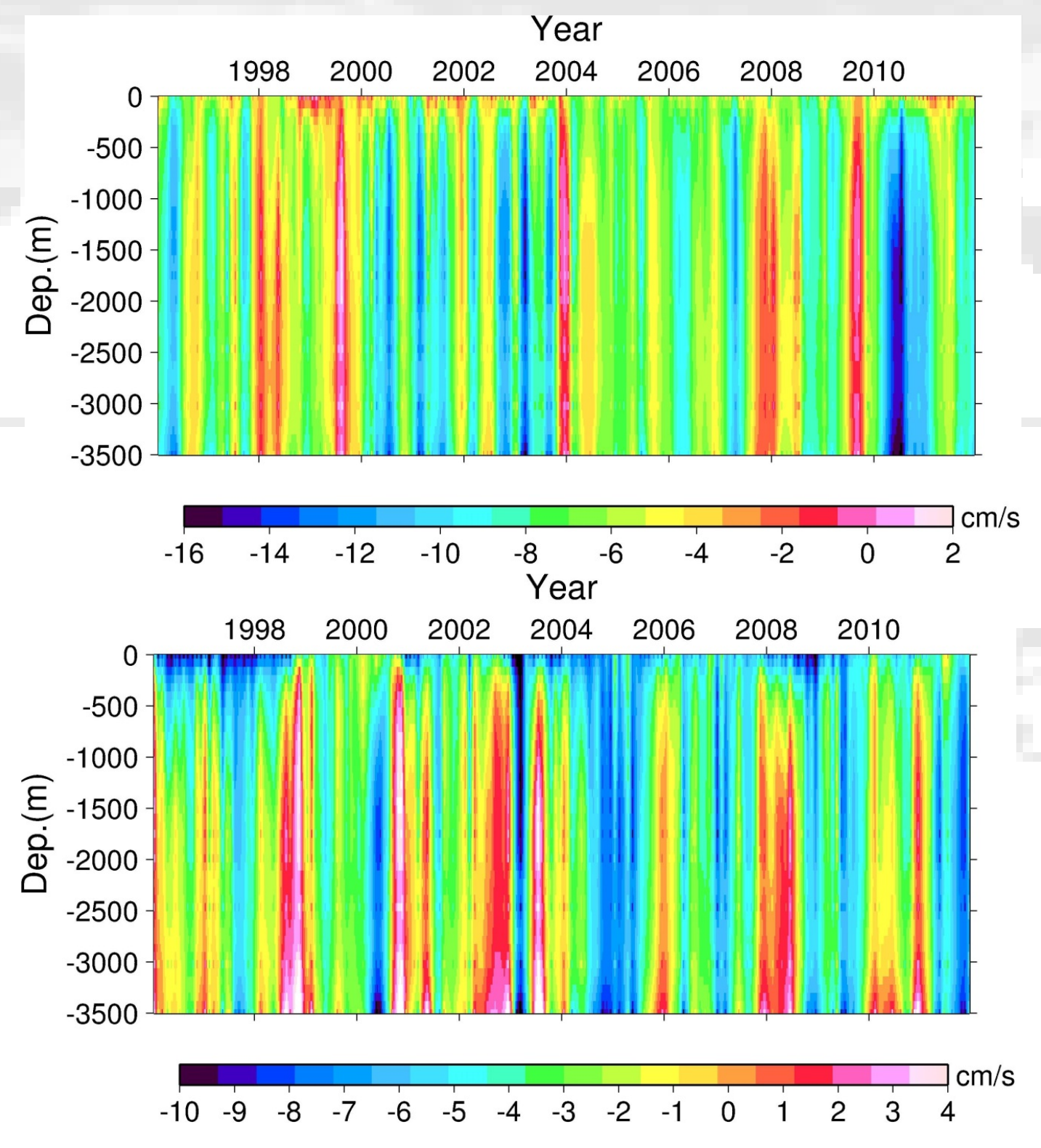


Fig. 6 Time-depth current velocities transect in the south of Ionian Basin.

In Fig. 5 and 6, upper and lower panels indicate the current velocity in zonal and meridional direction, respectively. Fig. 5 shows the transect in the south of Sicilia Island, while Fig. 6 shows the transect in the south of Ionian Basin. X axis indicates time, while y axis indicates depth in meter.

Currents in the south of Sicilia Island are mainly eastward but in meridional direction it shows the variation in direction. During 1998-2002 and 2009-2011 it shows a southward pattern, while in other periods it is northward. Below the depth of 150 *m*, the subsurface current is mainly northwestward (See Fig. 5).

In the south of Ionian Basin, zonal geostrophic current is mainly westward, while meridional current shows a variant pattern. Especially, during 1999, 2002, 2008, and 2010, meridional component shows a northward pattern, which indicates that subsurface current here shows a whether southwestward or northwestward pattern.

Conclusions

- GOCE-TIM5 with narrower filter HWHM than ITG-GRACE2010S to reach a smaller RMS compared with *in-situ* data from GDP and it also preserves more detail current patterns.
- Geostrophic current velocities and the patterns at different layers were resolved by combining altimetry, gravity field model, and T/S profile data. In the section in the south of Sicilia Island, currents in the upper 150 *m* shows a southeastward to northeastward varying pattern. Meridional component of subsurface geostrophic current in the section in the south of Ionian Basin also shows an inter-annual cycle.