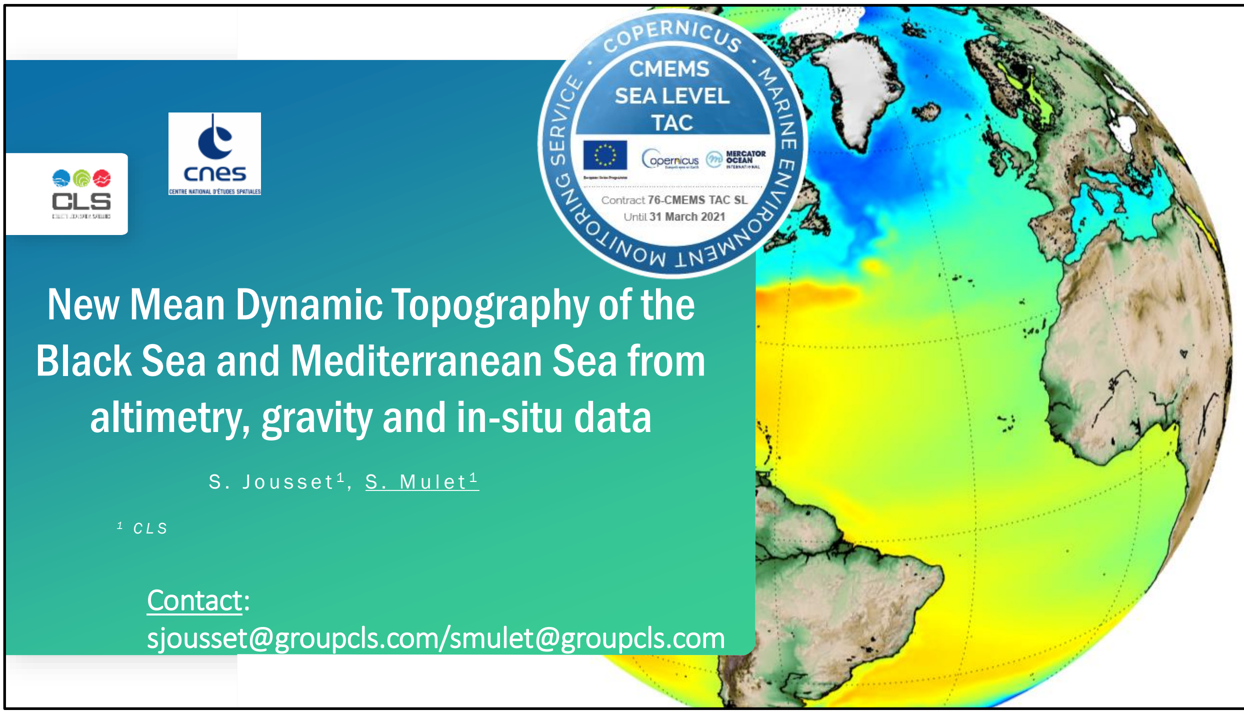
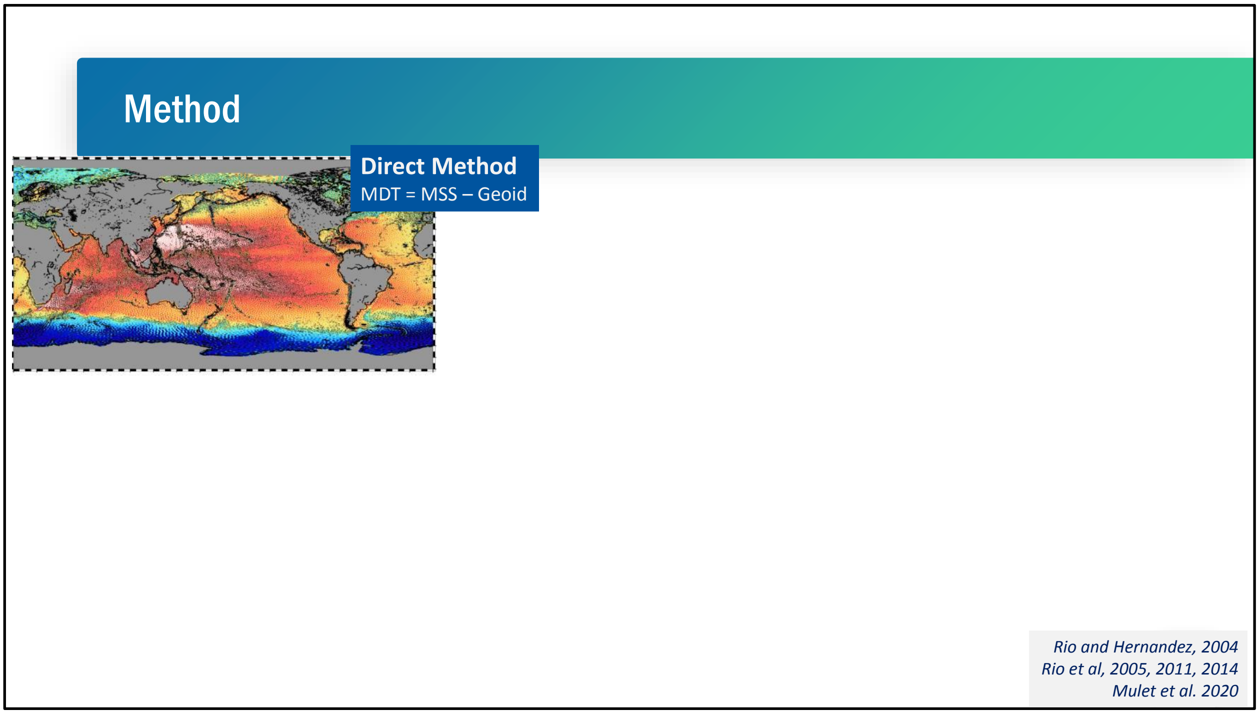
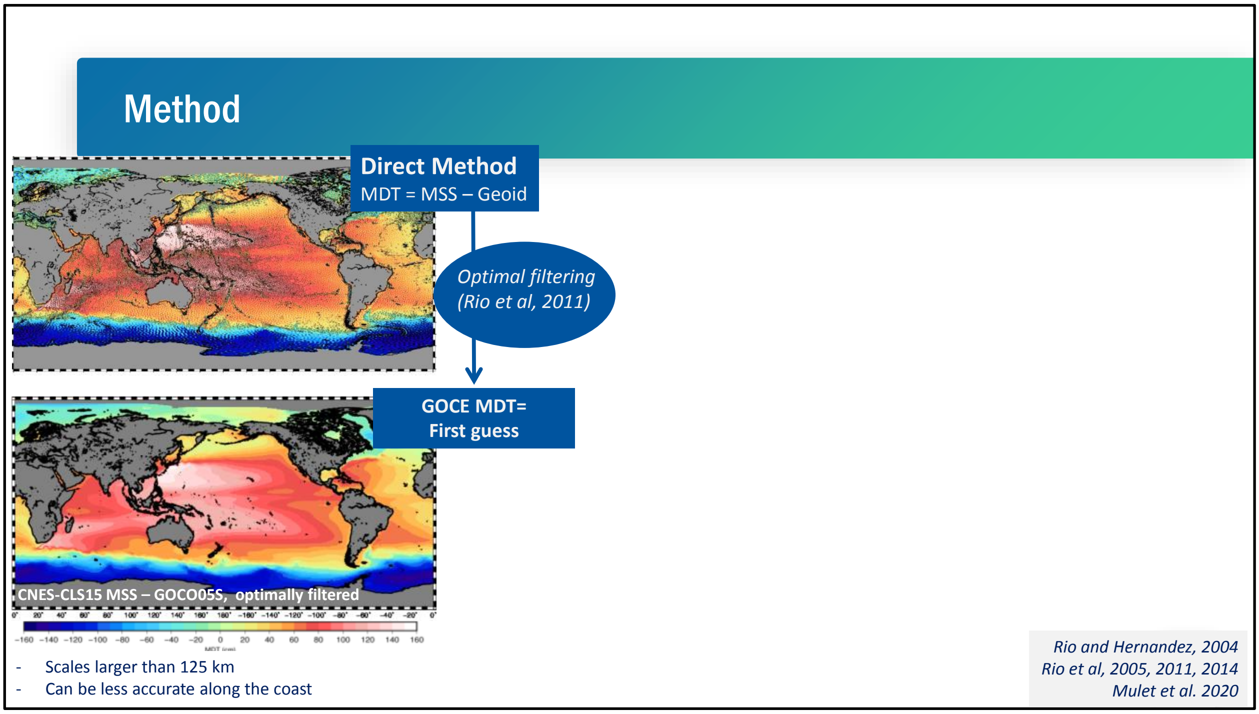


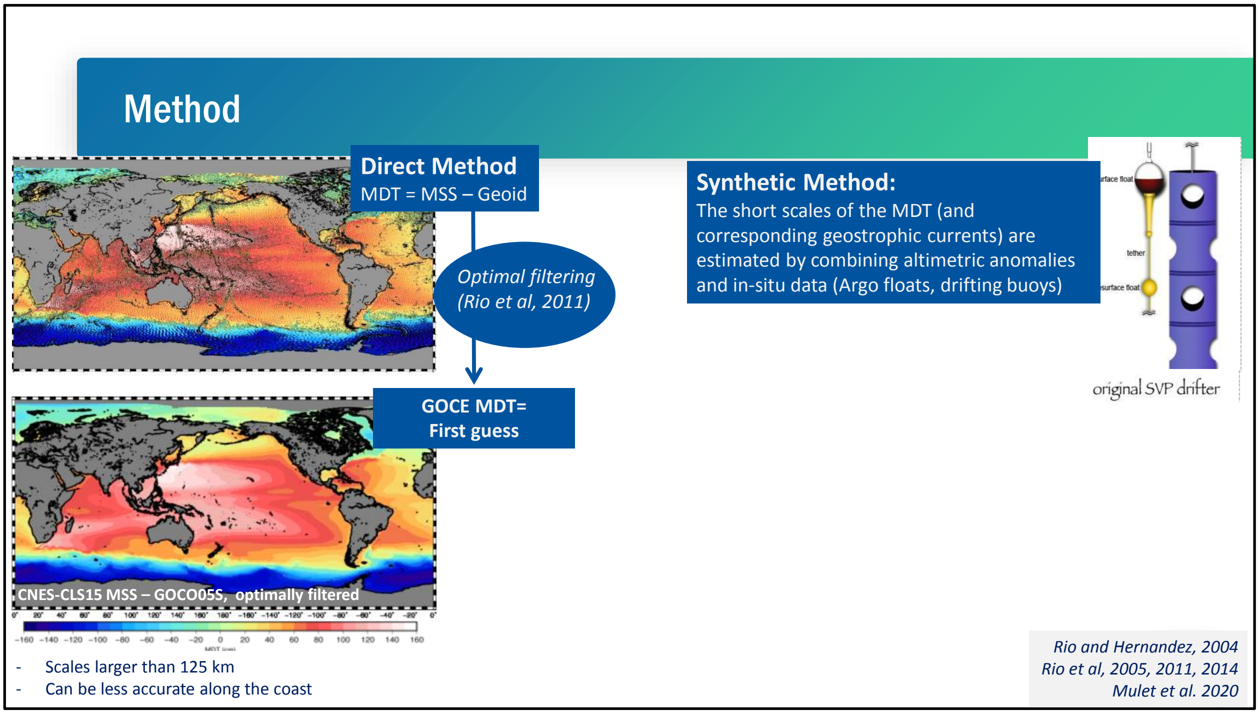
This presentation presents the latest MDTs: the global one, a regional one in the Black Sea and a regional one in the Mediterranean Sea. This work was carried out at CLS by S Jousset and S. Mulet.



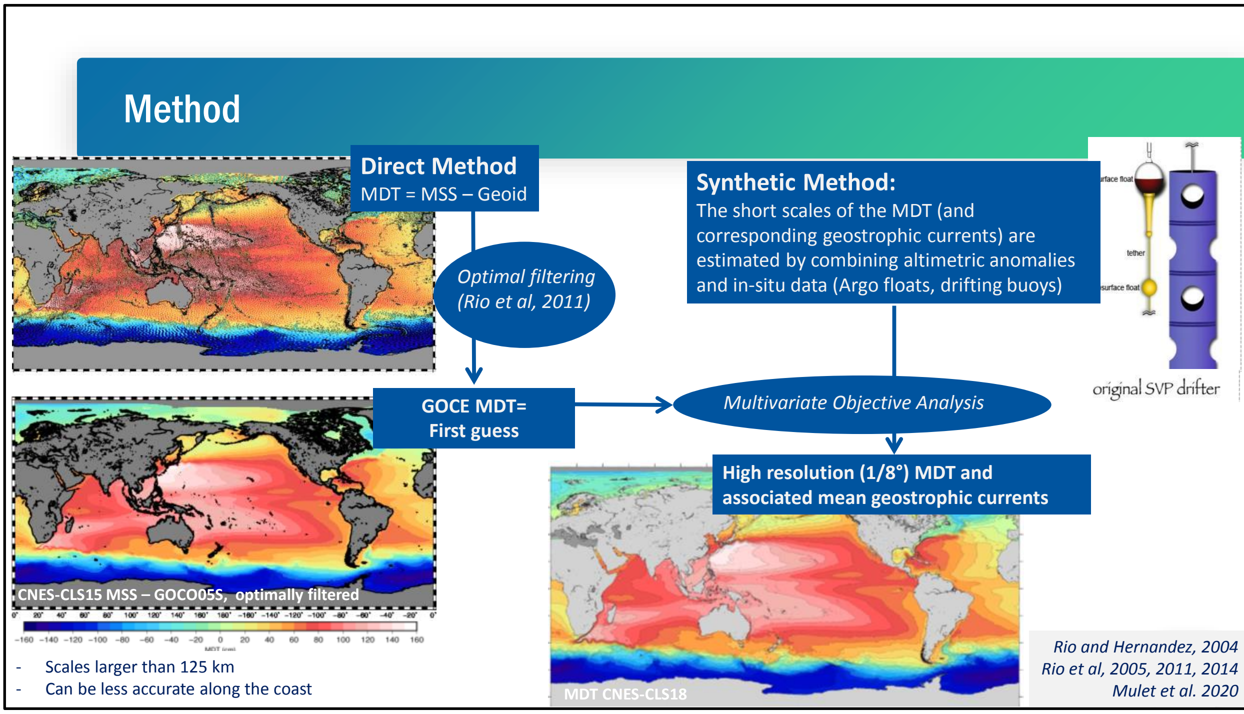
The general method used to calculate the regional and global Mean Dynamic Topography is similar to the one used in previous MDT versions. A detailed description can be found in (Rio and Hernandez, 2004, Rio et al, 2011, Rio et al, 2014a, Mulet et al. 2020). It is a three steps approach.



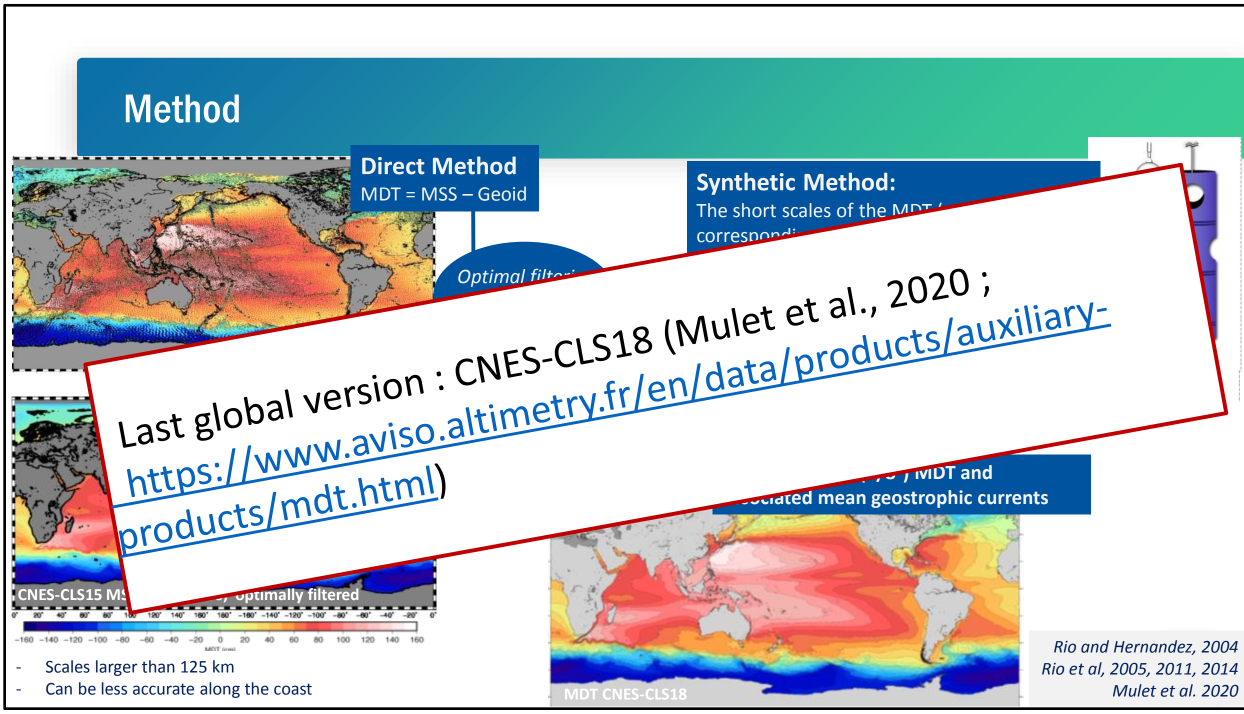
A first MDT solution is calculated from the optimally filtered differences between an altimeter Mean Sea Surface (MSS) and a geoid model. The effective resolution of the obtained field depend of the level of noise of the raw difference between MSS and geoid height. It thus depends of the areas, but it is around 100-125km (Bruinsma et al., 2014).



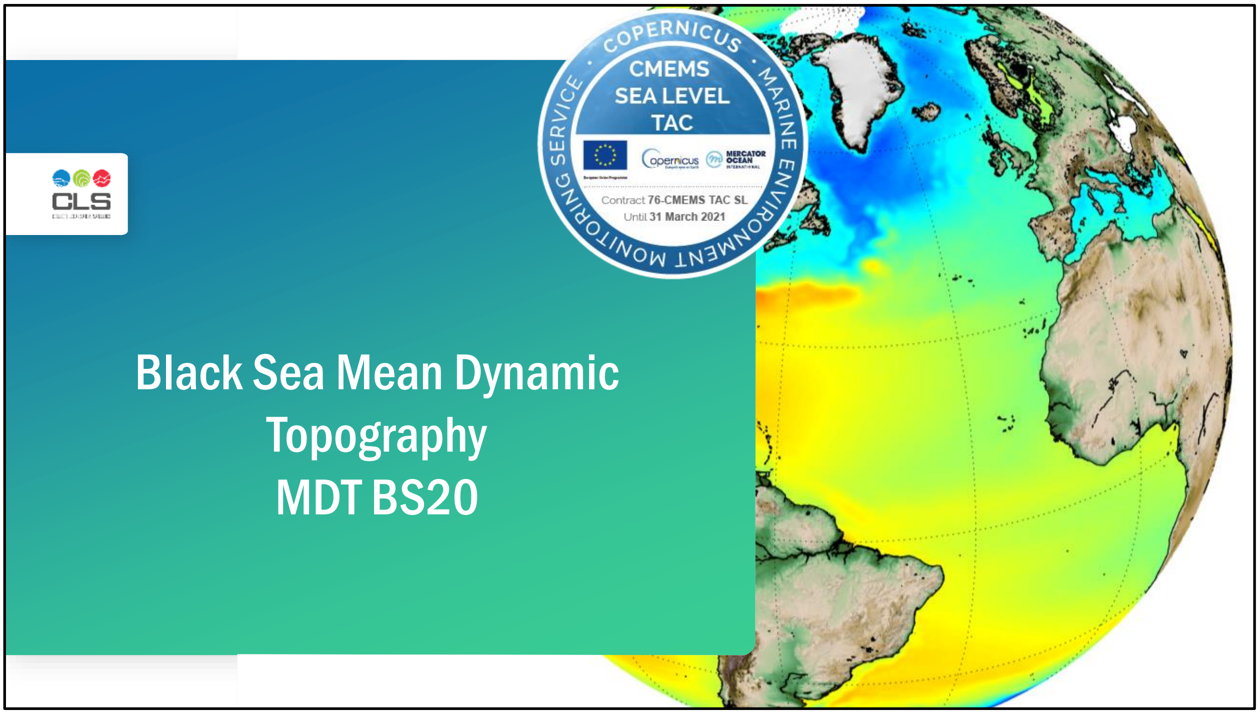
In the second step of the method, synthetic estimates of the MDT and mean geostrophic velocities are calculated using in-situ measurements of the ocean dynamic heights and surface velocities. First the in-situ measurements are processed so as to extract the geostrophic component only from the drifting buoy total velocities, and to complete the dynamic heights with the missing barotropic and deep baroclinic components. The temporal variability of the measured heights and velocities is further removed by subtracting the altimeter sea level and geostrophic velocity anomalies respectively. The processed in-situ measurements are further averaged into 1/4 and 1/8 boxes to obtain respectively the synthetic mean heights and velocities.



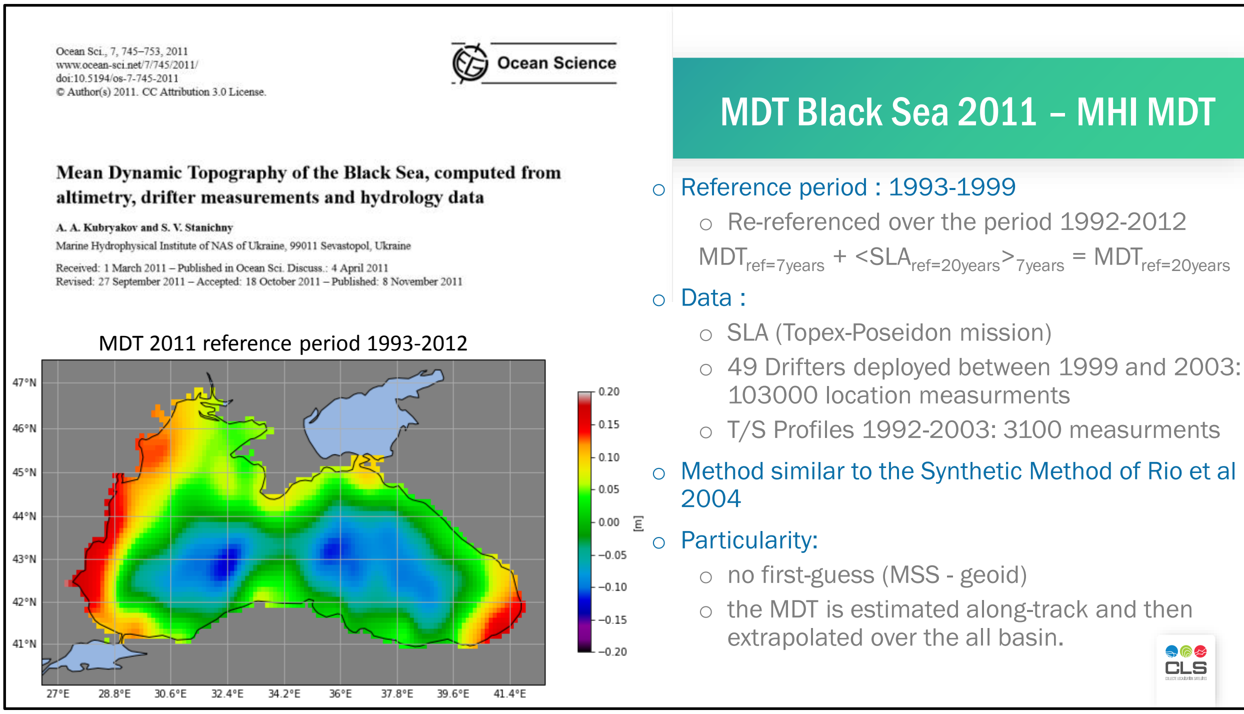
The synthetic velocities and heigths are finally used in the third step to improve the accuracy of the filtered MDT obtained at step 1 and bring information at shorter scales. This is done through a multivariate objective analysis whose required inputs are: the synthetic mean heights and velocities and their error, the first guess MDT, the a-priori knowledge of the MDT variance and zonal and meridional correlation scales.



The last CNES-CLS global version is the CNES-CLS18: see https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mdt.html



First, we present the calculation of the MDT in the Black Sea.



To start, here is the latest MDT estimated in the Black Sea from satellite and in situ data, carried out in 2011 by KUBRYAKOV AND STANICHNY from the Marine Hydrophysical Institute of Ukraine. In the rest of the presentation I will call this MDT the MHI MDT.

Firstly, this MDT was estimated over the reference period 1993-1999 and then re-referenced over the period 1993-2012.

The data used are :

-SLA data from Topex-Poseidon missions,

-velocity data estimated from 49 drifters

- and height data calculated from 3100 T/S profiles.

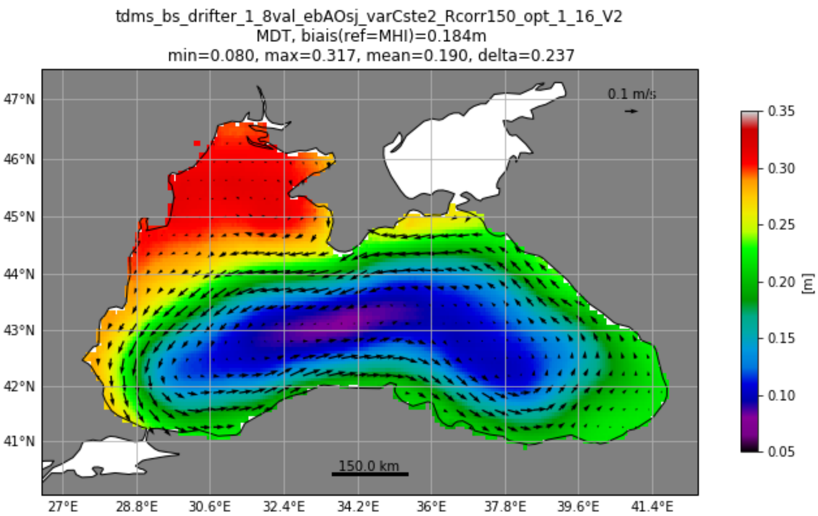
The method used is based on the synthetic method of Rio et al.2014. But this method is adapted because they did not use a first guess MDT estimated by subtracting a geoid model from the Mean Sea Surface. The particularity of this MDT is that it is estimated along the tracks and then extrapolated to the entire basin.

Black Sea MDT – reference period 1993-2012

		MDT_BS20
STEP 1	MSS	CNES-CLS15 (Pujol et al, 2018)
	Geoid	Eigen6c4
	First Guess filtering	Gaussian filter with a radius cutoff at 100 km
STEP 2	Drifter Data No heights data	Surface drifting buoy (drifter), both drogued and undrogued: **1999-2009** (Menna et al., 2017) 20% of drifters kept for validation
	Ekman model + wind Slippage > wind driven currents	Method : linear regression model (Poulain et al., 2012) Parameters : (Menna et Poulain, 2014) Wind : Cross-calibrated, multi-platform (CCMP) ocean surface wind velocities (Atlas et al., 2009)
	Drifter filtering	24 hours (Inertial Period about 17h)
	Altimeter data	Delayed-Time CMEMS-DUACS 2018 (Taburet et al, 2019)
STEP 3	Combination of first guess with in-situ data	Objective Analysis applied twice with correlation radius=300km and then correlation radius=150km
	Resolution	**1/16°**

For the Black Sea, the methodology is similar to the one applied for the global MDT. In step 2, we do not process mean synthetic heights, we keep heights data for validation. Step 3 is applied twice with different parameters. In the first objective analysis a large correlation radius (300km) is used to improve large scales and in the second analysis this radius is reduced to 150 km to improve smaller scales.
We used the drifters velocities data from the OGS database and the processing of Menna and Poulain 2014 to remove the wind-driven currents.
Finally the MDT resolution is 1/16° and the reference period is 1993-2012.

MDT Black Sea and geostrophic currents associated



Description :

- MDT defines a cyclonic circulation with higher water levels at the periphery than in the centre.
- One elongated gyre
- Fairly smooth
- No mesoscale structures

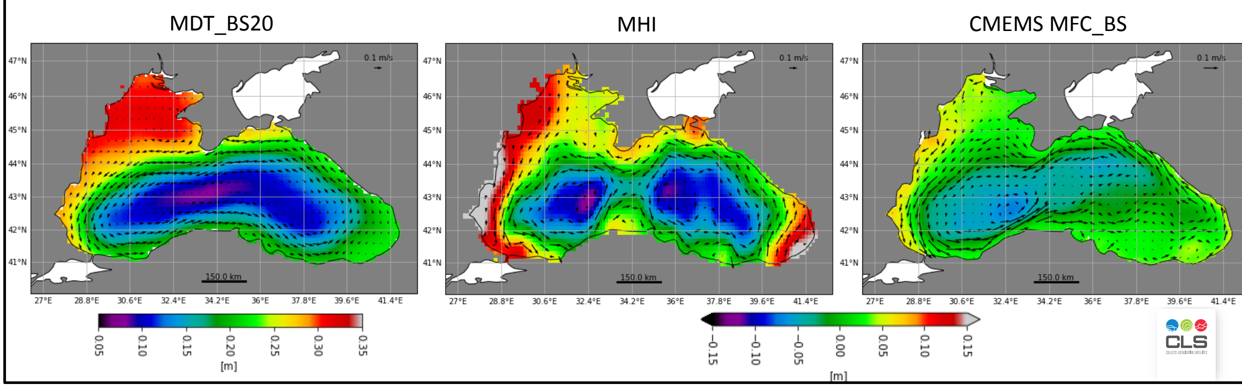
The new MDT defines a cyclonic circulation with higher water levels at the periphery than in the centre. The minimum of the gyre is central. This gyre is elongated from west to east. The cyclonic current breaks away from the coast to the southeast and the area to the east is flatter, it is the place of the non-permanent eddy Batumi. MDT is fairly smooth and does not represent mesoscale structures.

Comparaison with others MDTs : MHI MDT and CMEMS MFC_BS MDT

CMEMS MDT = average of the SSH (Sea Surface Height) of the CMEMS regional model in Black Sea (MFC_BS) over the 1993-2012 period

- Biais 19cm
- CMEMS MDT flatter than the others and MHI MDT sharper

Name	Mean [cm]	Delta max-min [cm]
MDT_BS20	19	23,7
mdt MHI	1,1	31,4
mdt CMEMS	0,1	15,2

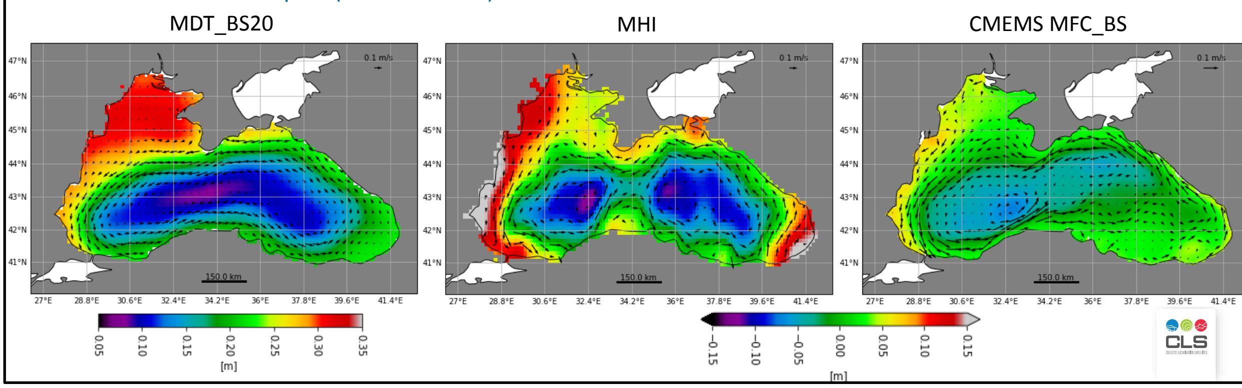


The MDT is compared to other MDTs: the observed MDT of Kubryakov et al (2011) called mdt MHI, and one modeled, it is the average over the 1993-2012 reference period of the SSH (Sea Surface Height) of the regional CMEMS model in Black Sea (MFC_BS). These both MDTs are centered around 0cm instead of 19cm for MDT_BS20 MDT (see Table).
There is often bias between observed MDT and MDT from numerical model (this is also the case for global MDT). This is explained because the reference surface are not the same: in a numerical model, the reference is given by the bathymetry, there is no geoid information and geoid height = 0. For 'observed' MDT the reference surface is the geoid height by construction and by definition. For more detail see https://marine.copernicus.eu/faq/differences-reference-ssh-ocean-models-altimetric-observations-global-products/?idpage=169

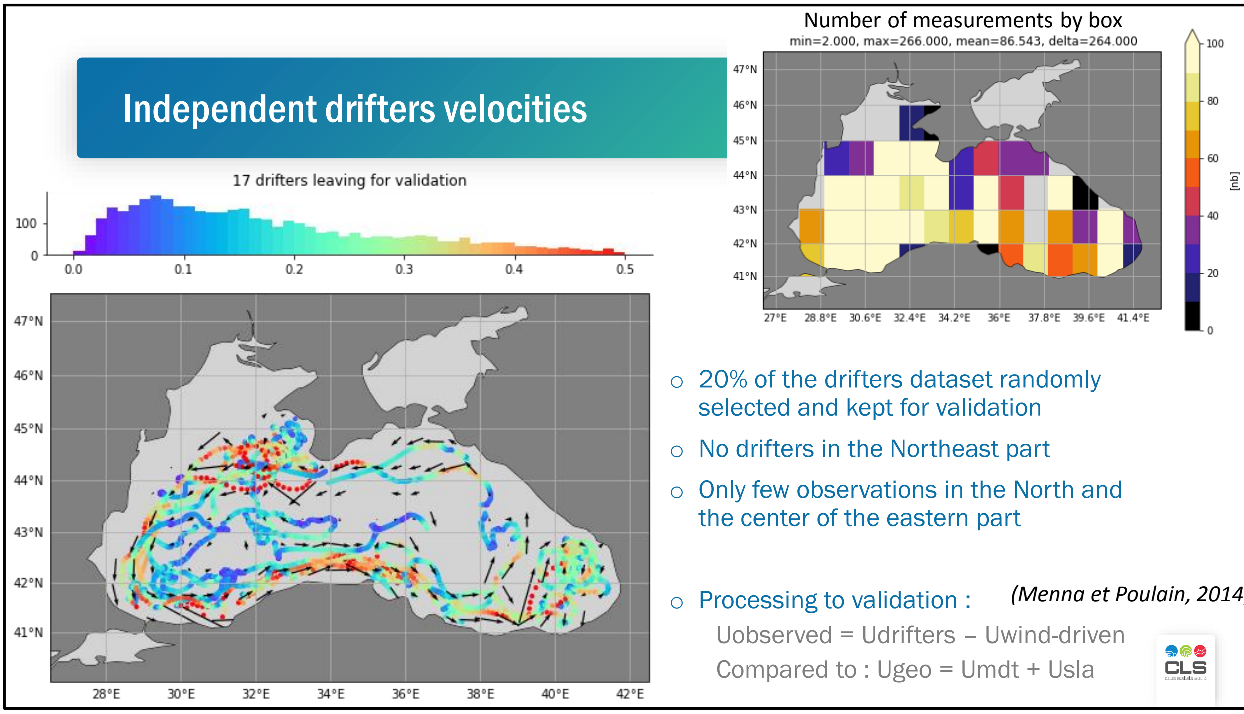
The CMEMS MDT is flatter than the others. And the MHI MDT is sharper.

Comparaison with others MDTs : MHI MDT and CMEMS MDT

- Significant differences between the MHI MDT and the others
- The East gyre does not extend to the east of the basin in the CMEMS model compared to others
- Northwestern part (over the shelf) different in three MDTs

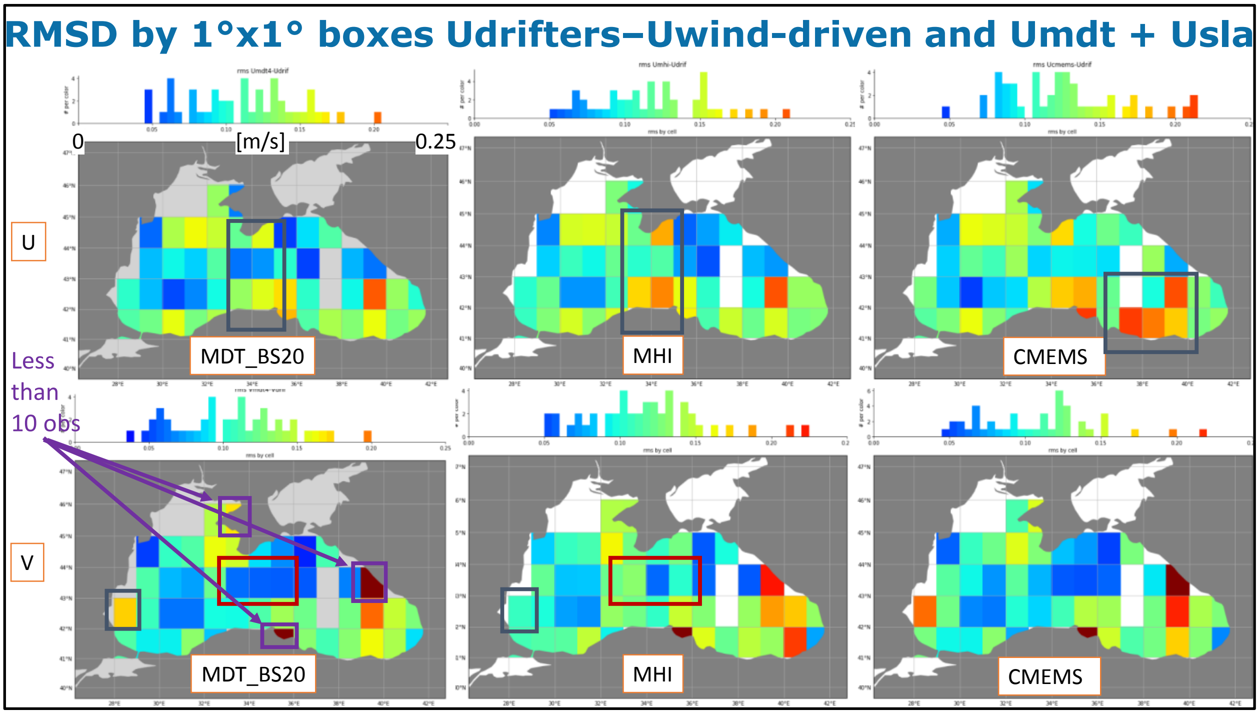


The MDT MHI is very different from the other two.
The new MDT and MDT CMEMS are mostly different in the eastern part and northwestern part of the basin .
In the MDT CMEMS, the eastern gyre remains in the northern part and the cyclonic current breaks away from the coast further west. While in the new MDT, the Southeast current remains attached to the coast.
The three TMDs are also different in the northwestern part.



20% of the drifters dataset are randomly selected and kept for validation (independent data). The Figure shows the 17 drifters kept for the validation of the MDT. There are no drifters in the Northeast part of the Black Sea above the plateau. In addition, there are few observations in the North and the center of the eastern part.

Thereafter, to compare to the MDT, we remove the wind-driven current (estimated with method and parameters from *Menna et Poulain, 2014)* to keep only the geostrophic signal and compare it to the geostrophic currents (Umdt +Usla).



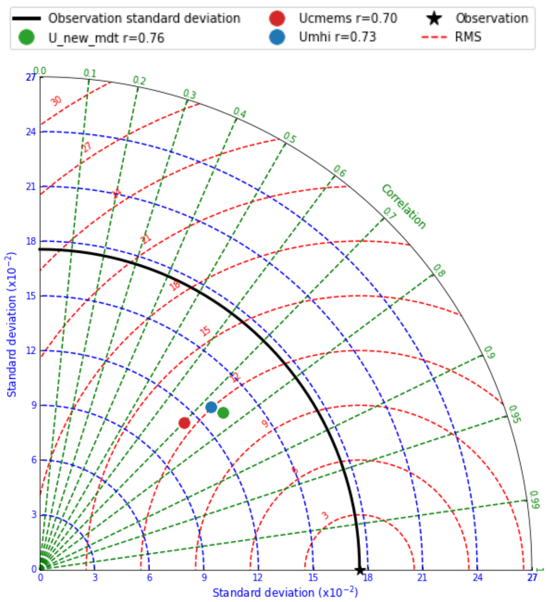
Here is represented the RMS (Root Mean Squared) of the difference in boxes of 1° by 1° between the drifting currents, from which the wind-driven part has been removed, and geostrophic currents estimated from the different MDTs and altimetry (SLA). Above are the comparisons on the zonal component and below on the meridional component, for from left to right the new MDT, the MDT MHI and the MDT CMEMS.
The scale is the same for all figures and ranges from 0 to 0.25 m/s.

For the zonal component, the RMS is globally lower for the MDT_BS20. In particular, it is better than MHI in the center of the basin (framed area) where the circulations are different. And it can also be noted that the RMS is high for the MDT CMEMS in the South East (framed area), where the cyclonic current breaks away from the coast.

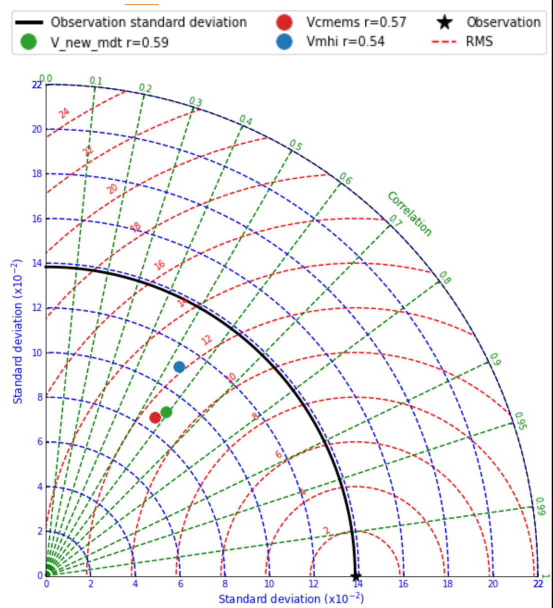
For the meridional component, the RMS is globally lower for the new MDT, especially in the center (red box) compared to MHI where the system of two very distinct gyres seems less good compared to the drifters' speeds. On the other hand the MDT MHI is better in some boxes (grey-blue boxes) for example in the far west, where the stronger currents of MHI give better results. However, the more eastern boxes are better with the new MDT with weaker currents in this area.

Taylor diagrams between Udrifters – Uwind-driven and Umdt + Usla

Zonal component U



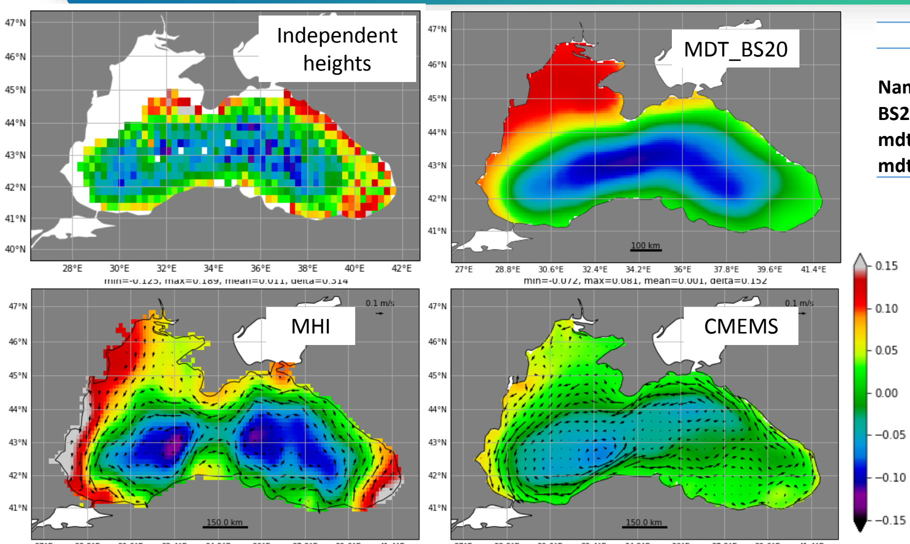
Meridional component V



Here are represented the Taylor diagrams for the U zonal component on the left and the V meridian component on the right of the current. The geostrophic currents are compared over the whole zone: Udrifter - Uwind-driven and Umdt + Usla. In green we have the new MDT, in blue the MDT MHI and in red the MDT CMEMS.

For both components, the new MDT is better for correlation with observations and in RMS. However, it lacks variability with respect to the observations because it does not represent mesoscale structures.

Comparaison with independent dynamic heights (from T/S profils)



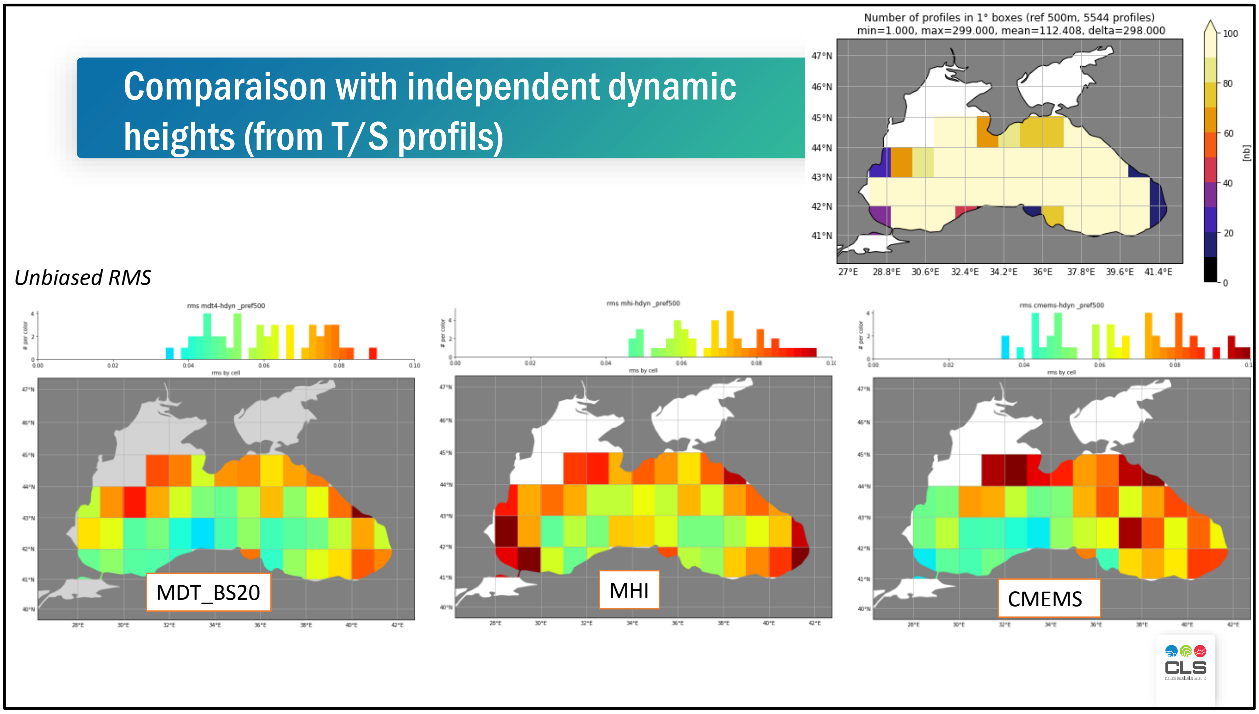
	Dynamic heights	
Name	RMS [cm]	Correlation coef.
BS20	5,92	0,61
mdt MHI	6,98	0,47
mdt CMEMS	6,79	0,44

We also compared the MDT BS20 to dynamic height referenced to 500m and estimated from T/S profiles available in the area.

We did not use these data in the objective analysis (estimation of the MDT) because we observed that these heights are not correlated with the SLA in the Black Sea . Indeed, to use the heights in the MDT estimation we have to correct these heights with the SLA to remove the temporal variability and thus have an average over the reference period. However as the SLA and these heights are decorrelated, we could not find a suitable correction. We do not have at this time any explanation for the fact that the heights and the SLA are decorrelated.

Here we compare the anomaly of the dynamic heights (with respect to the average over the whole Black Sea) averaged by box with the MDTs (the MDT BS20 is recentered on 0).

The MDT BS20 is consistent with these data, it has the lowest RMS and the best correlation.



Here we represent the RMS per 1°x1° boxes of the different MDTs minus the dynamic heights averaged per 1°x1° box.
Globally, the new MDT is better than the two others on the middle of the basin. In the West, it can be noted that the MDT CMEMS is better close to the coast, the MDT MHI being too high in this western part.

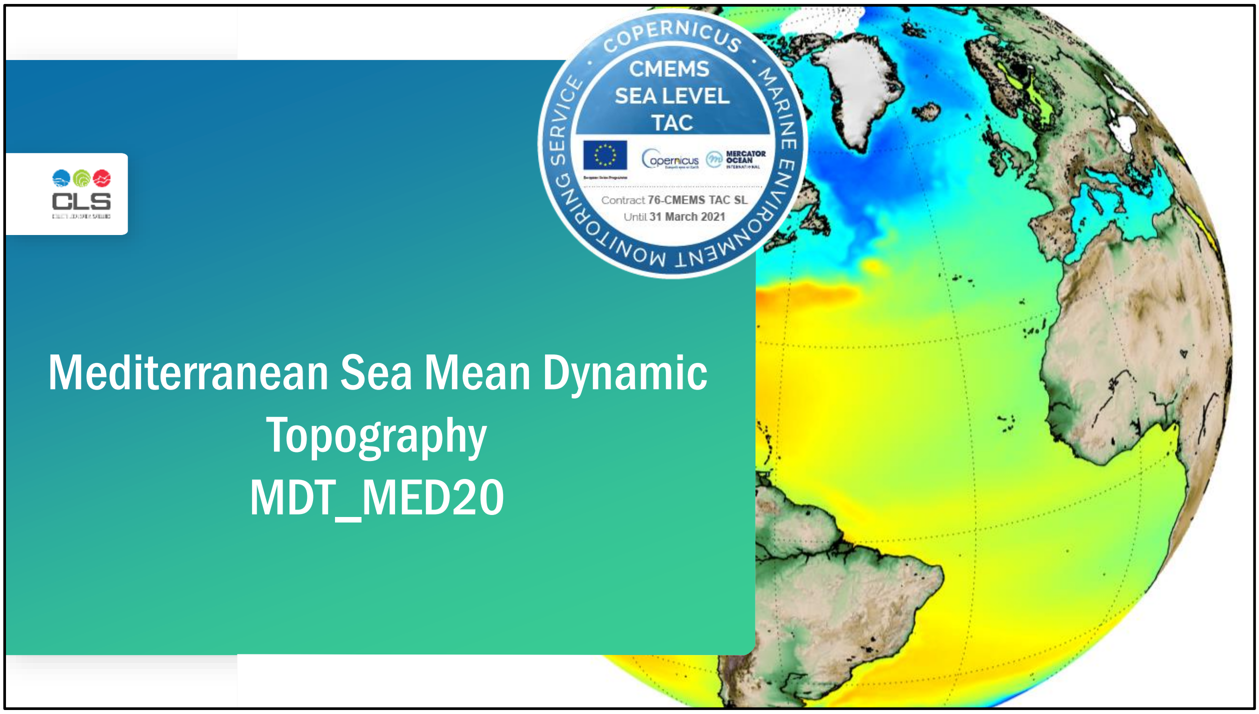
MDT_BS20 MDT Conclusions

- Reference period : 1993-2012
- Represents well the large scale structures of the Black Sea.
- Better compared to MHI and model (compared to drifters and T/S profiles)
- Lack of variability (does not represent mesoscale structures)
- Good consistency with height data
- No data in the North-West part on the shelf (non-validated area), the solution comes from altimetry and geoid model.

➢ **Expected available in CMEMS catalogue in Spring 2021**

➢ If you are interested to be beta tester, let us know (sjousset@groupcls.com/smulet@groupcls.com)

CLS



Now, we present the calculation of the MDT in the Mediterranean Sea.

Mediterranean Sea

What is new ?

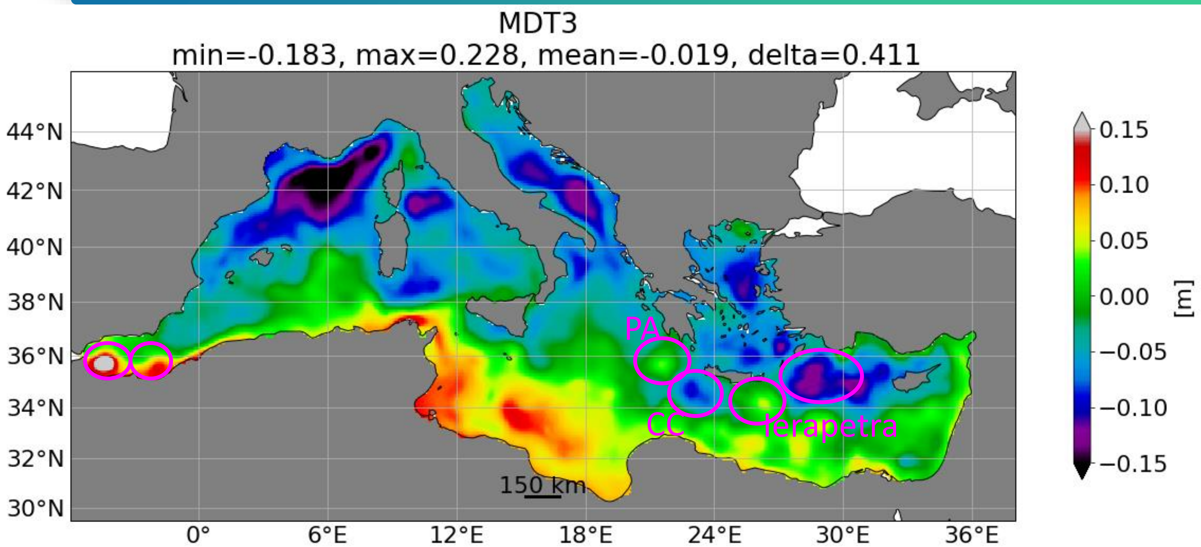
		SMDT 2014 (Rio et al. 2014)	MDT_MED20
STEP1	MSS	-	**CNES-CLS15 (Pujol et al, 2018)**
	Geoid	-	**Eigen6c4**
	First Guess filtering	-	2d Gaussian filter R=100km
	First Guess	Model output The modeled MDT was computed averaging over the 1993–1999 period outputs from the 1/16 ◦ MFS model (Mediterranean Forecasting System; Adani et al., 2011)	**Filtered MSS - geoid**
STEP2	Hydrological data	The hydrological profiles (CTD and Argo floats) from 1993 to 2012	CTD and ARGO from CORA **from 1993 to 2018**
	Drifter Data	Surface drifting buoy (drifter), both drogued and undrogued (OGS dataset): 1993-2011 Drifters over June-December 2011 kept for validation	Surface drifting buoy (drifter), both drogued and undrogued: **1993-2016** (Menna et al., 2017) 15% of drifters kept for validation
	Ekman model + wind Slippage > wind driven currents	Method and parameters: Poulain et al. (2012) Wind : Cross-calibrated, multi-platform (CCMP) ocean surface wind velocities (Atlas et al., 2009)	Method and parameters: Poulain et al. (2012) Wind : Cross-calibrated, multi-platform (CCMP) ocean surface wind velocities (Atlas et al., 2009)
	Drifter filtering	36h	36h
	Altimeter data	Delayed-Time DUACS-2010 (Dibarboure et al, 2011)	Delayed-Time CMEMS-DUACS 2018 (Taburet et al, 2019)
STEP3	Resolution	Global 1/8°	Global **1/24°**

For the Mediterranean, the same methodology as the global MDT is applied. In step 1, a 2d Gaussian filter with a radius of 100km is used. Step 2 is identical, and step 3 keeps the same methodology with slightly different parameters (correlation radius for example). This table summarizes the standards and the differences with the old SMDT 2014 (Rio et al. 2014b).
The reference period is 1993-2012.

The main difference with SMDT 2014 is that the first guess is made from altimetry data and a geoid model (MSS- geoid) instead of a first guess made from a model.
Then the database of drifting buoys and T/S profiles are larger: drifters until 2016 instead of 2011, T/S profiles until 2018 instead of 2012.
The treatment is identical to SMDT2014, but a larger number of data sets are kept for validation (about 15% of the data sets instead of 1%).

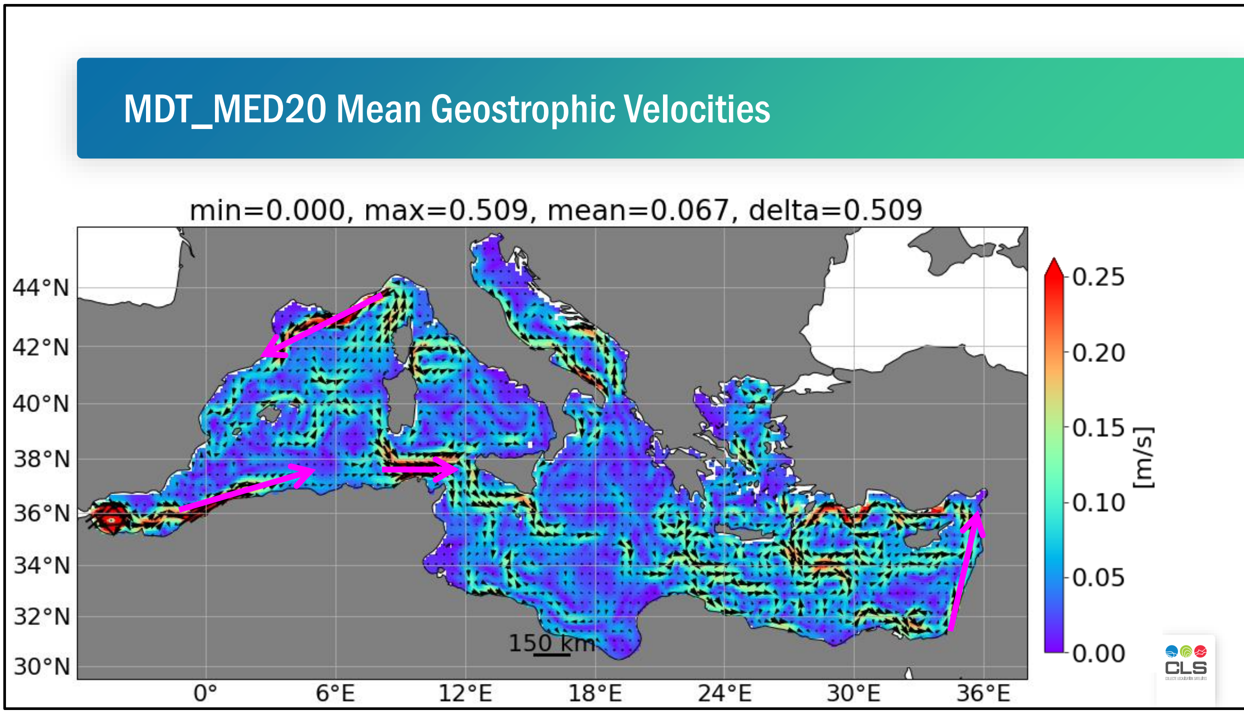
And finally the MDT is calculated at the resolution 1/24° (instead of 1/8°).

MDT_MED20 Mean Dynamic Topography



The new MDT_MED20, with some remarkable structures :

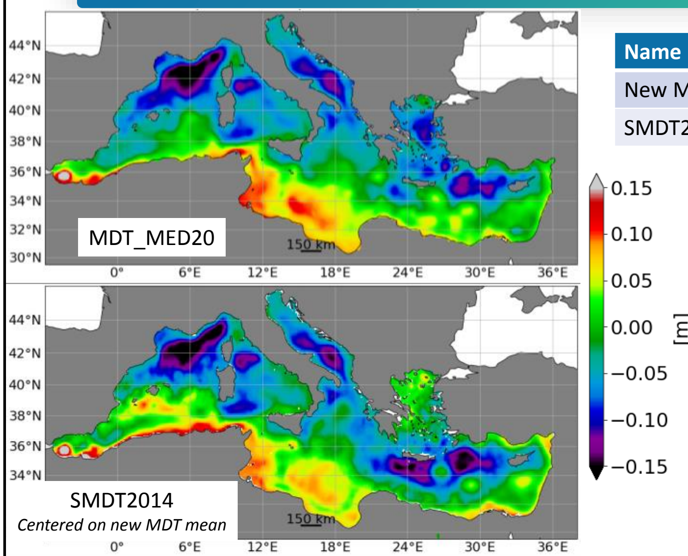
- Alboran Sea eddies
- Pelops Anticyclone (PA) and Cretan Cyclone (CC)
- Anticyclonic Ierapetra eddy and cyclonic Rhodes eddy



The associated geostrophic circulation and some remarkable currents :

- Algerian Current
- Current between Sardinia and Tunisia
- Liguro-Provençal Current
- East current of the Levantine basin

MDT_MED20 vs SMDT 2014 (centered on new MDT mean)



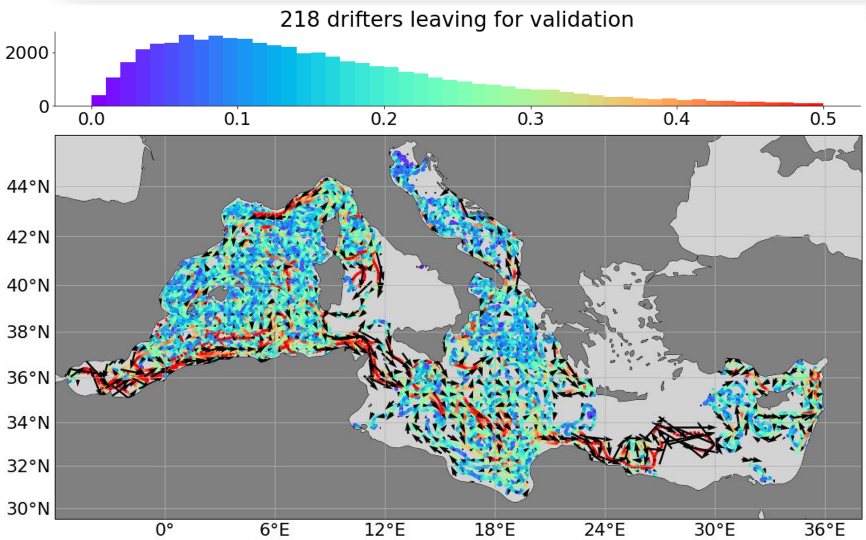
Name	Min [cm]	Max [cm]	Mean [cm]	Delta [cm]
New MDT	-18.3	22.8	-1.9	41.1
SMDT2014	-22.2	18.7	-7.1	40.9

- Algerian current, coastal current of the east of Levantin basin and Asia Minor Current are less intense in the new MDT
- Very different pattern in Aegan Sea, in Southern Baleric Islands and in Levantin basin

Here are shown the new MDT at the top and the SMDT2014 at the bottom. There is a bias between the two of about 5cm, which can be explained by the fact that the first guess of the new MDT is given by altimetry and a geoid model whereas the one of the SMDT2014 comes from a model which does not have the same height reference.
On the other hand, we have an equivalent delta (max -min) for both MDTs.

Visually we can note that the Algerian Current, the coastal current east of the Levantine Basin and the Asia Minor Current are less intense in the new MDT than the old one.
And we have very different patterns south of the Balearic Islands, in the Aegean Sea and in the Levantine Basin.

Validation - Independent drifters velocities



- 15% of the drifters dataset kept for validation
- Validation dataset **independent** of the MDT_MED20 and SMADT2014
- no drifters in the East of the Tyrrhenian Sea, in Aegean Sea
- Only few drifters in Levantin Basin and offshore Lybia
- Processing to validation :
  - Uobserved = Udrifters – Uwind-driven *(Poulain et al., 2012)*
  - Compared to : Ugeo = Umdt + Usla

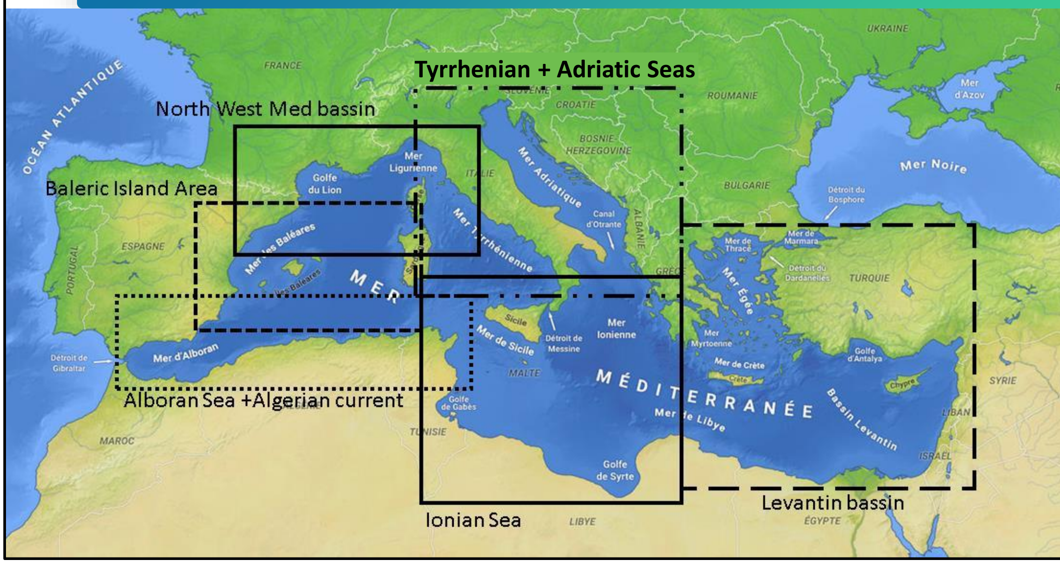
15% of the drifters dataset kept for validation (independent data). This validation dataset contains the validation set drifters of SMDT 2014 and drifters randomly chosen since 2012 in order to have an independent validation set of the new MDT but also of SMDT2014.

The Figure shows the drifters kept for the validation of the MDT.

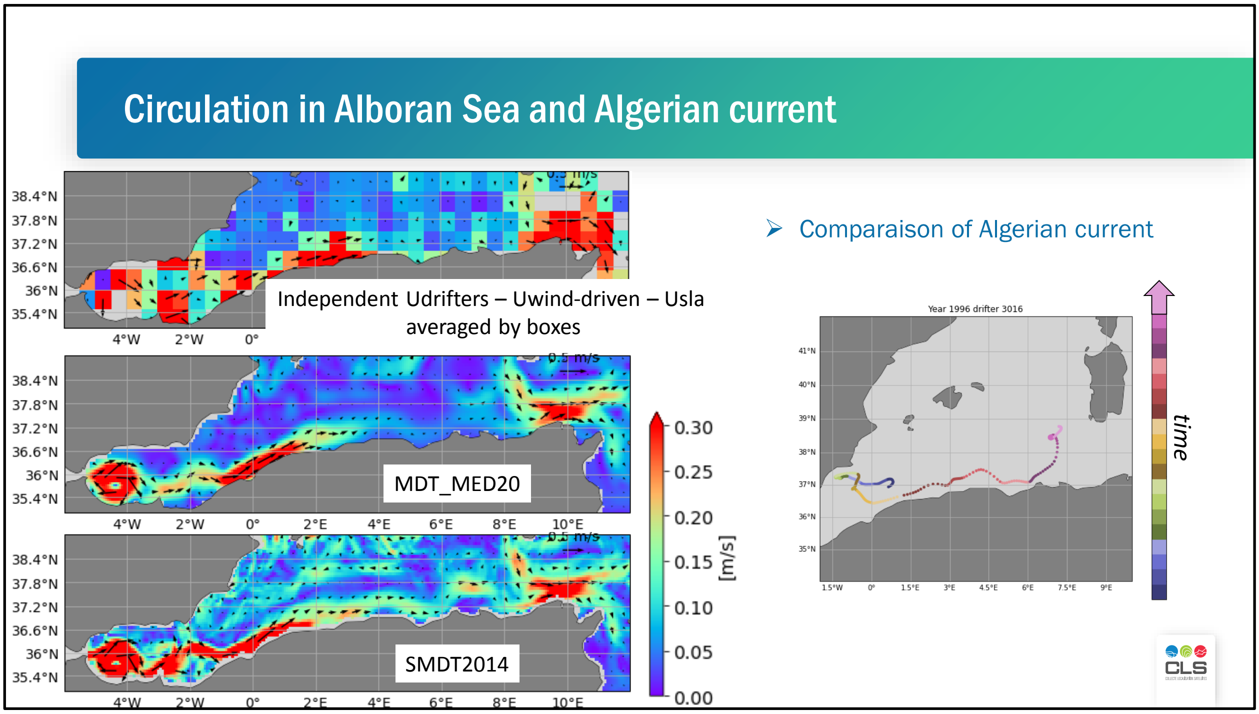
There are no drifters in the East of the Tyrrhenian Sea, in Aegean Sea and only few drifters in Levantin Basin and offshore Libya.

Thereafter, to compare to the MDT, we remove the wind-driven current (estimated with method and parameters from Poulain et al. (2012*))* to keep only the geostrophic signal and compare it to the geostrophic currents (Umdt +Usla).

Validation zones



For the validation, we work by zones:
- Alboran Sea + Algerian Current
- Baleric Islands Area
- North West Mediterranean basin
- Tyrrhenian + Adriatic Seas
- Ionian Sea
- Levantin Basin



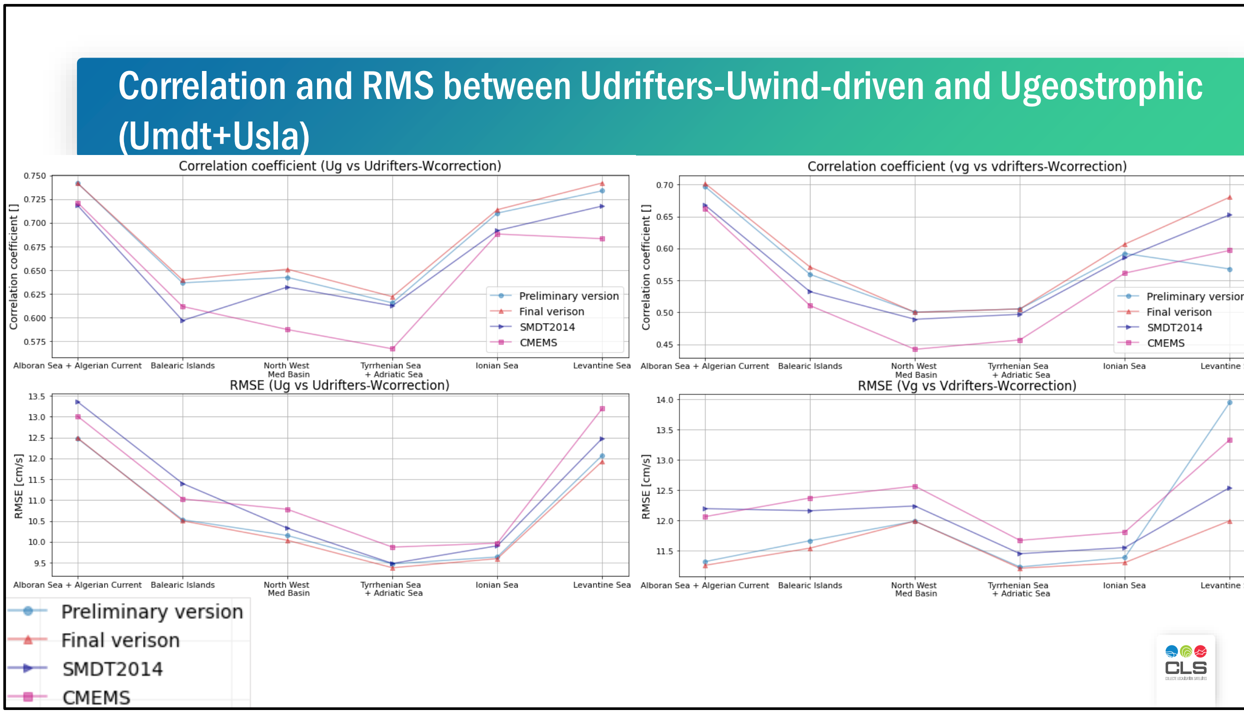
We now compare the average circulations of the validation drifters and the two MDTs. At the top is shown the mean speed per 1° by 1° box of the drifters currents from which the wind-driven current and the geostrophic current derived from altimetry (SLA) have been removed. In the middle (resp. bottom) are represented the mean geostrophic velocities associated with the new MDT (respectively SMDT2014).

The Algerian current is more intense in SMDT 2014, especially between longitudes 2°E and 8°E.

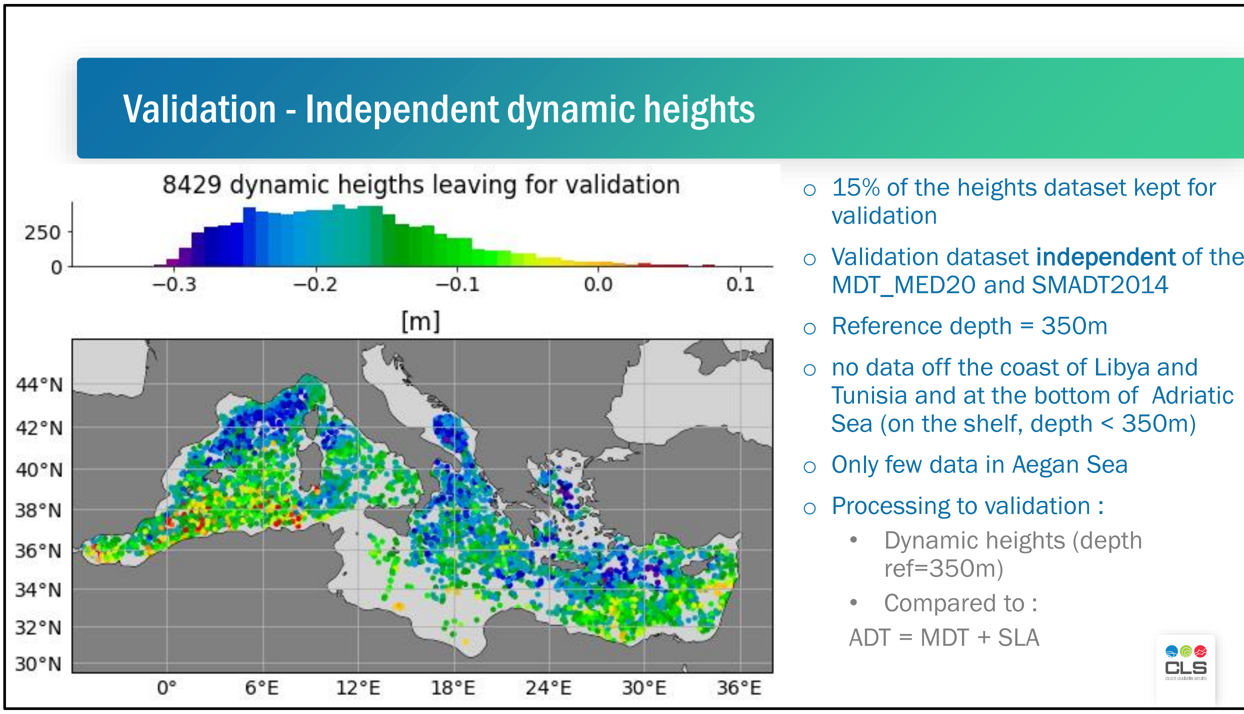
In the MDT MED20 MDT, it almost disappears between longitudes 4°E and 8°Ein agreement with drifters. Indeed in this zone, eddies can drive the drifters towards the North like the example of a drifter on the right.

The difference with the SMDT 2014 is certainly due to the fact that the MDT MED20 first guess (MSS - geoid) is smother than the SMDT2014 first guess (from numerical model), probably less accurate close to the coast and does not represent this very coastal current while it was present in the first guess model of the SMDT2014.

In future work we plan to analyze in detail the impact of drifters sampling on the final MDT results and to perform further validation to evaluate the performance of this new MDT in this area.

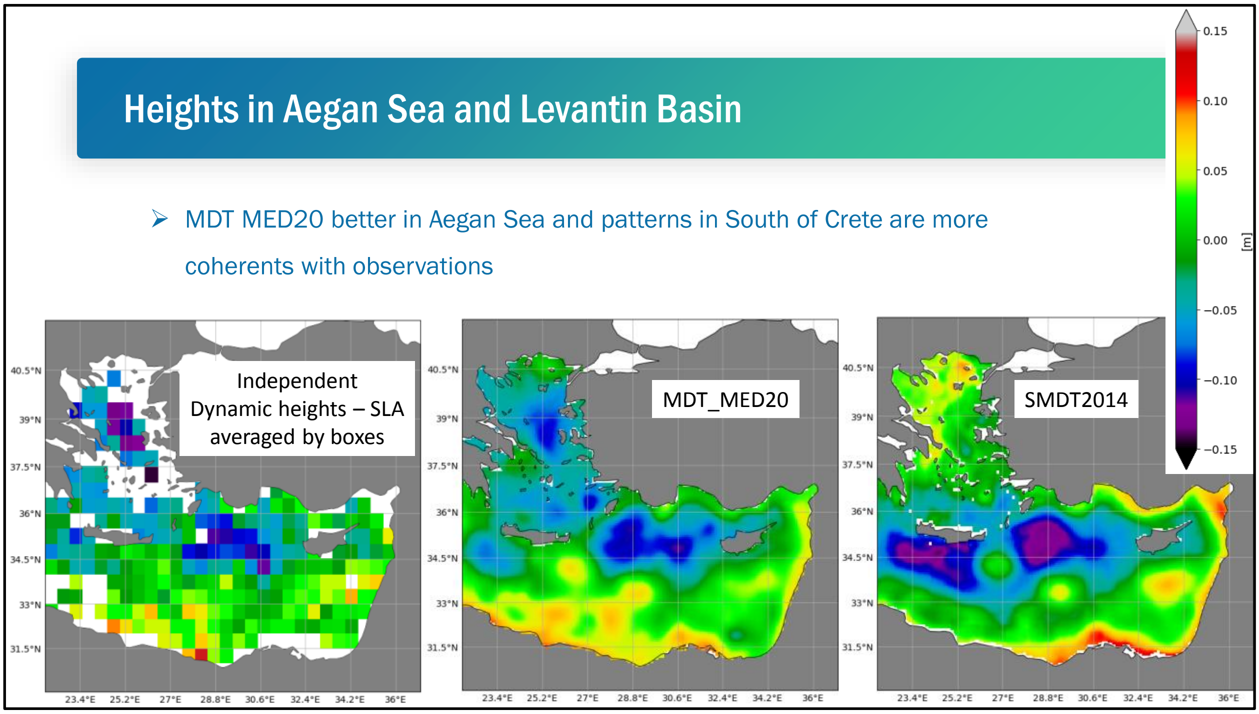


Here are represented the correlation coefficients by geographical zone (top) between wind corrected drifters speeds and geostrophic speeds derived from MDT and SLA (zonal component on the left and meridional component on the right). Below are shown the RMS scores by zone between the geostrophic velocities (MDT + SLA) and the wind corrected drifters velocities. In different colors are represented the results for the new MDT MED20, a preliminary version of this MDT, the SMDT2014 and the MDT model (average of the SSH of the CMEMS model over the reference period).
In all zones, for both current components the correlation coefficients are higher for the new MDT than for the SMDT2014 and the RMSE is lower.



15% of the dynamic heights dataset kept for validation (independent data). This validation dataset has been randomly chosen since 2012 in order to have an independent validation set of the new MDT but also of SMDT2014.
The Figure shows the dynamic heights kept for the validation of the MDT. The dynamic heights were computed from hydrological profiles available relative to 350 m. The reference depth (350m) choice results from making a compromise between the number of profiles available (the deeper the reference depth, the less the profiles available) and the dynamical content of the calculated dynamic heights (the deeper the reference depth, the more complete the captured baroclinic content). The reference depth is the same than for SMDT2014.

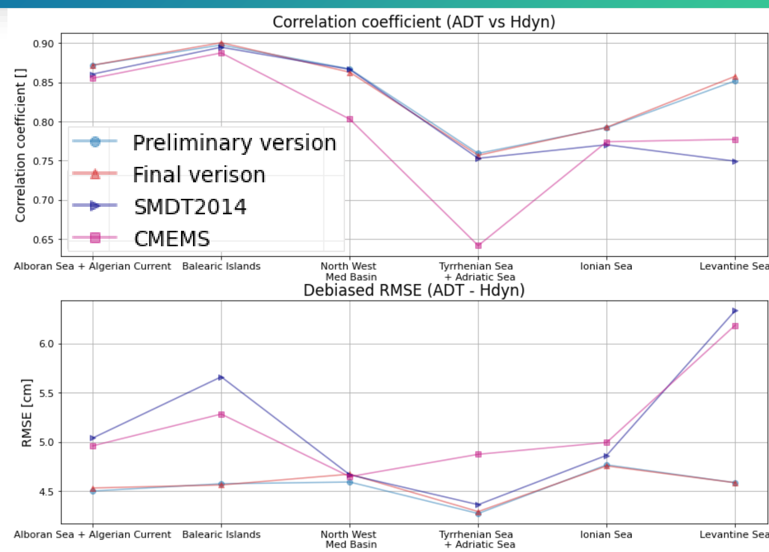
There are no data off the coast of Libya and Tunisia and at the bottom of Adriatic Sea (on the shelf, because the depth is less than 350m).
Thereafter, to compare MDT MED20 and SMDT, we use Absolute Dynamic Topography (ADT=MDT+SLA) compared to dynamic heights.



Here we compare the dynamic heights at which SLA was removed and averaged by box of 1° by 1° to compare them to the MDTs. In order to compare these heights, we have also removed the average over the entire Mediterranean (heights centered around 0 and MDTs centered around 0).

In the Aegean Sea, the new MDT seems a little better than SMDT2014 on the global height of the Sea but we do not have enough data to validate the represented structures.
Improvements are clearer around Crete with a representation more consistent with observations of patterns south of Crete (Irapetra and Rhodes eddies).
On the other hand, as we have seen with drifters, coastal currents are less intense with the new MDT (we cannot really compare to heights because we do not have enough data in this coastal part due to data processing).

Correlation and unbiased RMS between dynamic heights and ADT (MDT+SLA)



Here are represented the correlation coefficients by geographical zone (top) between dynamic heights and Absolute Dynamic Topography (MDT + SLA). Below are shown the RMS scores by zone between ADT (MDT + SLA) and dynamic heights. In different colors are represented the results for the new MDT MDT MED20, a preliminary version of this MDT, the SMDT2014 and the MDT model (average of the SSH of the CMEMS model over the reference period).
In all zones, correlation coefficients are higher for the new MDT than for the SMDT2014 and the RMSE is lower.

MDT_MED20 Conclusions

- Reference period : 1993-2012
- MDT represents well the large-scale and mesoscale structures of the Mediterrean Sea.
- Globally **improved performance** compared to SMDT2014 but **with less intense coastal currents** (Algerian current, coastal current at east of Levantin basin and Asia Minor Current).
- Few data for validation in Aegean Sea and off the coast of Libya
- Feedbacks done also by beta users: **Thanks a lot to all of them for their valuable feedbacks !!**

❑ Further improvements needed: **At short scales and in coastal areas**

➢ **Expected available in CMEMS catalogue in Spring 2021**

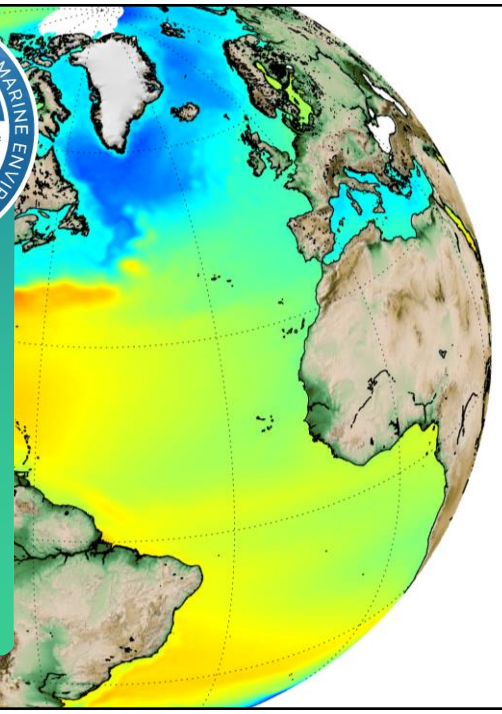
➢ If you are interested to be beta tester, let us know (sjousset@groupcls.com/smulet@groupcls.com)

Thanks !

Do not hesitate to give feedback about these new regional MDTs, feedbacks are always very helpful.

We thank beta users for their valuable feedbacks.

Contact:
sjousset@groupcls.com
smulet@groupcls.com



References

Kubryakov, A. A., and S. V. Stanichny. « Mean Dynamic Topography of the Black Sea, Computed from Altimetry, Drifter Measurements and Hydrology Data ». Ocean Science 7, n° 6 (8 novembre 2011): 745-53. https://doi.org/10.5194/os-7-745-2011.

Menna, M., R. Guerin, A. Bussani, and P.-M. Poulain. « The OGS Mediterranean Drifter Dataset: 1986-2016 », 2017.

Mulet, S., Rio, M. H., Etienne, H., C. Artana, M. Cancet, G. Dibarboure, H. Feng, N. Picot, C. Provost, P.T. Strub (2020). The new CNES-CLS18 Global Mean Dynamic Topography. In preparation.

Rio, M.H., A. Pascual, P.-M. Poulain, M. Menna, B. Barceló-Llull, and Joaquín Tintoré. « Computation of a new mean dynamic topography for the Mediterranean Sea from model outputs, altimeter measurements and oceanographic in situ data », 2014.

Rio, M. H, Mulet, S., Picot, N. (2014). Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry, and in situ data provides new insight into geostrophic and Ekman currents. Geophys. Res.Lett. 41, 8918-8925.508.

Rio, M. H., Guinehut, S., Larnicol, G. (2011). New CNES-CLS09 global mean dynamic topography computed from the combination of GRACE data, altimetry, and in situ measurements. J. Geophys. Res., 116 (C7).

Rio, M. H., and Hernandez, F. (2004). A mean dynamic topography computed over the world ocean from altimetry, in-situ measurements and a geoid model, J. Geophys. Res., 109, C12032, doi:10.1029/2003JC002226.