



Mediterranean Sea Production Centre MEDSEA_ANALYSIS_FORECAST_PHYS_006_013

Issue: 1.2

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Approval date by the CMEMS product quality coordination team: 30/04/19

CHANGE RECORD

When the quality of the products changes, the Quid is updated and a row is added to this table. The third column specifies which sections or sub-sections have been updated. The fourth column should mention the version of the product to which the change applies.

Issue	Date	§	Description of Change	Author	Validated By
1.0	25-09-2017	All	Release of EAS2 version of the Med-Currents analysis and forecast product at 1/24° resolution	E. Clementi , A. Grandi, P. DiPietro, , J. Pistoia, D. Delrosso, G. Mattia	
1.1	18-01-2018	All	Release of EAS3 version of the Med-Currents analysis and forecast product at 1/24° resolution	E. Clementi , A. Grandi, P. DiPietro, , J. Pistoia, D. Delrosso, G. Mattia	
1.2	28-01-2019	All	Release of EAS4 version of the Med-Currents analysis and forecast product at 1/24° resolution	E. Clementi , A. Grandi, R. Escudier, Vladyslav Lyubartsev	Mercator Ocean

TABLE OF CONTENTS

<i>I</i>	<i>Executive summary</i>	<i>4</i>
	<i>I.1 Products covered by this document</i>	<i>4</i>
	<i>I.2 Summary of the results</i>	<i>4</i>
	<i>I.3 Estimated Accuracy Numbers.....</i>	<i>5</i>
<i>II</i>	<i>Production system description</i>	<i>10</i>
	<i>II.1 Description of the Med-Currents EAS4 model system</i>	<i>11</i>
	<i>II.2 New features of the Med-Currents EAS4 system</i>	<i>14</i>
	<i>II.3 Upstream data and boundary condition of the NEMO-3DVAR system</i>	<i>15</i>
<i>III</i>	<i>Validation framework.....</i>	<i>17</i>
	<i>Validation results</i>	<i>24</i>
	<i>III.1 Temperature</i>	<i>24</i>
	<i>III.2 Seabed Temperature.....</i>	<i>32</i>
	<i>III.3 Salinity</i>	<i>35</i>
	<i>III.4 Sea Level Anomaly</i>	<i>41</i>
	<i>III.5 Currents</i>	<i>44</i>
	<i>III.6 Mixed Layer Depth.....</i>	<i>46</i>
<i>IV</i>	<i>System's Noticeable events, outages or changes</i>	<i>49</i>
<i>V</i>	<i>Quality changes since previous version</i>	<i>50</i>
<i>VI</i>	<i>References</i>	<i>51</i>

I EXECUTIVE SUMMARY

I.1 Products covered by this document

The product covered by this document is the MEDSEA_ANALYSIS_FORECAST_PHY_006_013: the analysis and forecast nominal product of the physical component of the Mediterranean Sea with 1/24° (~4.5 km) horizontal resolution and 141 vertical levels.

The variables produced are:

- 3D daily, hourly and monthly mean fields of: Potential Temperature, Salinity, Zonal and Meridional Velocity
- 2D daily, hourly and monthly mean fields of: Sea Surface Height, Mixed Layer Depth, Sea Bed Temperature (temperature of the deepest layer or level)

Product reference:

Clementi E., Pistoia J., Escudier R., Delrosso D., Drudi M., Grandi A., Lecci R., Cretí S., Ciliberti S., Coppini, G. Masina S. & N. Pinardi (2019). *Mediterranean Sea Analysis and Forecast (CMEMS MED-Currents 2016-2019)* (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_ANALYSIS_FORECAST_PHY_006_013_EAS4

I.2 Summary of the results

The quality of the MEDSEA_ANALYSIS_FORECAST_PHY_006_013 analysis and forecast product provided by the EAS4 modeling system, is assessed over 1 year period from 01/01/2017 to 31/12/2017 by means of temperature, salinity, sea level anomaly, sea surface height, currents, seabed temperature and mixed layer depth using independent (for surface currents), quasi-independent satellite and in-situ observations, climatological datasets as well as the inter-comparison with the previous MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product timeseries corresponding to the EAS3 modeling system.

The main results of the MEDSEA_ANALYSIS_FORECAST_PHY_006_013 quality assessment are summarized below:

Sea Surface Height: the EAS4 system presents a similar accuracy in terms of sea surface height representation with respect to the previous version. The quality of the predicted SLA has been assessed by considering the RMS of misfits between the model and the satellite along track observations. The new system presents a SLA skill similar to the one of the previous system with an averaged RMS misfit of about 4cm.

Temperature: the temperature is accurate with an error below 0.8°C when comparing to vertical in-situ observations at surface and below 0.7°C when comparing SST to satellite observations. The accuracy of the temperature along the water column presents higher RMS differences at first layers, which decreases below 60 m. Considering the SST, the RMS differences with respect to satellite

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
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observations vary according to the different areas of the basin, ranging from 0.5°C to 0.7°C. The MED-Currents products usually have a warm SST bias. Med-Currents EAS3 and EAS4 systems exhibit similar skill in terms of surface temperature when comparing with satellite.

Salinity: the salinity is accurate with RMS values lower than 0.19 PSU. The error is higher in the first layers and decreases significantly below 150 m. The EAS3 and EAS4 systems present very similar skill in predicting the salinity.

Currents: Surface currents RMS and bias are evaluated with respect to moored buoys in coastal areas and due to the low number of observations mainly located in coastal areas the statistical relevance of currents performance is poor. In addition to the surface currents validation assessment, a derived validation assessment is provided in terms of transport at Straits including the net, eastward and westward transport through the Strait of Gibraltar showing a good agreement with literature values.

Bottom temperature: the bottom temperature of EAS4 system has been compared to SeaDataNet monthly climatologies showing a good skill in representing the seasonal variability of the temperature at deepest level and a general overestimation with respect to the climatological dataset. The spatial pattern of the seabed temperature is correctly represented by the system.

Mixed Layer Depth: the MLD predicted by EAS4 system has been compared to climatological values from literature (Houpert et al., 2015) showing that the model is able to correctly represent the depth of the mixed layer with spatial and seasonal differences. In general, it can be noticed that the main differences could arise from the low resolution of the climatological dataset that moreover do not cover the whole domain of the Mediterranean Sea.

I.3 Estimated Accuracy Numbers

Estimated Accuracy Numbers (EANs), that are the mean and the RMS of the difference between the model and in-situ or satellite reference observations, are provided in the following table.

EAN are computed for:

- Temperature;
- Salinity;
- Sea Surface Temperature (SST).
- Sea Level Anomaly (SLA)

The observations used are:

- vertical profiles of temperature and salinity from Argo, XBTs and Gliders floats: INSITU_MED_TS_NRT_OBSERVATIONS_013_035
- SST satellite data from Copernicus OSI-TAC product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004
- Satellite Sea Level along track data from Copernicus SL-TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019
SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021

The EANs are evaluated for the EAS3 and EAS4 systems over 1 year period from January to December 2017 and are computed over 9 vertical layers (for temperature and salinity) and for the Mediterranean Sea and 16 sub-regions Figure 1: (1) Alboran Sea, (2) South West Med 1 (western part), (3) North West Med, (4) South West Med 2 (eastern part), (5) Tyrrhenian Sea 2 (southern part), (6) Tyrrhenian Sea 1 (northern part), (7) Ionian Sea 1 (western part), (8) Ionian Sea 2 (south-eastern part), (9) Ionian Sea 2 (north-eastern part), (10) Adriatic Sea 2 (southern part), (11) Adriatic Sea 1 (northern part), (12) Levantine Sea 1 (western part), (13) Aegean Sea, (14) Levantine Sea 2 (central-northern part), (15) Levantine Sea 3 (central southern part), (16) Levantine Sea 4 (eastern part).

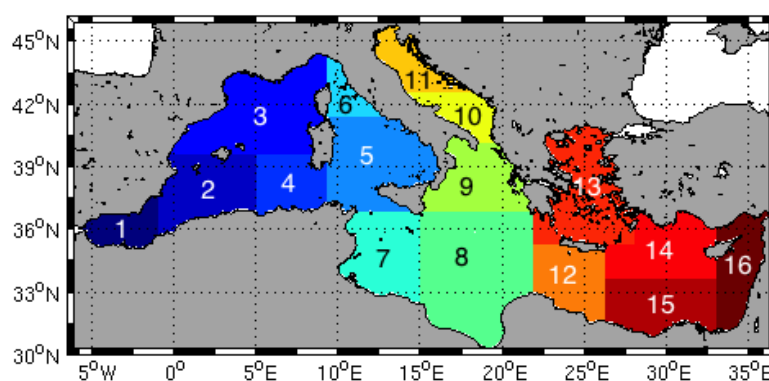


Figure 1. The Mediterranean Sea sub-regions subdivision for validation metrics

EANs of temperature and salinity are then evaluated at 9 different layers: 0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 [m] in order to better verify the model ability to represent the vertical structure of the temperature and salinity fields.

In the following tables the EANs (Mean and RMS Difference) for the EAS4 system are presented:

T prod - T ref [°C]	EAS4 system	
Layer (m)	Mean T-<X-Y>m-D-CLASS4-PROF-BIAS- Jan2017-Dec2017	RMSD T-<X-Y>m-D-CLASS4-PROF-RMSD- Jan2017-Dec2017
0-10	0.04	0.54
10-30	0.01	0.77
30-60	0.08	0.72
60-100	0.05	0.50
100-150	0.02	0.34
150-300	-0.01	0.28
300-600	-0.02	0.23
600-1000	0.01	0.10
1000-2000	-0.01	0.05

Table 1: EANs of temperature at different vertical layers evaluated for EAS4 system for the year 2017: T-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017, T-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017 specified in Table 7:
List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily model observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for 9 different vertical layers: 0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000.
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily model and satellite observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for the entire Mediterranean basin and selected sub-basins.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model and satellite observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for the entire Mediterranean basin and selected sub-basins.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model and satellite observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for the entire Mediterranean basin and selected sub-basins.

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Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
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SST prod – SST ref [°C]	EAS4 system	
REGION	Mean	RMSD
	SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017
MED SEA	0.26	0.59
REGION 1	0.02	0.64
REGION 2	0.13	0.53
REGION 3	0.06	0.59
REGION 4	0.19	0.49
REGION 5	0.41	0.62
REGION 6	0.33	0.59
REGION 7	0.39	0.59
REGION 8	0.26	0.55
REGION 9	0.32	0.58
REGION 10	0.48	0.70
REGION 11	0.38	0.70
REGION 12	-0.03	0.52
REGION 13	0.21	0.59
REGION 14	0.43	0.72
REGION 15	0.23	0.55
REGION 16	0.42	0.63

Table 2: EANs of Sea Surface Temperature evaluated for EAS4 system for the year 2017 for the Mediterranean Sea and 16 regions (see Figure 1): SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017, SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017 specified in Table 7: List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2
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S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily model observations averaged over the period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily model and satellite observations averaged over the period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model and satellite observations averaged over the period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model and satellite observations averaged over the period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.

Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
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S prod – S ref [PSU]	EAS4 system	
Layer (m)	Mean S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	RMSD S-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017
0-10	-0.01	0.2
10-30	-0.02	0.2
30-60	-0.02	0.19
60-100	-0.02	0.16
100-150	-0.01	0.13
150-300	0.00	0.07
300-600	-0.01	0.05
600-1000	-0.02	0.04

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2
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1000-2000	-0.01	0.03
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Table 3: EANs of salinity at different vertical layers evaluated for EAS4 system for year 2017: S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec 2017, S-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec 2017 specified in Table 7: List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily measurements (averaged over Dec 2017). This quantity is evaluated for 9 different depth layers: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily anomalies (averaged over Dec 2017). This quantity is evaluated for 9 different sub-basins: Adriatic, Aegean, Alboran, Balearic, Cretan, Ligurian, Tyrrhenian, Ionian, and Sicilian.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature anomalies (averaged over Dec 2017). This quantity is evaluated for 9 different sub-basins: Adriatic, Aegean, Alboran, Balearic, Cretan, Ligurian, Tyrrhenian, Ionian, and Sicilian.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature anomalies (averaged over Dec 2017). This quantity is evaluated for 9 different sub-basins: Adriatic, Aegean, Alboran, Balearic, Cretan, Ligurian, Tyrrhenian, Ionian, and Sicilian.

Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
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SLA prod – SLA ref [cm]	EAS3 system	EAS4 system
REGION	RMSD SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	RMSD SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017

<p>QUID for MED MFC Product</p> <p>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013</p> <p>Date: 28 January 2019</p> <p>Issue: 1.2</p>
-----------------------------------------------------------------------------	-----------------------------------------------------------------------------------

MED SEA	3.9	3.9
REGION 1	4.3	5.0
REGION 2	4.4	4.1
REGION 3	3.7	3.6
REGION 4	3.8	3.9
REGION 5	3.1	3.1
REGION 6	4.0	3.9
REGION 7	4.6	4.5
REGION 8	4.0	4.2
REGION 9	3.6	3.8
REGION 10	2.3	2.2
REGION 11	NA	NA
REGION 12	4.3	4.4
REGION 13	3.7	3.6
REGION 14	3.6	3.5
REGION 15	4.7	4.7
REGION 16	3.4	3.4

Table 4: EANs of Sea Level evaluated for EAS3 and EAS4 systems for year 2017 for the Mediterranean Sea and 16 regions (see Figure 1): SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec 2017 see Table 7: List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily med observations averaged (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily RMSD from satellite observations (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature RMSD from model and satellite observations (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins: 150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350.

<p>QUID for MED MFC Product</p> <p>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013</p> <p>Date: 28 January 2019</p> <p>Issue: 1.2</p>
-----------------------------------------------------------------------------	-----------------------------------------------------------------------------------

SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature and satellite observation period (Jan-Dec 2017). This quantity is evaluated. The statistics are for selected sub-basins.
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Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
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The metrics of Table 1 and Table 2 give indications about the accuracy of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 temperature variable along the water column and at the surface for the Mediterranean Sea and 16 sub-regions. The values for all the vertical levels are computed using Argo profiles while the SST is evaluated by comparing with satellite observations. The temperature RMS and MEAN values are higher at the first levels and decrease significantly below the fourth layer. The error is always lower than 0.8°C along the water column, while it ranges between 0.49 and 0.72°C considering the SST.

The statistics listed in Table 3 give indications about the accuracy of the MEDSEA_ANALYSIS_FORECAST_PHY_006_013 salinity field. The values for all the levels are computed using Argo profiles. The skill of the system presents a RMS difference always lower than 0.2 PSU with higher error at surface which decreases below 150 m.

The metrics shown in Table 4 define the accuracy of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 sea level anomaly. The statistics are computed along the satellite tracks. The new system presents an overall RMS difference lower than 4 cm in the whole region, while it ranges between 2.2 and 5.0 cm in the different regions. Region 11 presents no data since the SLA data assimilation scheme (using the dynamic height) prevents the assimilation of data in areas shallower than 1000 m.

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
--------------------------------------------------------------------------	----------------------------------	-----------------------------------------------------------

II PRODUCTION SYSTEM DESCRIPTION

Production centre name: CMCC

Production system name: Analysis and Forecast Med-Currents EAS4 system

CMEMS Product name: MEDSEA_ANALYSIS_FORECAST_PHY_006_013

External product: Temperature (3D), Salinity (3D), Meridional and Zonal Currents (3D), Sea Surface Height (2D), Mixed Layer Depth (2D), Seabed Temperature (2D)

Frequency of model output: daily (24-hrs) averages, hourly (1-hr) averages, monthly averages

Geographical coverage: -17.2917°W → 36.29167°E; 30.1875°N → 45.97917°N (Gulf of Biscay is excluded)

Horizontal resolution: 1/24°

Vertical coverage: From surface to 5754 m (141 vertical unevenly spaced levels).

Length of forecast: 10 days for the daily mean fields, 5 days for the hourly mean fields.

Frequency of forecast release: Daily.

Analyses: Yes.

Hindcast: Yes.

Frequency of analysis release: Weekly on Tuesday.

Frequency of hindcast release: Daily.

The Analyses and forecasts physical product of the Med-MFC is produced with two different cycles. The analysis cycle is done weekly, on Tuesday, for the previous 15 days, because a shorter analysis cycle would not allow getting enough observations into the assimilation, for both in situ and satellite data. The forecast cycle is daily and it produces 10-day forecast fields starting each day at 12:00:00 UTC. The forecast is initialized by a background field every day except Tuesday, when an analysis is used. The production chain is illustrated in Figure 2.

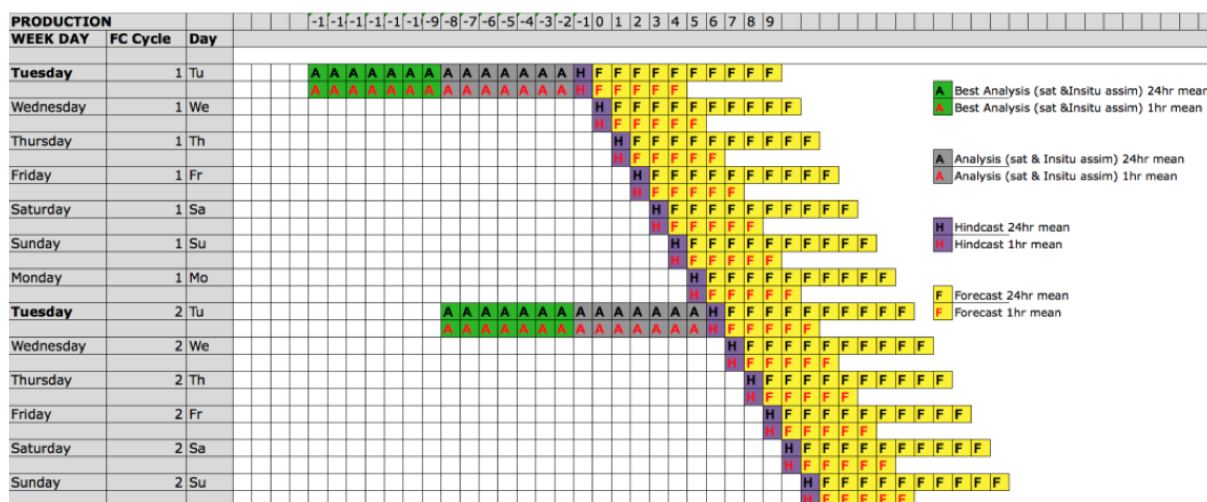


Figure 2: Scheme of the analysis and forecast CMEMS Med-Currents processing chain.

The Med-Currents system run is composed by several steps:

1. Upstream Data Acquisition, Pre-Processing and Control of: ECMWF atmospheric forcing (Numerical Weather Prediction), Satellite (SLA and SST) and in-situ (T and S) data.
2. Forecast/Hindcast: NEMO-WW3 modeling system is run to produce one day of hindcast and 10-day forecast.
3. Analysis/Hindcast (only on Tuesday): NEMO-WW3 modeling system is combined with a 3DVAR assimilation scheme in order to produce the best estimation of the sea (i.e. analysis). The NEMO+WW3+3DVar system is running for 15 days into the past in order to use the best available along track SLA products. The latest day of the 15 days of analyses, produces the initial condition for the 10-day forecast.
4. Post processing: the model output is processed in order to obtain the products for the CMEMS catalogue.
5. Output Delivery.

II.1 Description of the Med-Currents EAS4 model system

The Mediterranean Forecasting System, MFS, (Pinardi et al., 2003, Pinardi and Coppini 2010, Tonani et al., 2014) is providing, since year 2000, analysis and short-term forecast of the main physical parameters in the Mediterranean Sea and it is the physical component of the Med-MFC called Med-Currents.

The analysis and forecast Med-Currents system at CMEMS EAS4 is provided by means of a coupled hydrodynamic-wave model implemented over the whole Mediterranean basin and extended into the Atlantic Sea in order to better resolve the exchanges with the Atlantic Ocean at the Strait of Gibraltar. The model horizontal grid resolution is $1/24^\circ$ (ca. 4.5 km) and has 141 unevenly spaced vertical levels.

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
--------------------------------------------------------------------------	----------------------------------	-----------------------------------------------------------

The hydrodynamics are supplied by the Nucleus for European Modelling of the Ocean (NEMO v3.6) while the wave component is provided by WaveWatch-III. The model solutions are corrected by the variational assimilation (based on a 3DVAR scheme) of temperature and salinity vertical profiles and along track satellite Sea Level Anomaly observations.

Circulation model component (NEMO)

The oceanic equations of motion of Med-currents system are solved by an Ocean General Circulation Model (OGCM) based on NEMO (Nucleus for European Modelling of the Ocean) version 3.6 (Madec et al., 2016). The code is developed and maintained by the NEMO-consortium.

NEMO has been implemented in the Mediterranean at $1/24^\circ \times 1/24^\circ$ horizontal resolution and 141 unevenly spaced vertical levels (Clementi et al., 2017a) with time step of 300sec. The model covers the whole Mediterranean Sea and also extends into the Atlantic in order to better resolve the exchanges with the Atlantic Ocean at the Strait of Gibraltar.

The NEMO code solves the primitive equations using the time-splitting technique that is the external gravity waves are explicitly resolved with non-linear free surface formulation and time-varying vertical z-star coordinates.

The advection scheme for active tracers, temperature and salinity, is a mixed up-stream/MUSCL (Monotonic Upwind Scheme for Conservation Laws; Van Leer, 1979), originally implemented by Estubier and Lévy (2000) and modified by Oddo et al. (2009). The vertical diffusion and viscosity terms are a function of the Richardson number as parameterized by Pacanowsky and Philander (1981).

The model interactively computes air-surface fluxes of momentum, mass, and heat. The bulk formulae implemented are described in Pettenuzzo et al. (2010) and are currently used in the Mediterranean operational system (Tonani et al., 2015). A detailed description of other specific features of the model implementation can be found in Oddo et al. (2009, 2014).

The vertical background viscosity and diffusivity values are set to $1.2\text{e-}6 \text{ [m}^2/\text{s]}$ and $1.0\text{e-}7 \text{ [m}^2/\text{s]}$ respectively, while the horizontal bilaplacian eddy diffusivity and viscosity are set respectively equal to $-1.2\text{e}8 \text{ [m}^4/\text{s]}$ and $-2.\text{e}8 \text{ [m}^4/\text{s]}$. A quadratic bottom drag coefficient with a logarithmic formulation has been used according to Maraldi et al. (2013) and the model uses vertical partial cells to fit the bottom depth shape.

The hydrodynamic model is nested in the Atlantic within the Global analysis and forecast system GLO-MFC daily data set ($1/12^\circ$ horizontal resolution, 50 vertical levels) that is interpolated onto the Med-Currents model grid. Details on the nesting technique and major impacts on the model results are in Oddo et al., 2009.

The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae using the 6-hours (for the first 3 days of forecast a 3-hours temporal resolution is used), $1/8^\circ$ horizontal-resolution operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) and the model predicted surface temperatures (details of the air-sea physics are in Tonani et al., 2008). The water balance is computed as Evaporation minus Precipitation and Runoff. The evaporation is derived from the latent heat flux, precipitation is provided by ECMWF as daily averages, while the runoff of the 39 rivers implemented is provided by monthly mean datasets: the Global Runoff Data Centre dataset (Fekete et al., 1999) for the Po, Ebro, Nile and

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
--------------------------------------------------------------------------	----------------------------------	-----------------------------------------------------------

Rhone rivers; the dataset from Raicich (1996) for: Vjosë, Seman rivers; the UNEP-MAP dataset (Implications of Climate Change for the Albanian Coast, Mediterranean Action Plan, MAP Technical Reports Series No.98., 1996) for the Buna/Bojana river; the PERSEUS dataset for the following 32 rivers: Piave, Tagliamento, Soca/Isonzo, Livenza, Brenta-Bacchiglione, Adige, Lika, Reno, Krka, Arno, Nerveta, Aude, Trebisjnica, Tevere/Tiber, Mati, Volturno, Shkumbini, Struma/Strymonas, Meric/Evros/Maritsa, Axios/Vadar, Arachtos, Pinios, Acheloos, Gediz, Buyuk Menderes, Kopru, Manavgat, Seyhan, Ceyhan, Gosku, Medjerda, Asi/Orontes.

The Dardanelles Strait is implemented as a lateral open boundary condition by using GLO-MFC daily Analysis and Forecast product and daily climatology derived from a Marmara Sea box model (Maderich et al., 2015); while in the previous modeling version EAS3, it was considered as volume input (Kourafalou and Barbopoulos, 2003) through a river-like parameterization.

The topography is created starting from the GEBCO 30arc-second grid (http://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/), filtered (using a Shapiro filter) and manually modified in critical areas such as: islands along the Eastern Adriatic coasts, Gibraltar and Messina straits, Atlantic box edge.

Wave model component (WW3)

The Wave dynamic is solved by a Mediterranean implementation of the WaveWatch-III (WW3) code version 3.14 (Tolman, 2009). WaveWatch covers the same domain and follows the same horizontal discretization of the circulation model ($1/24^\circ \times 1/24^\circ$) with a time step of 300 sec. The wave model uses 24 directional bins (15° directional resolution) and 30 frequency bins (ranging between 0.05 Hz and 0.7931 Hz) to represent the wave spectral distribution.

WW3 has been forced by the same $1/8^\circ$ horizontal resolution ECMWF atmospheric forcings (the same used to force the hydrodynamic model). The wind speed is then modified by considering a stability parameter depending on the air-sea temperature difference according to Tolman (2002).

The wave model takes into consideration the surface currents for wave refraction but assumes no interactions with the ocean bottom. WW3 model solves the wave action balance equation that describes the evolution, in slowly varying depth domain and currents, of a 2D ocean wave spectrum where individual spectral component satisfies locally the linear wave theory. In the present application WW3 has been implemented following WAM cycle4 model physics (Gunther et al., 1993). Wind input and dissipation terms are based on Janssen's quasi-linear theory of wind-wave generation (Janssen, 1989, 1991). The dissipation term is based on Hasselmann (1974) whitecapping theory according to Komen et al. (1984). The non-linear wave-wave interaction is modelled using the Discrete Interaction Approximation (DIA, Hasselmann et al., 1985). No interactions with the ocean bottom are considered.

Model coupling (NEMO-WW3)

The coupling between the hydrodynamic model (NEMO) and the wave model (WW3) is achieved by an online hourly two-way coupling and consists in exchanging the following fields: NEMO sends to WW3 the air-sea temperature difference and the surface currents, while WW3 sends to NEMO the neutral drag coefficient used to evaluate the surface wind stress.

More details on the model coupling and on the impact of coupled system on both wave and circulation fields can be found in Clementi et al. (2017b).

Data Assimilation scheme

The data assimilation system is the 3DVAR scheme developed by Dobricic and Pinardi (2008) and modified by Storto et al. (2015). The background error correlation matrices vary monthly for each grid point in the discretized domain of the Mediterranean Sea. Observational error covariance matrix is evaluated with Desroziers et al. (2005) relationship. EOFs have been evaluated from a three years simulation run (in the future a new set of EOFs will be evaluated from an analysis run).

The assimilated data include: along track Sea Level Anomaly (a satellite product accounting for atmospheric pressure effect is used, as specified in II.3) from CLS SL-TAC, and in-situ vertical temperature and salinity profiles from VOS XBTs (Voluntary Observing Ship-eXpandable Bathythermograph) and ARGO floats. Objective Analyses-Sea Surface Temperature (OA-SST) fields from CNR-ISA OSI-TAC are used for the correction of surface heat fluxes with the relaxation constant of $110 \text{ W m}^{-2} \text{ K}^{-1}$ applied close to midnight (in the previous system EAS3 the relaxation was performed during the whole day using a relaxation constant of $40 \text{ W m}^{-2} \text{ K}^{-1}$) since the observed dataset corresponds to the foundation SST (\sim SST at midnight).

II.2 New features of the Med-Currents EAS4 system

The main differences between the CMEMS Med-Currents EAS3 and EAS4 systems are summarized in Table 5 and described hereafter.

	CMEMS Med-Currents EAS3	CMEMS Med-Currents EAS4
Dardanelles Strait	Closed using a river-like parameterization with climatological fields	Lateral open boundary forced with daily fields
SST nudging	Relaxation during the whole day with a relaxation constant of $40 \text{ W m}^{-2} \text{ K}^{-1}$	Relaxation close to midnight with a relaxation constant of $110 \text{ W m}^{-2} \text{ K}^{-1}$

Table 5: Differences between CMEMS Med-Currents EAS3 and EAS4 systems.

The main differences between CMEMS EAS3 and CMEMS EAS4 are:

- Improvement in the SST nudging: In the EAS3 previous modeling system an SST nudging toward observed satellite SST was applied on the atmospheric heat flux at each timestep over the whole day. However, the observed dataset corresponds to the foundation SST or the SST at midnight, meaning that the model was relaxed toward midnight SST during the whole day. This might reduce the daily cycle of SST, especially in summer when it is strong. Indeed, the first layer of the model is 1 meter deep which is much shallower than the 5 meters depth of the foundation SST. With low winds, this could mean $0.5\text{-}1^\circ\text{C}$ difference (Donlon et al, 2002). A modified SST relaxation has been implemented in EAS4 which is applied at the observation

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
--------------------------------------------------------------------------	----------------------------------	-----------------------------------------------------------

time (midnight for our observation of SST) with a modified relaxation coefficient (from 40 to $110 \text{ Wm}^{-2}\text{K}^{-1}$).

- Implementation of the Dardanelles strait as a lateral open boundary condition: The Mediterranean Sea ocean numerical model is forced by a water inflow from the Marmara Sea through the Dardanelles strait which, until EAS3 modeling version, it was implemented as a Surface Boundary Condition (SBC) through a river-like parameterization using climatological inflow volume flux and a climatological inflow salinity, both from Kourafalou et al. (2003). In order to better represent this crucial forcing of the Mediterranean Sea circulation a modified implementation of the Dardanelles Strait as Later Open Boundary Condition (LOBC) is provided and forced with CMEMS GLO-PHY Analysis and forecast daily fields (temperature and sea level), and Maderich et al. (2015) daily climatological velocity and salinity dataset.

II.3 Upstream data and boundary condition of the NEMO-3DVAR system

The CMEMS MED-Currents system uses the following upstream data:

1. Atmospheric forcing (including precipitation): NWP 6-h (3-h for the first 3 days of forecast), 0.125° horizontal-resolution operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) distributed by the Italian National Meteo Service (USAM/CNMA)
2. Runoff: Global Runoff Data Centre dataset (Fekete et al., 1999) for Po, Ebro, Nile and Rhone, the dataset from Raicich (Raicich, 1996) for the Adriatic rivers Vjosë and Seman; the UNEP-MAP dataset (Implications of Climate Change for the Albanian Coast, Mediterranean Action Plan, MAP Technical Reports Series No.98., 1996) for the Buna/Bojana river; the PERSEUS project dataset for the new 32 rivers added.
3. Data assimilation:
 - Temperature and Salinity vertical profiles from Copernicus INSITU TAC
 - INSITU_MED_NRT_OBSERVATIONS_013_035
 - Satellite along track Sea Level Anomaly from Copernicus SL TAC:
 - SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021 (till 29th March 2017)
 - SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 (till 30th March 2017)
 - SEALEVEL_MED_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_048 (from 1st June 2017).
 - SEALEVEL_EUR_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_043 (from May 2019)
 - Satellite SST from Copernicus OSI TAC (nudging):
 - SST_MED_SST_L4_NRT_OBSERVATIONS_010_004

<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: Date: Issue:</p>	<p>CMEMS-MED-QUID-006-013 28 January 2019 1.2</p>
--------------------------------------------------------------------------	----------------------------------	-----------------------------------------------------------

4. Initial conditions of temperature and salinity at 1/1/2016 are the winter climatological fields from WOA13 V2 (World Ocean Atlas 2013 V2, <https://www.nodc.noaa.gov/OC5/woa13/woa13data.html>)
5. Lateral boundary conditions from Copernicus Global Analysis and Forecast system: GLOBAL_ANALYSIS_FORECAST_PHY_001_024 at 1/12° horizontal resolution, 50 vertical levels. In particular for the lateral boundary conditions in the Atlantic Ocean, the following conditions are considered:
 1. The radiative phase velocity (Cx and Cy) is computed at the open boundaries using Orlanski (NPO) formulation with adaptative nudging for baroclinic velocities and tracers (Marchesiello et al., 2001).
 2. The radiation algorithm is applied to zonal and meridional components of the open boundary conditions velocities using the phase velocities computed at point 1
 3. The Flather boundary condition (Flather, 1976) is applied to barotropic velocities at open boundaries for the time-splitting free surface case
 4. The total velocities are updated on the basis of point 2 and 3
 5. For tracers the 2D radiation condition is applied using radiative phase velocity computed at point 1

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2
------------------------------------------------------------------	--------------------------------------------------------------------

III VALIDATION FRAMEWORK

In order to evaluate and assure the quality of the MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product, an assimilation experiment has been performed using the system described in section II, which is going to be operational starting in April 2019, and covering 3 years from January 2016 to December 2018 (the period from January to December 2016 is considered as a spin-up time).

In particular the qualification task has been carried out over 1 year period, from January to December 2017, based on Class 1 and 4 diagnostics.

The performance of the Med-Currents EAS4 system has been assessed by using external products, i.e. temperature, salinity, sea level anomaly using independent coastal moorings, quasi-independent satellite and in-situ observations, moreover climatological datasets have been used to assess the quality of the seabed temperature and mixed layer depth.

Quasi-independent data are all the observations (Satellite SLA and SST and in situ vertical profiles of temperature and salinity from XBT and Argo) which are assimilated into the system. Diagnostic in terms of RMS of the misfits and/or bias are computed.

The datasets of observations used for the qualification task are listed below in Table 6 presenting the lists of the used quasi-independent data with the corresponding CMEMS product names.

QUASI-INDEPENDENT DATA	
TYPE	CMEMS PRODUCT NAME
ARGO, XBT GLIDER	INSITU_MED_NRT_OBSERVATIONS_013_035
SLA	SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021 (till 29th March 2017) SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 (till 29th March 2017) SEALEVEL_MED_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_048 (from 30th March 2017) SEALEVEL_EUR_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_043 (from May 2019)
SST	SST_MED_SST_L4_NRT_OBSERVATIONS_010_004_a

Table 6: list of the quasi-independent observations

The list of metrics used to provide an overall assessment of the product, to quantify the differences with the available observations and to assess the improvements with respect to the previous system (CMEMS EAS3) is presented in Table 7: List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2
------------------------------------------------------------------	--------------------------------------------------------------------

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily model observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins (150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350).
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily model observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins (150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350).
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins (150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350).
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily model observations averaged over the testing period (Jan-Dec 2017). This quantity is evaluated for 9 different sub-basins (150, 150-300, 300-450, 450-600, 600-750, 750-900, 900-1050, 1050-1200, 1200-1350).

Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
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<p>QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2</p>
--------------------------------------------------------------------------	-----------------------------------------------------------------------------

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
T-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	<p>Temperature daily RMSs of the difference between model and insitu observations averaged over the qualification testing period (Jan-Dec 2017).</p> <p>This quantity is evaluated on the model analysis.</p> <p>The statistics are defined for all the Mediterranean Sea and are evaluated for 9 different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)</p>
T-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	<p>Temperature daily mean differences between model and insitu observations averaged over the qualification testing period (Jan-Dec 2017).</p> <p>This quantity is evaluated on the model analysis.</p> <p>The statistics are defined for all the Mediterranean Sea and are evaluated for 9 different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)</p>
S-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	<p>Salinity daily RMSs of the difference between model and insitu observations averaged over the qualification testing period (Jan-Dec 2017).</p> <p>This quantity is evaluated on the model analysis.</p> <p>The statistics are defined for all the Mediterranean Sea and are evaluated for 9 different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)</p>

Table 7: List of metrics for Med-Currents evaluation using in-situ and satellite observation (continues overleaf).

<p>QUID for MED MFC Product</p> <p>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013</p> <p>Date: 28 January 2019</p> <p>Issue: 1.2</p>
-----------------------------------------------------------------------------	-----------------------------------------------------------------------------------

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
S-<X-Y>m-D-CLASS4-PROF-BIAS-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily mean differences between model and insitu observations averaged over the qualification testing period (Jan-Dec 2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for 9 different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin and selected sub-basins.	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Sea level daily RMSs of the difference between model and satellite observations averaged over the qualification testing period (Jan-Dec 2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and 16 selected sub-basins.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily RMSs of the difference between model and satellite observations averaged over the qualification testing period (Jan-Dec 2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and 16 selected sub-basins.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin and selected sub-basins.	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Sea surface temperature daily mean differences between model and satellite observations averaged over the qualification testing period (Jan-Dec 2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and 16 selected sub-basins.

Table 8: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data. Daily comparison				
T-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of temperature daily RMSs of the difference between model and insitu observations evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for seven different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)
S-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2017-Dec2017	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 9 layers for the Mediterranean basin	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of salinity daily RMSs of the difference between model and insitu observations evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for seven different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m)
SLA-D-CLASS4-ALT-RMSD-Jan2017-Dec2017	Sea level anomaly comparison with Copernicus Sea Level TAC (satellite along track) data for the Mediterranean basin	Sea Level Anomaly	Satellite Sea Level along track data from Copernicus Sea Level TAC product: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Time series of sea level anomaly daily RMSs of the difference between model and satellite observations evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea.
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Time series of sea surface temperature daily RMSs of the difference between model and satellite observations evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Time series of sea surface temperature daily BIAS (difference between model and satellite observations) evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea.

Table 9: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

<p>QUID for MED MFC Product</p> <p>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013</p> <p>Date: 28 January 2019</p> <p>Issue: 1.2</p>
-----------------------------------------------------------------------------	-----------------------------------------------------------------------------------

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data. Daily comparison				
SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Time series of sea surface temperature daily RMSs of the difference between model and satellite observations evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea.
SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4 (satellite) data for the Mediterranean basin	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Time series of sea surface temperature daily BIAS (difference between model and satellite observations) evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea.

Table 10: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

<p>QUID for MED MFC Product</p> <p>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</p>	<p>Ref: CMEMS-MED-QUID-006-013</p> <p>Date: 28 January 2019</p> <p>Issue: 1.2</p>
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Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data. Weekly comparison of misfits				
T-<X-Y>m-W-CLASS4- PROF-RMSD-MED- Jan2017-Dec 2017	Temperature vertical profiles comparison with assimilated Copernicus INSITU TAC data at 5 specified depths.	Temperature	Argo floats, Gliders and XBT from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of weekly RMSs of temperature misfits (observation minus model value transformed at the observation location and time). Together with the time series, the average value of weekly RMSs is evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated at five different depths: 8, 30, 150, 300 and 600 m.
S-<X-Y>m-W-CLASS4- PROF-RMSD-MED- Jan2017-Dec 2017	Salinity vertical profiles comparison with assimilated Copernicus INSITU TAC data at 5 specified depths.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of weekly RMSs of salinity misfits (observation minus model value transformed at the observation location and time). Together with the time series, the average value of weekly RMSs is evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated at five different depths: 8, 30, 150, 300 and 600 m.
SLA-SURF-W-CLASS4- ALT-RMSD-MED- Jan2017-Dec 2017	Sea level anomaly comparison with assimilated Copernicus Sea Level TAC satellite along track data for the Mediterranean basin.	Sea Level Anomaly	Satellites (Jason2, Jason2N, Jason3, CryoSat-2, Saral/Altika) Sea Level along track data from Copernicus Sea Level TAC products: SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021	Time series of weekly RMSs of sea level anomaly misfits (observation minus model value transformed at the observation location and time). Together with the time series, the average value of weekly RMSs is evaluated over the qualification testing period (2017). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for the different assimilated satellites.

Table 11: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation.

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: CMEMS-MED-QUID-006-013 Date: 28 January 2019 Issue: 1.2
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Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using independent data. Daily comparison with moored buoys				
UV-SURF-D-CLASS2-MOOR-RMSD-Jan2017-Dec2017	Surface currents comparison with Copernicus INSITU TAC	Currents	Moored buoys from Copernicus InSitu TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of daily sea surface currents of insitu observations and model outputs evaluated over the qualification testing period. Together with the time series, the average value of daily RMSs is evaluated over the qualification testing period. This quantity is evaluated on the model analysis.
UV-SURF-D-CLASS2-MOOR-BIAS-Jan2017-Dec2017	Surface currents comparison with Copernicus INSITU TAC	Currents	Moored buoys from Copernicus InSitu TAC products: INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of daily sea surface currents of insitu observations and model outputs evaluated over the qualification testing period. Together with the time series, the average value of daily bias is evaluated over the qualification testing period. This quantity is evaluated on the model analysis.
NRT evaluation of Med-MFC-Currents using Climatological dataset				
MLD-D-CLASS1-CLIM-MEAN_M-MED	Mixed Layer Depth comparison with climatology from literature in the Mediterranean Sea	Mixed Layer Depth	Monthly climatology from literature (Houpert et al., 2015)	Comparison of climatological maps form model outputs and a climatological dataset (Houpert et al., 2015)
SBT-D-CLASS4-CLIM-MEAN_M-MED	SeaBed Temperature comparison with a climatological dataset in the Mediterranean Sea	Sea Bottom Temperature	SeaDataNet EAS4 climatological datasets	Time series of monthly mean Sea Bottom Temperature from model outputs and SeaDataNetEAS4 climatologies. The time series are presented for the entire basin, for the area with topography < 500m and for the areas with topography < 1500m
SBT-D-CLASS1-CLIM-MEAN_M-MED	SeaBed Temperature comparison with a climatological dataset in the Mediterranean Sea	Sea Bottom Temperature	SeaDataNet EAS4 climatological datasets	Comparison of climatological maps form model outputs and SeaDataNetEAS4 climatologies for the area with topography < 1500m

Table 12: (continued) List of metrics for Med-Currents evaluation using in-situ and satellite observation

VALIDATION RESULTS

In this section the results of the validation task are presented in terms of: Temperature (including SST), Sea Bed Temperature, Salinity, Sea Level Anomaly, Sea Surface Height, Currents (in terms of transport at straits), and Mixed Layer Depth.

III.1 Temperature

In the following table are synthesised the values of the temperature Root Mean Square (RMS) differences and Bias calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product with quasi-independent data assimilated by the system (ARGO, CTD, /XBT and Satellite SST). The synthesis is based on 1 year period (2017) validation and provided at 5 depths (8, 30, 150, 300, 600 m) showing that the larger error is achieved at 30 m depth while below it is lower than 0.3°C.

Variables/estimated accuracy:	Metrics		Depth	Observation
SEA SURFACE TEMPERATURE (°C)	RMS Diff	BIAS		
	0.59±0.11	0.26±0.11	0	Satellite SST
TEMPERATURE (°C):	RMS Diff		Depth	Observation
	0.53±0.21		8	Argo
	0.74±0.43		30	Argo
	0.26±0.06		150	Argo
	0.20±0.03		300	Argo
	0.10±0.01		600	Argo
	0.35±0.34		8	XBT
	0.34±0.41		30	XBT
	0.28±0.22		150	XBT
	0.18±0.09		300	XBT
	0.17±0.03		600	XBT

Table 13: Quasi-independent validation. Analysis evaluation based over year 2017.

Figure 3 shows the time series of weekly RMSs of temperature misfits (observation minus model value transformed at the observation location and time before being assimilated) at 5 depths (8, 30, 150, 300, 600 m), T-<X-Y>m-W-CLASS4-PROF-RMSD-MED-Jan2017-Dec2017, for the CMEMS Med-MFC-currents EAS3 system (red line) and the EAS4 system (blue line); the values of the mean RMS difference are reported in the legend of the figures; the number of observed profiles are represented in shaded coloured areas.

The new system presents almost the same temperature skill with respect to EAS3 system. The temperature error is generally higher at depth around 30 m and has a better skill below 150 m. It presents a seasonal variability at first layers with higher values during warm seasons.

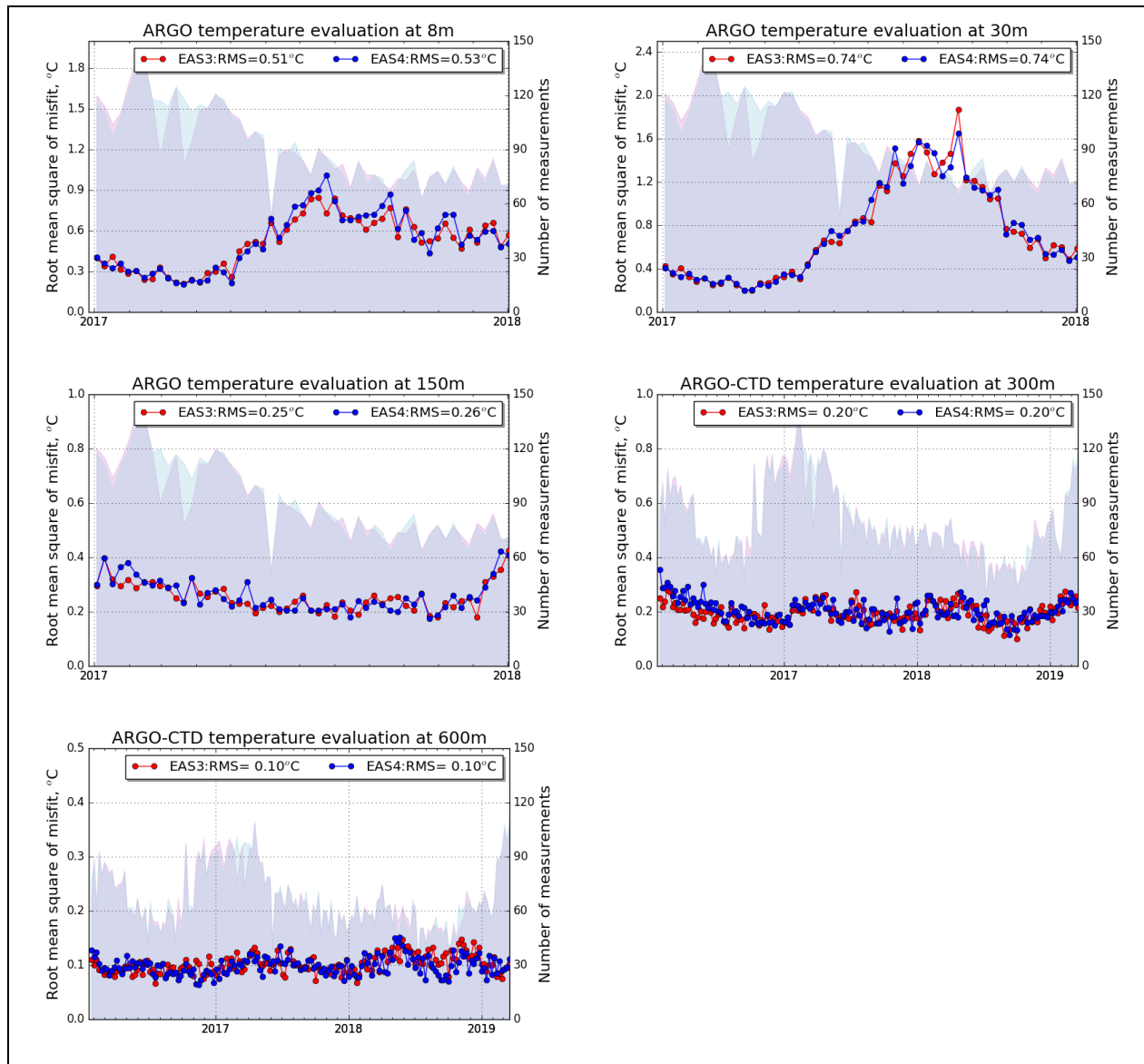


Figure 3: Time series of weekly RMS misfit of temperature (solid lines) and number of observed profiles (shaded area) at 8, 30, 150, 300 and 600 m (T-<X-Y>m-W-CLASS4-PROF-RMS-MED-Jan2017-Dec 2017)

Monthly mean RMS misfits of temperature for EAS3 and EAS4 systems are represented in the following (Depth-Time) Hovmoller diagrams (Figure 4) along the water column between surface and 900 m showing the vertical pattern of the error averaged in the whole Mediterranean Sea. Both systems present higher errors during summer-autumn seasons between 30-60 m depth, with a slightly increased skill in case of the EAS4 new system.

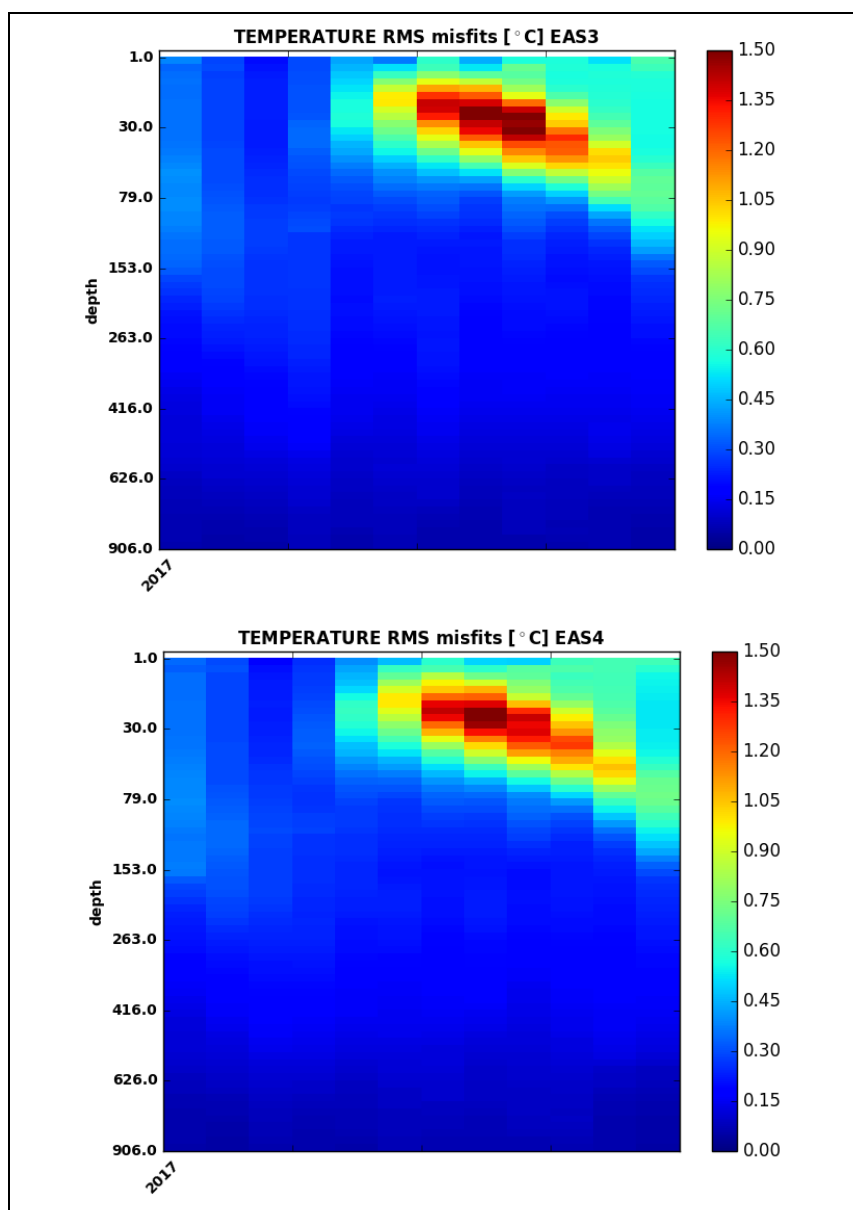


Figure 4: Hovmoller (Depth-Time) diagram of monthly mean RMS misfits of temperature along the water column averaged in the whole Mediterranean Sea during 2017. Top: EAS3; bottom: EAS4.

In addition to basin averaged statistics, the following panels in Figure 5 show the spatial pattern of the temperature RMS misfits for EAS4 system averaged over the entire qualification period (2017) at several depths (8, 30, 150, 300 and 600 m) with respect to ARGO data. The bottom right panel shows the number of data used for this analysis.

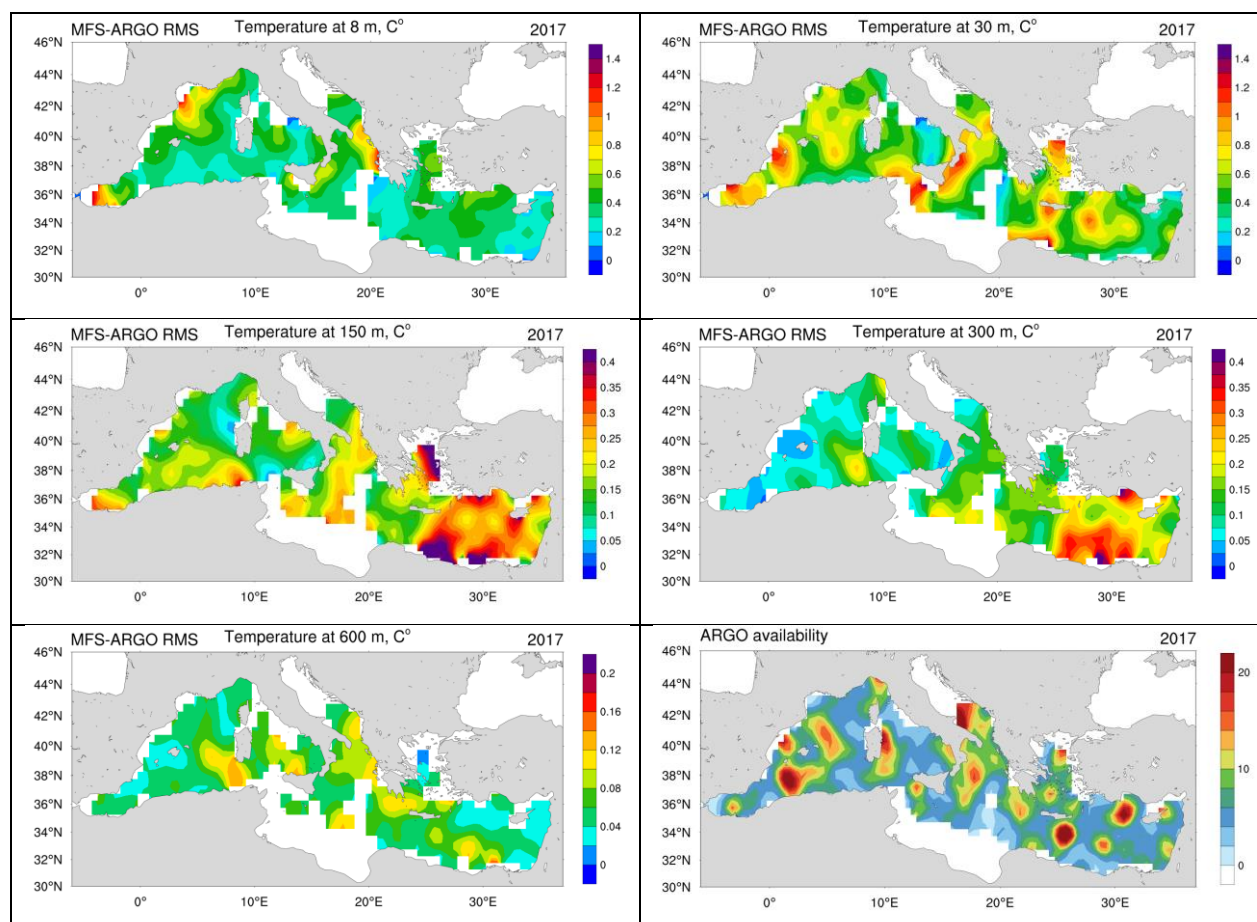


Figure 5: Maps of temperature RMS misfits for EAS4 system averaged in the entire qualification period (2017) at several depths (8, 30, 150, 300 and 600 m) with respect to ARGO data. The bottom right panel shows the number of data used for this analysis.

The following panels in **Erreur ! Source du renvoi introuvable.** show the time series of temperature daily RMS differences between model outputs and observations evaluated over the qualification period (2017). The statistics are evaluated for nine different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m): T-<X-Y>m-D-CLASS4-RMSD-MED-Jan2017-Dec 2017.

The differences between EAS3 and EAS4 systems are negligible. The average value of RMS over the entire period is the one listed in Table 1. The temperature error is generally higher above 100 m and presents a clear seasonal variability with higher values during warm seasons, then the error decreases significantly below 100 m and at lower levels.

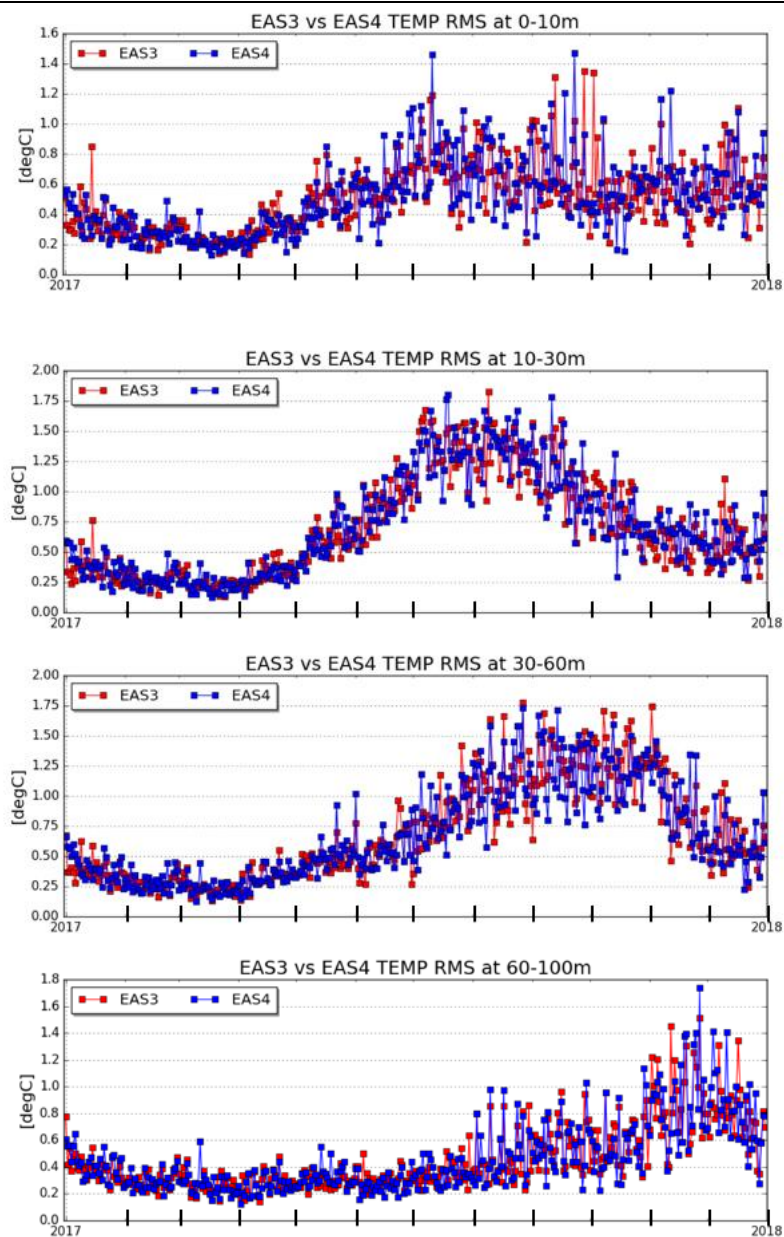


Figure 6: Time series of daily RMS of temperature at different vertical layers for EAS3 (red line) and EAS4 (blue line) systems (T-<X-Y>m-D-CLASS4-RMSD-MED-Jan2017-Dec2017) (continues overleaf).

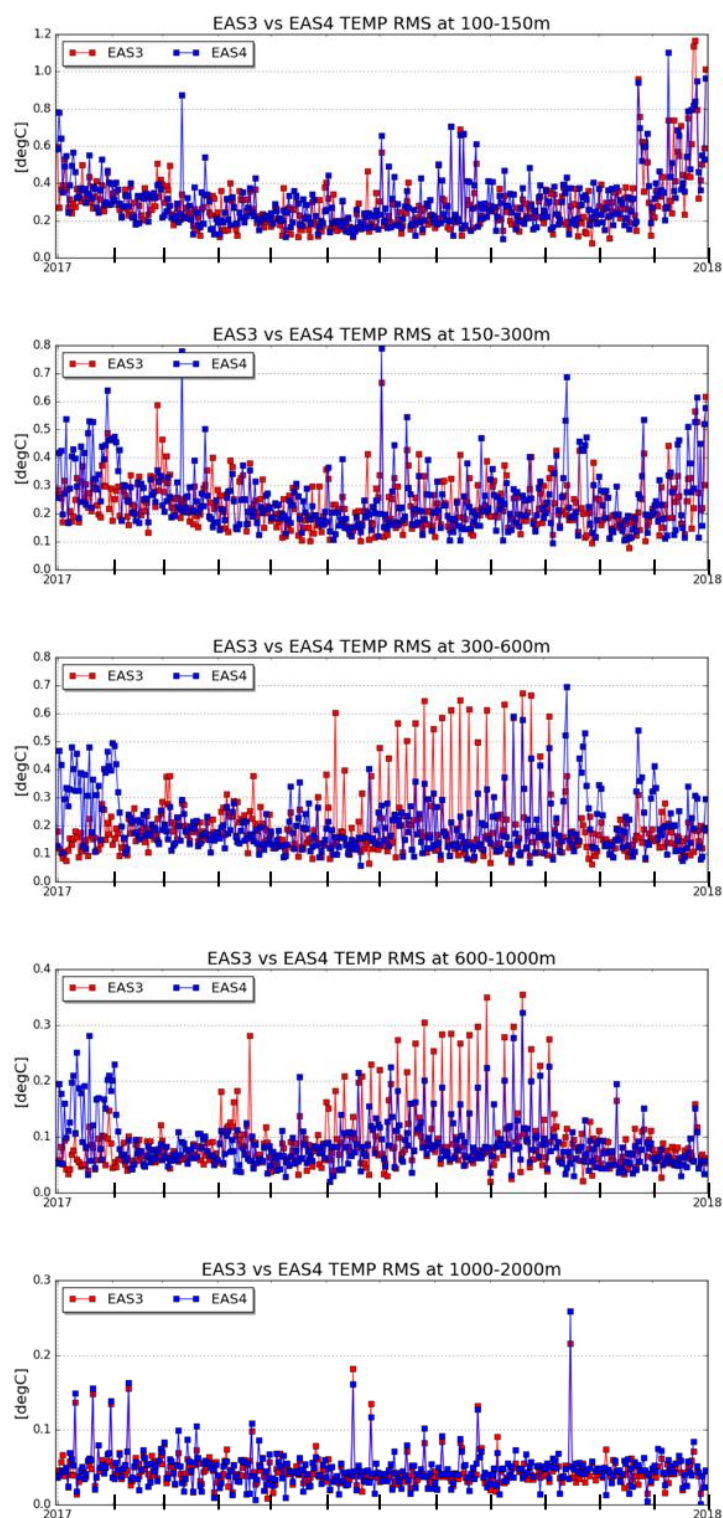


Figure 7: (continued) Time series of daily RMS of temperature at different vertical layers for EAS3 (red line) and EAS4 (blue line) systems (T-<X-Y>m-D-CLASS4-RMSD-MED-Jan2017-Dec2017).

Figure 8 shows the time series of Sea Surface Temperature daily RMS difference (top) and BIAS (bottom) between daily model outputs and observations (L4 satellite SST at 1/16 degree resolution) evaluated over the qualification testing period (Jan-Dec 2017): SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017 and SST-D-CLASS4-RAD-BIAS-Jan2017-Dec2017.

The EAS3 and EAS4 systems show similar performance. In general, the SST RMS is higher during warm periods and autumn while it decreases in April and the SST Bias is generally negative meaning that the models have lower SST with respect to the observations.

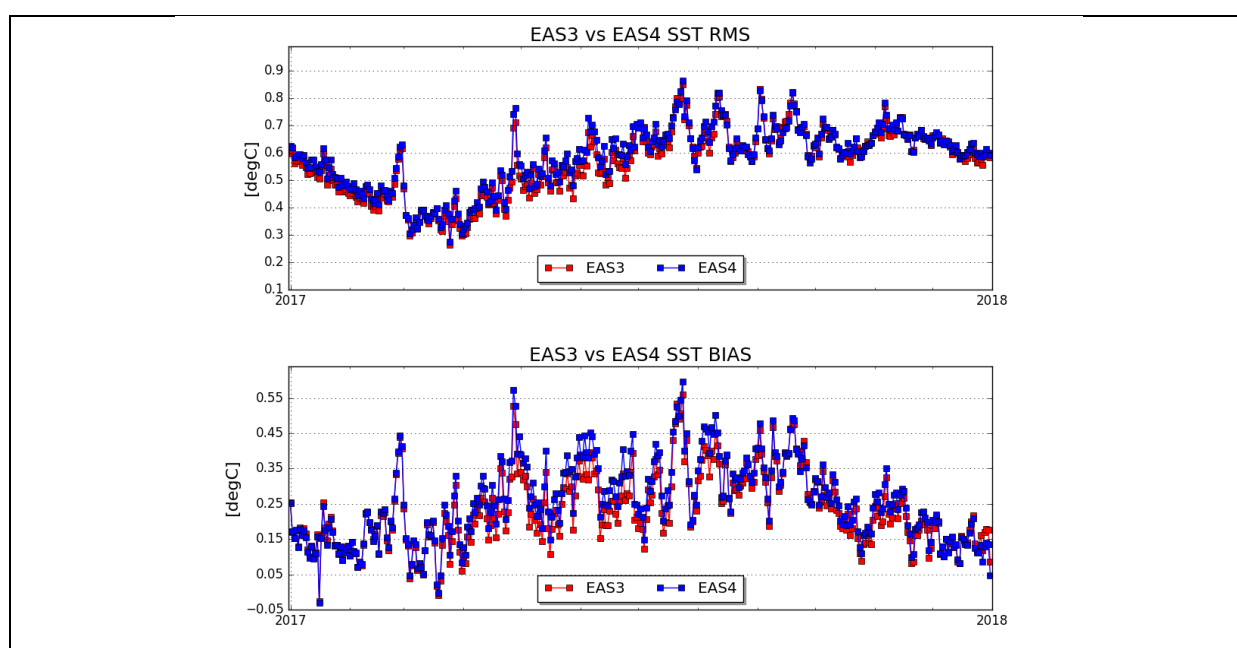


Figure 8: Time series of daily RMS difference (top) and Bias (bottom) of Sea Surface Temperature for EAS3 and EAS4 systems (SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017, SST-D-CLASS4-RAD-RMSD-Jan2017-Dec2017) with respect to satellite L4 data at 1/16 degree resolution.

In order to check the quality of midnight SST, hourly model outputs evaluated at midnight have been compared to Satellite SST and presented in Figure 9 showing time series of bias for EAS3 and EAS4 as well as in Figure 10 showing the map of EAS4 BIAS averaged in 2017.

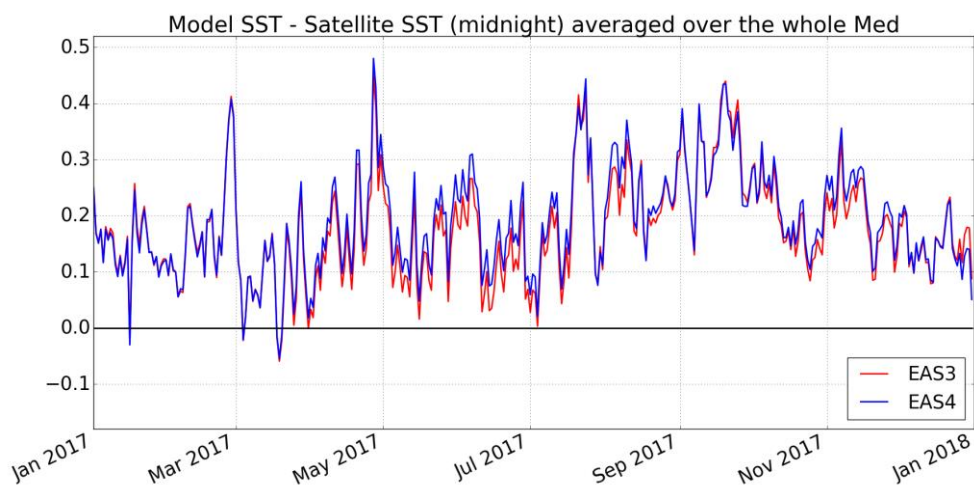


Figure 9: Time series of midnight SST model bias with respect to satellite SST for EAS3 (red line) and EAS4 (blue line)

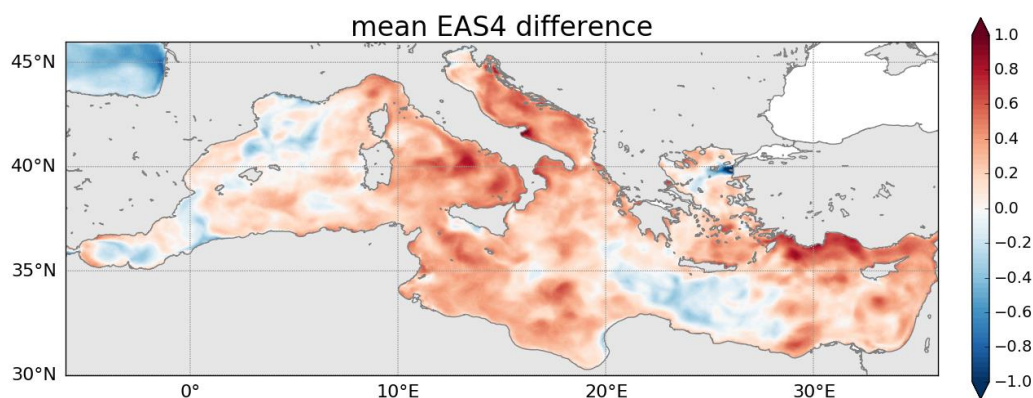


Figure 10: Map of midnight SST bias between EAS4 and satellite averaged for the year 2017.

III.2 Seabed Temperature

The bottom temperature, that is the temperature of the deepest level of the circulation model, has been compared to SeaDataNet dataset (see Tonani et al., 2013 for more details) for the year 2017.

Figure 10 shows the time series of the monthly climatological dataset (green line), EAS3 system (red line) and EAS4 system (blue line) evaluated as monthly averages for the year 2017. The left panel shows the climatological time series of seabed temperature at depths included between [0-500] m, while the right panel shows the comparison at depths included between [0-1500] m. It can be seen that the 2 systems provide very similar values and are able to reproduce the seasonal variability of the bottom temperature that is generally overestimated by the models with respect to the climatological dataset.

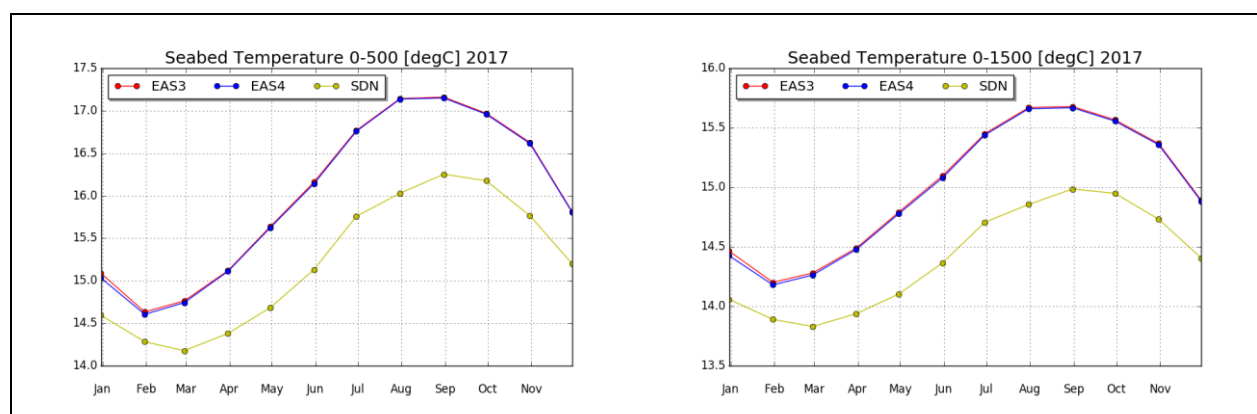


Figure 11: Time series of seabed temperature monthly climatologies from SeaDataNet dataset (green line), EAS3 system (red line) and EAS4 system (blue line): SBT-D-CLASS4-CLIM-MEAN_M-MED.

The following figures show the January (Figure 12), April (Figure 13), July (Figure 14) and October (Figure 15) monthly mean Seabed temperature in areas with topography included between 0 and 1500 m from SDN dataset (top), and corresponding monthly averages for Med-Currents EAS3 system (bottom-left), Med-Currents EAS4 system (bottom-right) evaluated for the year 2017. The two numerical systems exhibit similar temporal and spatial patterns compared to the climatological datasets. The main differences are related to warmer seabed temperature along the Tunisian and Libyan coasts predicted by the models with respect to both climatological datasets.

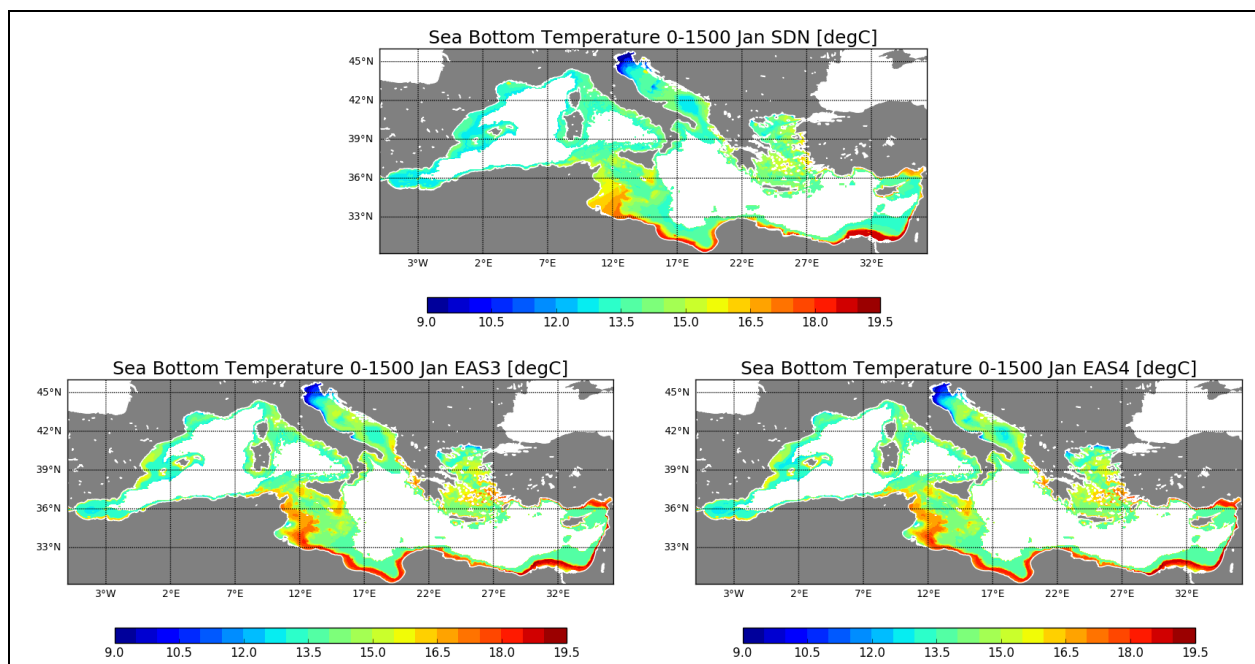


Figure 12: January Seabed temperature 2D maps in areas with topography lower than 1500 m: SDN climatologies (top), monthly average Med-Currents EAS3 system (bottom-left), monthly average Med-Currents EAS4 system (bottom-right): SBT-D-CLASS1-CLIM-MEAN_M-MED.

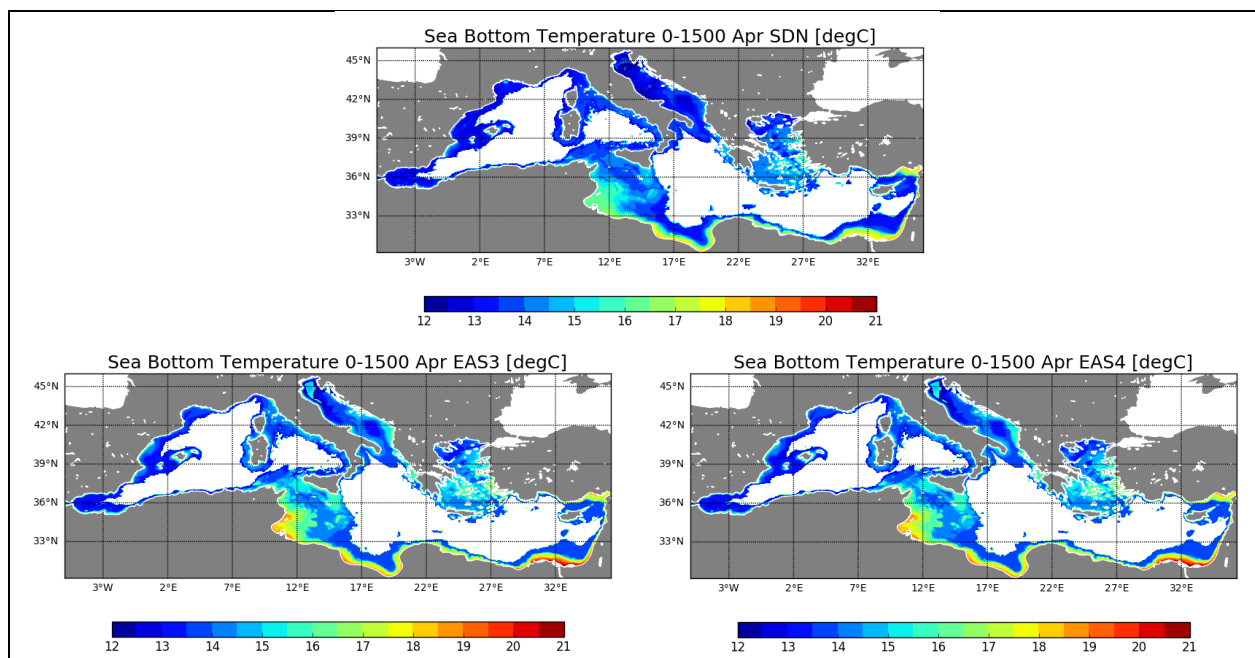


Figure 13: April Seabed temperature 2D maps in areas with topography lower than 1500 m: SDN climatologies (top), monthly average Med-Currents EAS3 system (bottom-left), monthly average Med-Currents EAS4 system (bottom-right): SBT-D-CLASS1-CLIM-MEAN_M-MED.

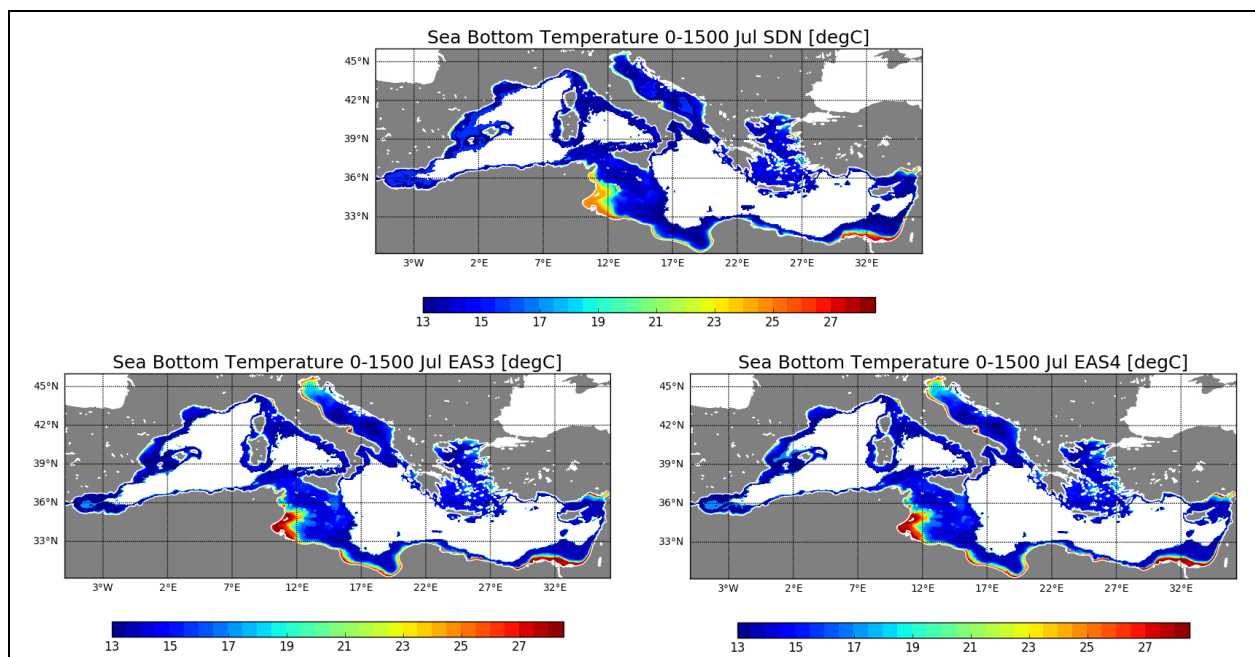


Figure 14: July Seabed temperature 2D maps in areas with topography lower than 1500 m: SDN climatologies (top), monthly average Med-Currents EAS3 system (bottom-left), monthly average Med-Currents EAS4 system (bottom-right): SBT-D-CLASS1-CLIM-MEAN_M-MED.

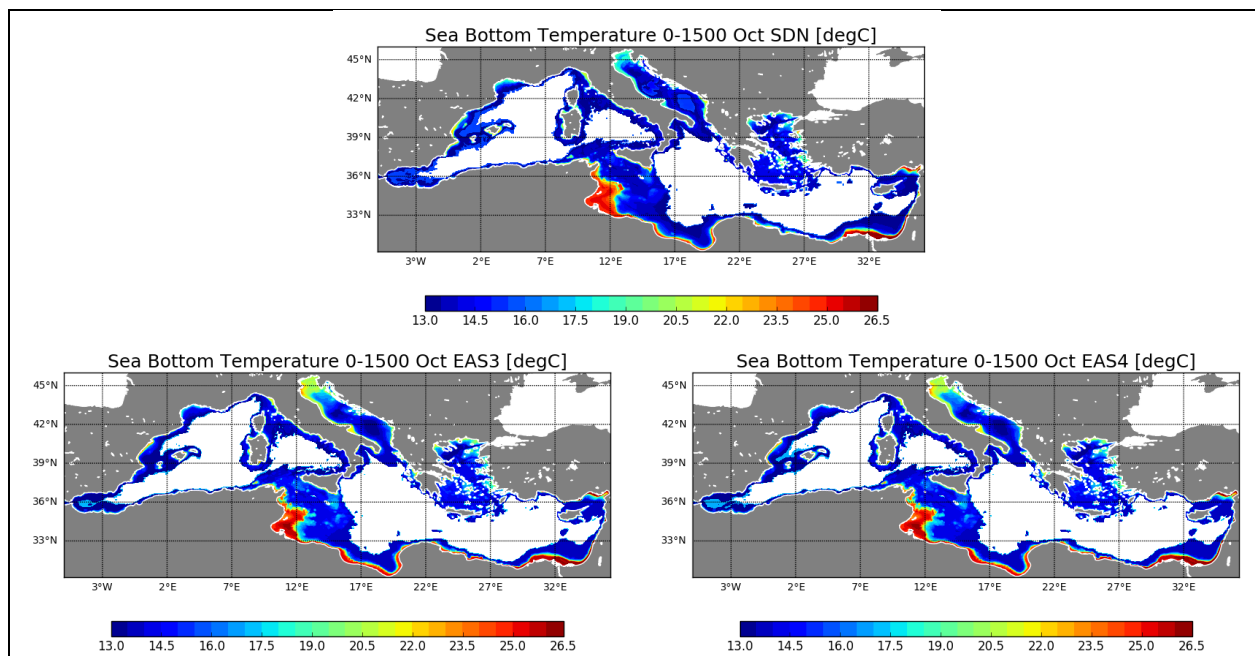


Figure 15: October Seabed temperature 2D maps in areas with topography lower than 1500 m: SDN climatologies (top), monthly average Med-Currents EAS3 system (bottom-left), monthly average Med-Currents EAS4 system (bottom-right): SBT-D-CLASS1-CLIM-MEAN_M-MED.

III.3 Salinity

In the following Table 14 there is synthesis of the values of the salinity Root Mean Square (RMS) differences calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product with quasi-independent data assimilated by the system for salinity (ARGO, CTD). The synthesis is based on 1 year period (2017) and provided at 5 depths (8, 30, 150, 300, 600 m). The error is always lower than 0.2 PSU and it is higher at surface and decreases significantly below 150m.

Variables/estimated accuracy:	Metrics	Depth	Observation
SALINITY (psu)	RMS Diff	Depth	Observation
	0.16±0.03	8	Argo
	0.16±0.04	30	Argo
	0.09±0.02	150	Argo
	0.05±0.00	300	Argo
	0.03±0.00	600	Argo

Table 14: Quasi-independent validation. Analysis evaluation based over year 2017.

The panels in Figure 16 show the time series of weekly RMS of salinity misfits (observation minus model value transformed at the observation location and time before being assimilated) at 5 depths (8, 30, 150, 300, 600 m), S-<X-Y>m-W-CLASS4-PROF-RMSD-MED-Jan2017-Dec2017, for the CMEMS Med-MFC-currents EAS3 system (red line) and the EAS4 system (blue line); the values of the mean RMS differences are reported in the legend of the figures; the number of observed profiles that have been assimilated are represented as shaded areas.

The new system presents the same performances of the previous system. The salinity error is generally higher above 30 m with values less than 0.2 PSU and better skill below 150 m with values lower than 0.1 PSU. It presents a seasonal variability at first layers with higher values during warm seasons.

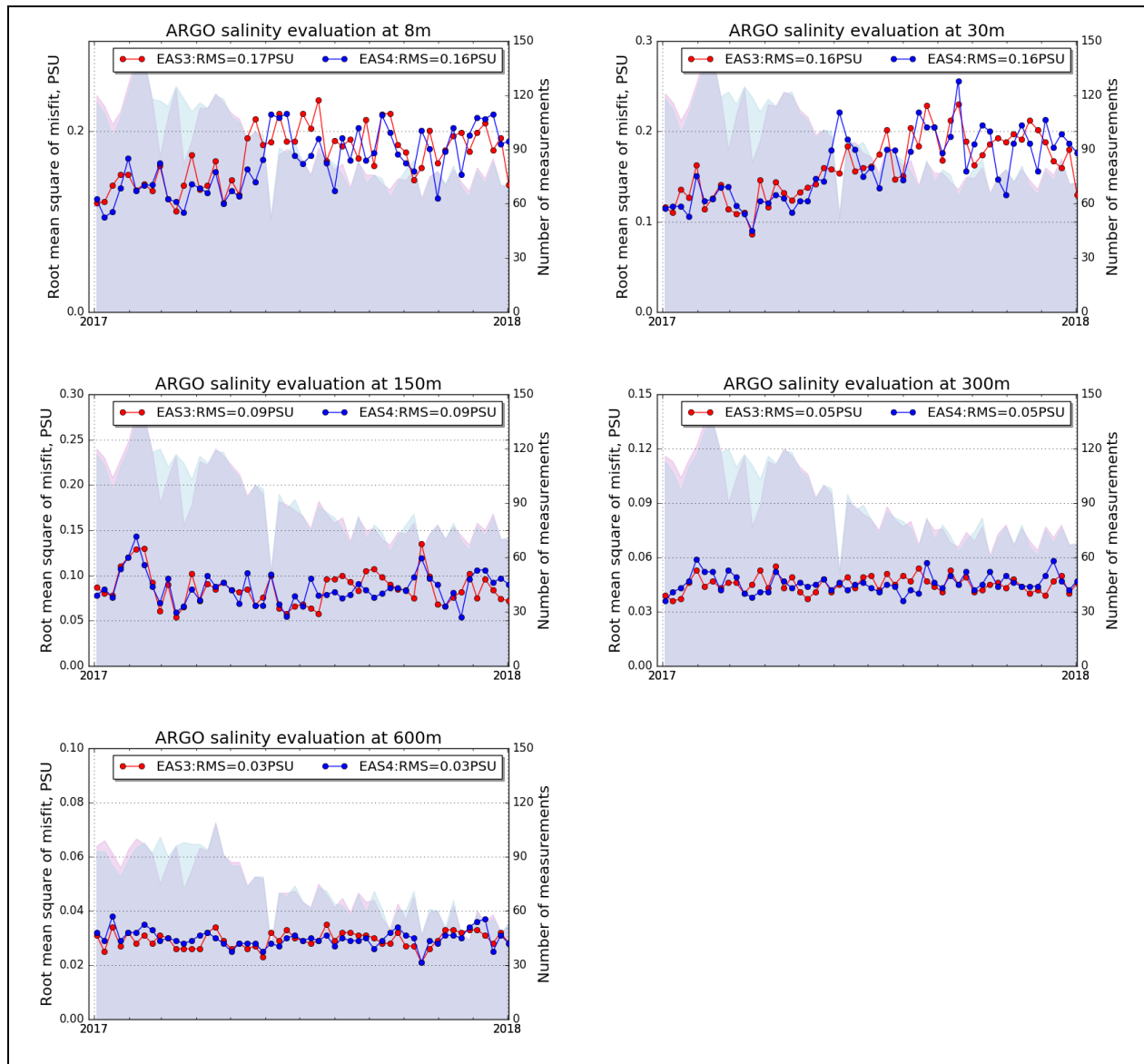


Figure 16: Time series of weekly RMS misfit of salinity ARGO-Model (solid lines) and number of observed profiles (shaded area) at 8, 30, 150, 300 and 600 m (S-<X-Y>m-W-CLASS4-PROF-RMSD-MED-Jan2017-Dec2017).

Monthly mean RMS misfits of salinity for EAS3 and EAS4 systems are represented in (Figure 17) the following Hovmöller diagrams (Depth-Time) along the water column between surface and 900 m showing the vertical pattern of the error averaged in the whole Mediterranean Sea. Both systems present higher errors in the first layers decreasing below 150 m. EAS4 system presents a slightly increased skill especially in the surface layers during summer.

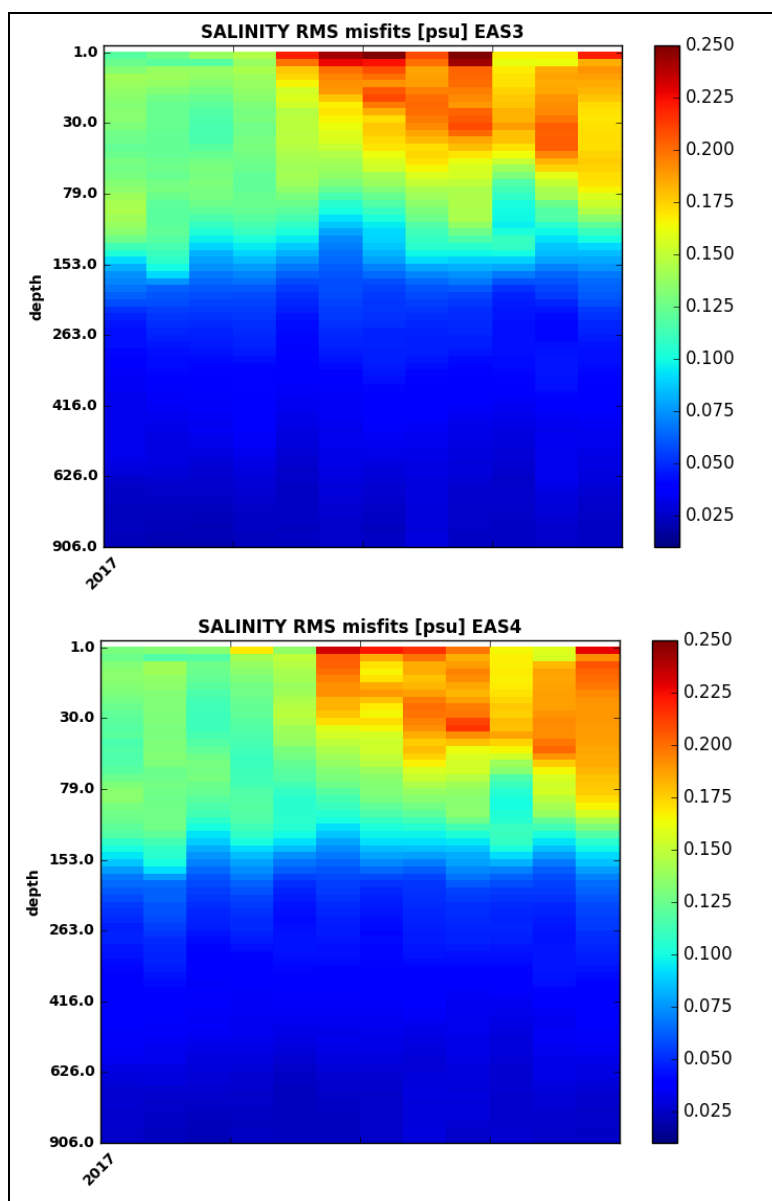


Figure 17: Hovmöller (Depth-Time) diagram of monthly mean RMS misfits of salinity along the water column averaged in the whole Mediterranean Sea. Top: EAS3; bottom: EAS4.

In addition to basin averaged statistics, the following figures (see panels in Figure 18) show the spatial pattern of the salinity RMS misfits for EAS4 system averaged in the entire qualification period (2017) at several depths (8, 30, 150, 300 and 600 m) with respect to ARGO data. The bottom right panel shows the number of data used for this analysis.

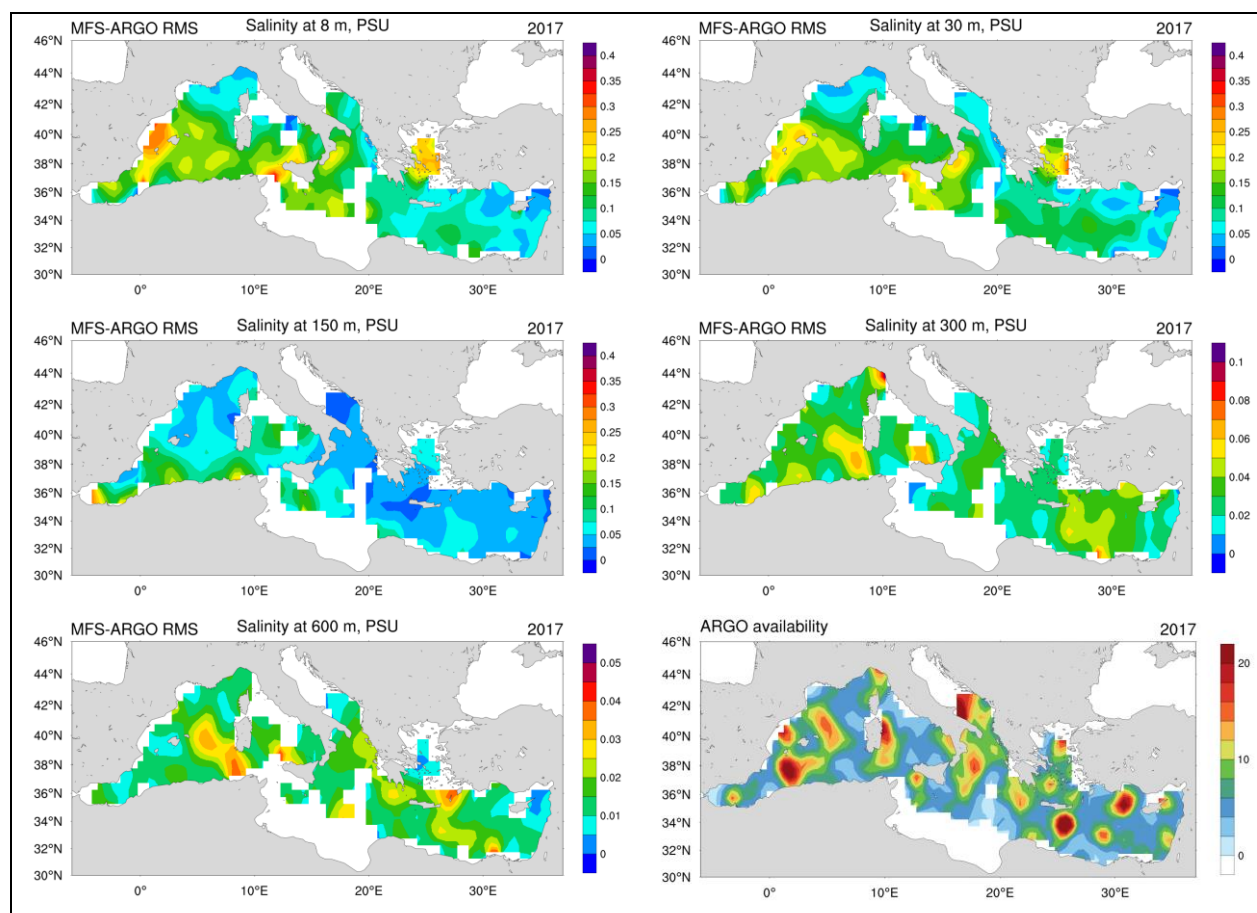


Figure 18: Maps of salinity RMS misfits for EAS4 system averaged in the entire qualification period (2017) at several depths (8, 30, 150, 300 and 600 m) with respect to ARGO data. The bottom right panel shows the number of data used for this analysis.

The following panels in **Erreur ! Source du renvoi introuvable.** show the time series of salinity daily RMSs of the difference between model outputs and observations evaluated over the qualification testing period (2017): S-<X-Y>m-D-CLASS4-PROF-RMSD-MED-Jan2017-Dec 2017. The statistics are evaluated for nine different layers (0-10, 10-30, 30-60, 60-100, 100-150, 150-300, 300-600, 600-1000, 1000-2000 m).

The differences between EAS4 and EAS3 systems are very small. The two systems present similar errors at all levels. The average value of RMS difference over the entire period is the one listed in Table 3. The salinity error is generally higher above 150 m then the error decreases significantly below 150 m.

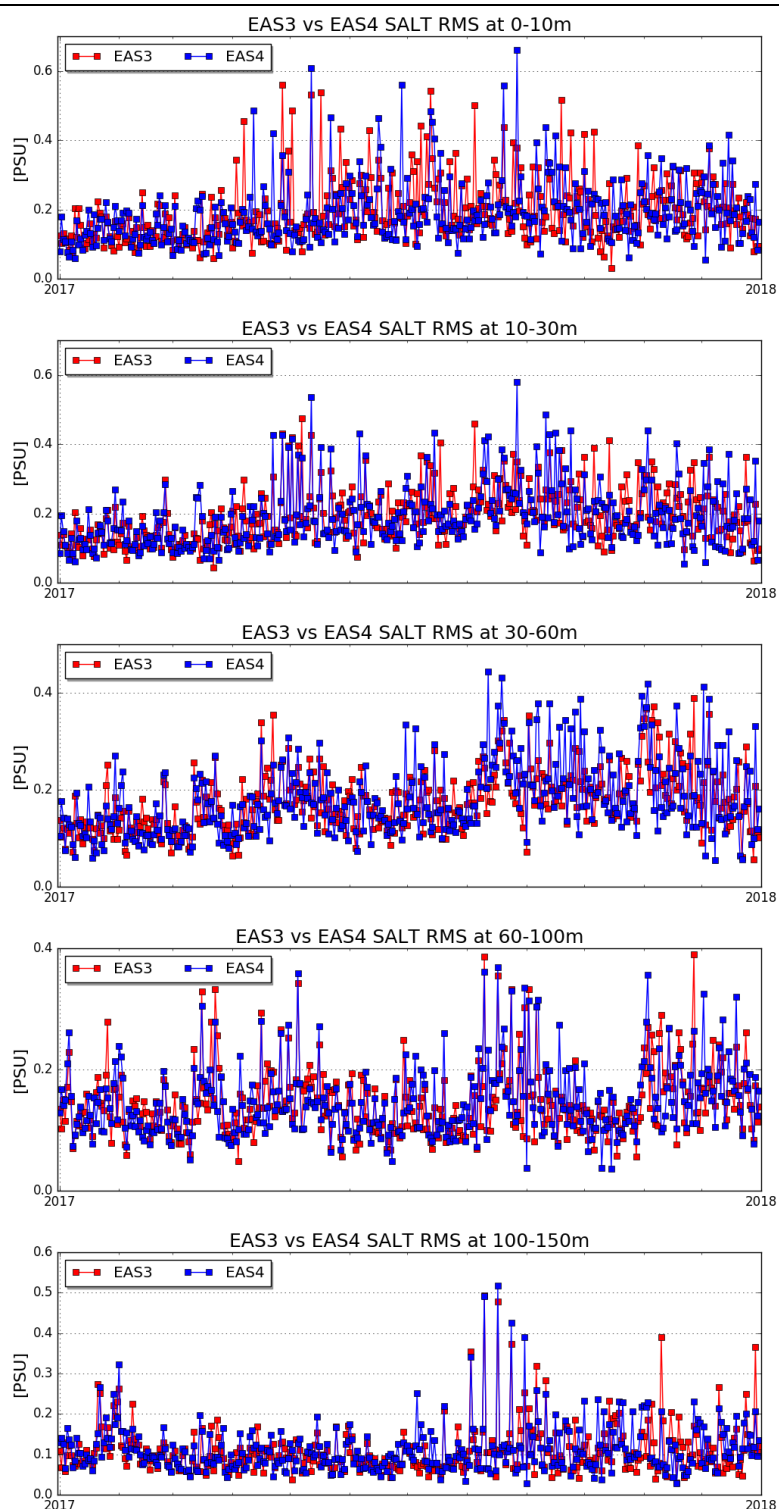


Figure 19: Time series of daily RMS of salinity at different vertical layers for EAS3 (red line) and EAS4 (blue line) systems (S-<X-Y>m-D-CLASS4-PROF-RMSD-MED-Jan2017-Dec 2017) (continues overleaf).

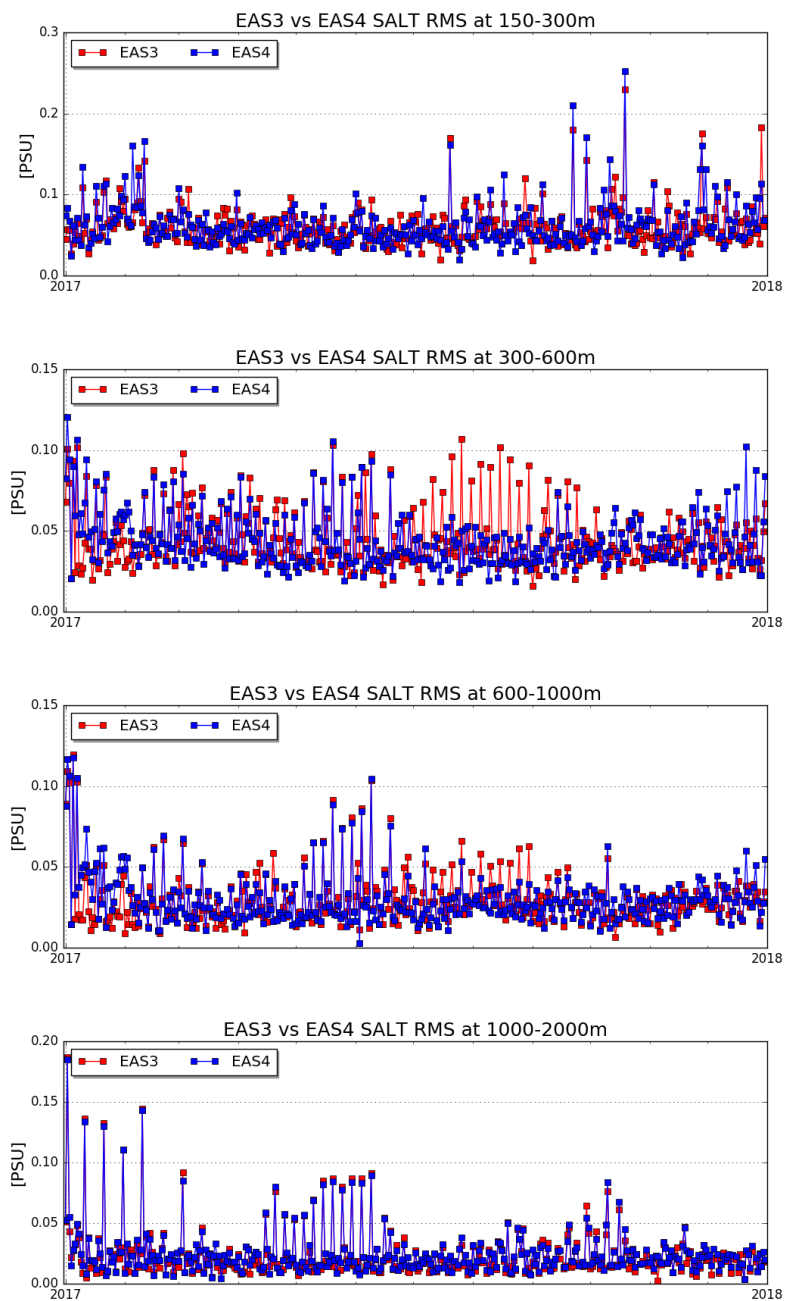


Figure 20: (continued) Time series of daily RMS of salinity at different vertical layers for EAS3 (red line) and EAS4 (blue line) systems (S-<X-Y>m-D-CLASS4-PROF-RMSD-MED-Jan2017-Dec 2017).

III.4 Sea Level Anomaly

In Table 10 there are the RMS differences for the Sea Level Anomaly calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product with each available satellite (along track observations) from January to December 2017.

SEA LEVEL ANOMALIES (cm)	RMS Diff	Availability
All Satellites	3.6	01/01/2017-31/12/2017
ALTIKA	3.5	01/01/2017-31/12/2017
CRYOSAT	3.6	01/01/2017-31/12/2017
JASON 2N	3.4	01/01/2017-15/03/2017 30/03/2016-17/05/2017
JASON3	3.6	01/01/2017-31/12/2017
SENTINEL3A	3.5	29/03/2017-31/12/2017

Table 15: Analysis evaluation based over 1 year time series (2017) for the Sea Level Anomaly for each available satellite.

The following Figure 21 shows the time series of weekly RMS of sea level anomaly misfits (observation minus model value transformed at the observation location and time before being assimilated), SLA-SURF-W-CLASS4-ALT-RMSD-MED-Jan2017-Dec2017, for the CMEMS Med-Currents EAS3 system (red line) and the EAS4 system (blue line); the number of assimilated data is provided as shaded areas.

The new system presents a similar skill with respect to EAS3 system for each of the available satellite with an overall error of about 3.5 cm in the whole basin.

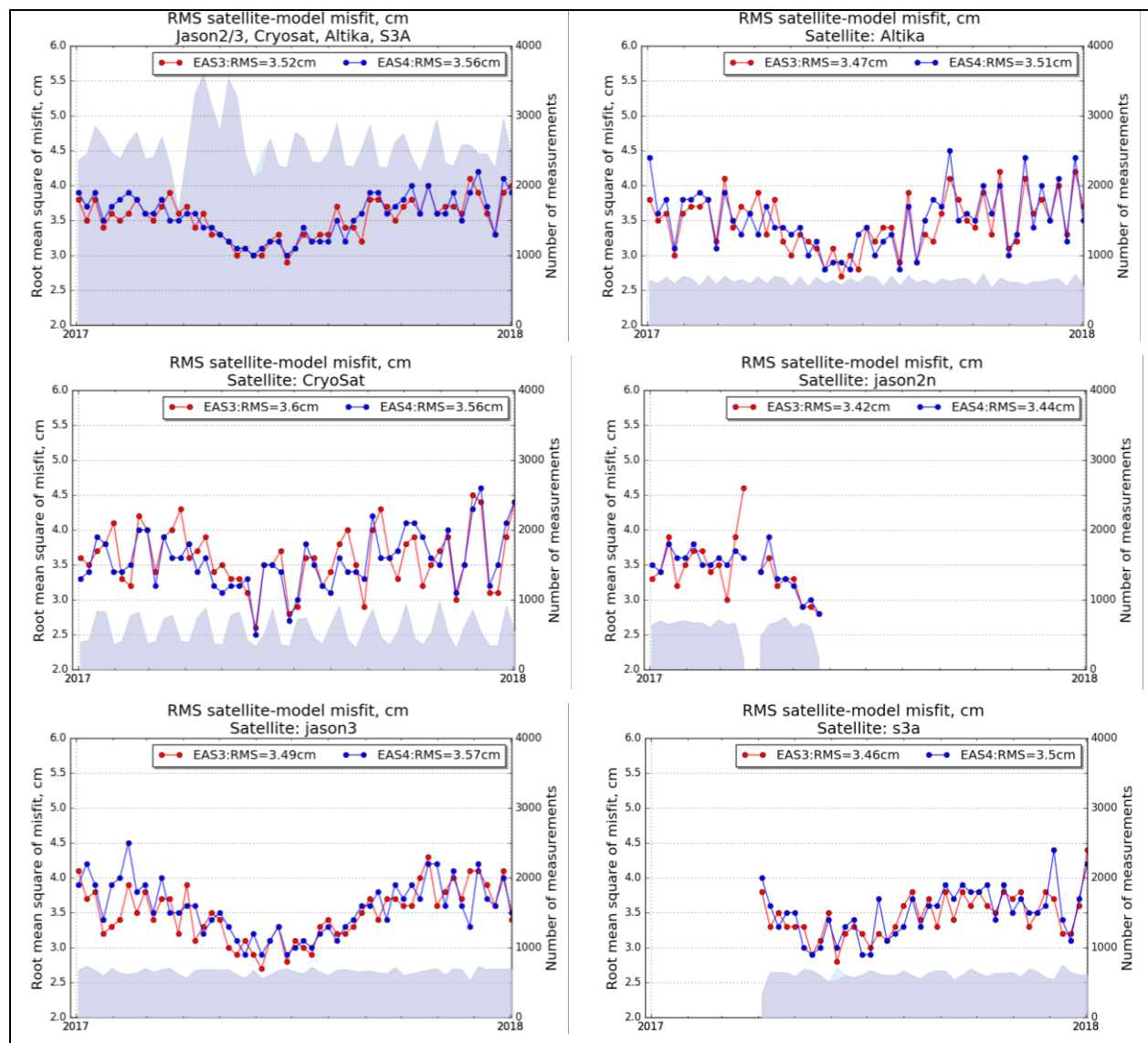


Figure 21 Time series of weekly RMS of satellite-model misfit along SLA data track for all the satellites (top-left panel), Altika (top-right), Cryosat (middle-left), Jason2/N (middle-right), Jason3 (bottom-left) and Sentinel3A (bottom-right) and corresponding number of assimilated data (shaded areas in the figures) for EAS3 (red line) and EAS4 (blue line) (SLA-SURF-W-CLASS4-ALT-RMSD-MED-Jan2017-Dec2017).

In addition to basin averaged statistics, the following figures (Figure 22) show the spatial pattern of the Sea Level Anomaly RMS misfits for EAS4 (top) system averaged in the entire qualification period (2017) with respect to SLA tracks and the number of data used for this analysis (bottom panel).

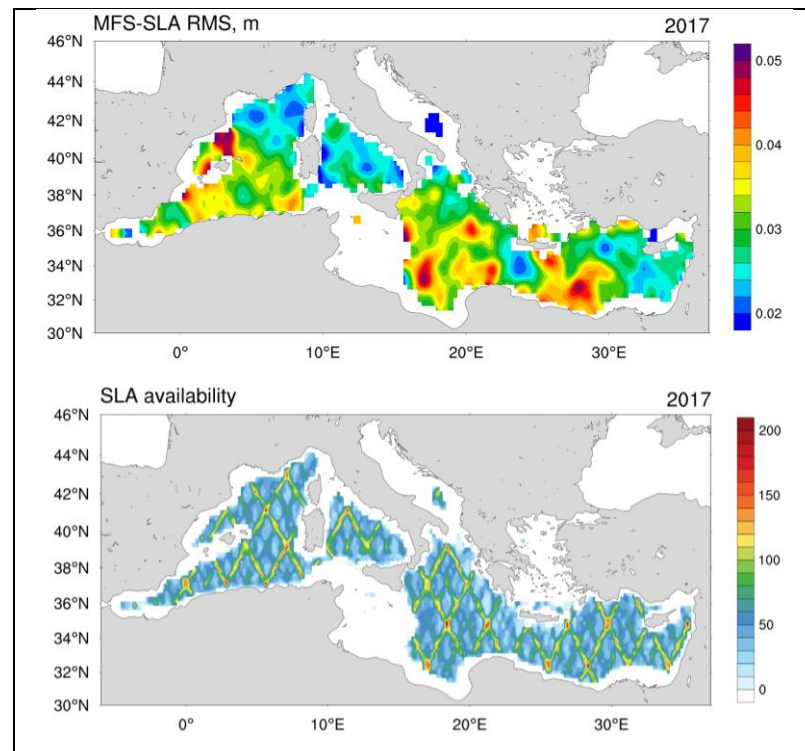


Figure 22: Maps of Sea Level Anomaly RMS misfits for EAS4 system averaged in the entire qualification period (2017) with respect to L3 along track Altimetry data (top) and number of data used for this analysis (bottom).

Figure 23 shows the daily time series of Sea Level Anomaly daily RMS of the difference between model outputs and observations evaluated over the qualification testing period (2017): SLA-SURF-D-CLASS4-RMSD-MED-Jan2017-Dec 2017. The new system (blue line) presents similar skill during all the simulated period if compared to EAS3 system (red line).

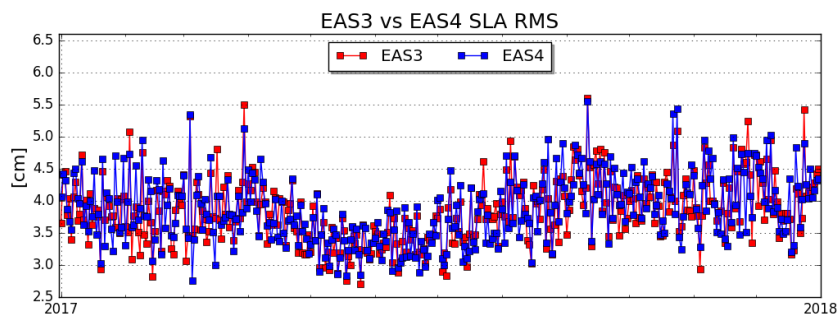


Figure 23: Time series of daily RMS of Sea Level Anomaly for EAS3 and EAS4 systems (SLA-SURF-D-CLASS4-RMSD-MED-Jan2017-Dec 2017)

III.5 Currents

The predicted sea surface currents skill is assessed by means of independent validation through coastal moorings.

Table 16 summarizes the RMS differences and the Bias calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHY_006_013 product with the independent in-situ data (MB: coastal moored buoys) for the year 2017.

Variables/estimated accuracy:	RMS diff	Bias	Depth	Obs	No. of Obs.
	UV-SURF-D-CLASS2-MOOR-RMSD-Jan2017-Dec2017	UV-SURF-D-CLASS2-MOOR-BIAS-Jan2017-Dec2017			
Current (cm/s) year 2017: EAS4	13.88	1.58	0-3	MB	11

Table 16: Independent observation evaluation based on 1-year time series (2017) of analysis and Moored Buoys observations.

Figure 24 shows an example of daily sea surface currents time series of EAS4 (blue line) model outputs against the Tarragona coastal mooring (green line) for year 2017, the figure presents also the Bias and RMS difference.

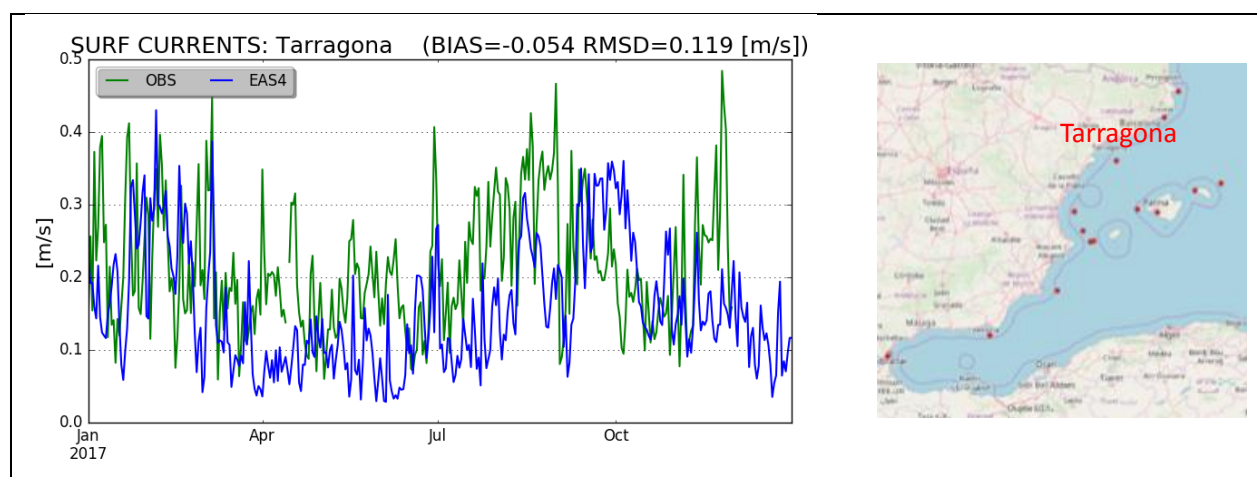


Figure 24: Left: Time series of daily sea surface currents at Tarragona buoy. Comparison between observations (green line) and EAS4 model outputs (blue line). (UV-SURF-D-CLASS2-MOOR-RMSD-Jan2017-Dec2017, UV-SURF-D-CLASS2-MOOR-BIAS-Jan2017-Dec2017). Right: Tarragona Buoy location.

In addition to surface current validation, an assessment of velocity derived variables is provided in terms of transport through the strait of Gibraltar.

In Figure 25 the time series of the mean daily Net flux through the Gibraltar Strait is represented for EAS3 (red line) and EAS4 (blue line) during 2017 showing very similar results for the two systems.

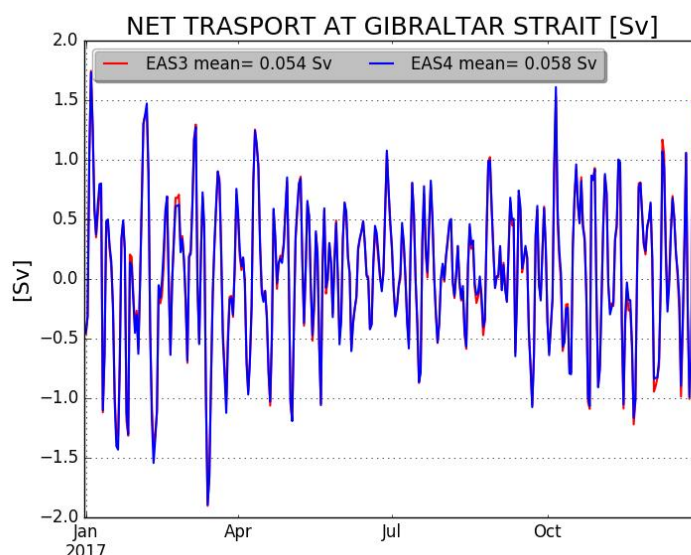


Figure 25: Time series of daily mean Net Flux through the Gibraltar Strait for EAS3 (red line) and EAS4 (blue line) systems.

In Table 17 the comparison of net, eastward and westward transports with respect to literature fluxes (Soto-Navarro et al., 2010) is included showing that the two systems yearly (2017, is considered a typical year) mean fluxes are very similar and are close to literature values.

Gibraltar Mean Flux [Sv]	EAS3 (2017)	EAS4 (2017)	Soto-Navarro et al., 2010
Net	0.054	0.058	0.038 ± 0.007
Eastward	0.877	0.882	0.81 ± 0.06
Westward	0.822	0.825	0.78 ± 0.05

Table 17: Gibraltar mean fluxes [Sv] from EAS3 and EAS4 systems averaged in the year 2017 compared to literature values.

III.6 Mixed Layer Depth

In order to assess the model ability to reproduce the Mixed Layer Depth (MLD), monthly averaged 2D maps of MLD have been compared to a climatological datasets available from literature (Houpert et al., 2015) providing monthly gridded climatologies produced using MBT, XBT, Profiling floats, Gliders, and ship-based CTD data from different database and carried out in the Mediterranean Sea between 1969 and 2013. Figure 26 to Figure 29 show the 2D maps of climatological MLD from literature (top), monthly averaged MLD from MED-Currents EAS3 (bottom-left) and MED-Currents EAS4 system (bottom-right).

It can be noticed that during March 2017 (Figure 26), the modelled MLD in the Gulf of Lyon is shallower than the climatological value and slightly deeper in the Aegean Sea, where the new system EAS4 is closer to climatology in the northern area with shallower MLD, probably improved thanks to the open boundary in the Dardanelles strait. During June 2017 (Figure 27) the modelled MLD is in general similar to the climatological one with a slightly deeper MLD in the North Adriatic Sea. During August 2017 (Figure 28) the Med-Currents EAS4 and EAS3 systems are very close to the climatology in the central and eastern basins, while the modelled MLD is deeper in the Western basin with respect to the climatology; in November 2017 (Figure 29) the 2 systems have similar spatial pattern with slightly deeper modelled MLD with respect to the climatology.

In general it can be noticed that the numerical systems are able to represent the spatial and seasonal distribution of the MLD and the main differences can be due to the low resolution of the climatological dataset that moreover do not cover the whole domain of the Mediterranean Sea as well as on the different period of evaluation.

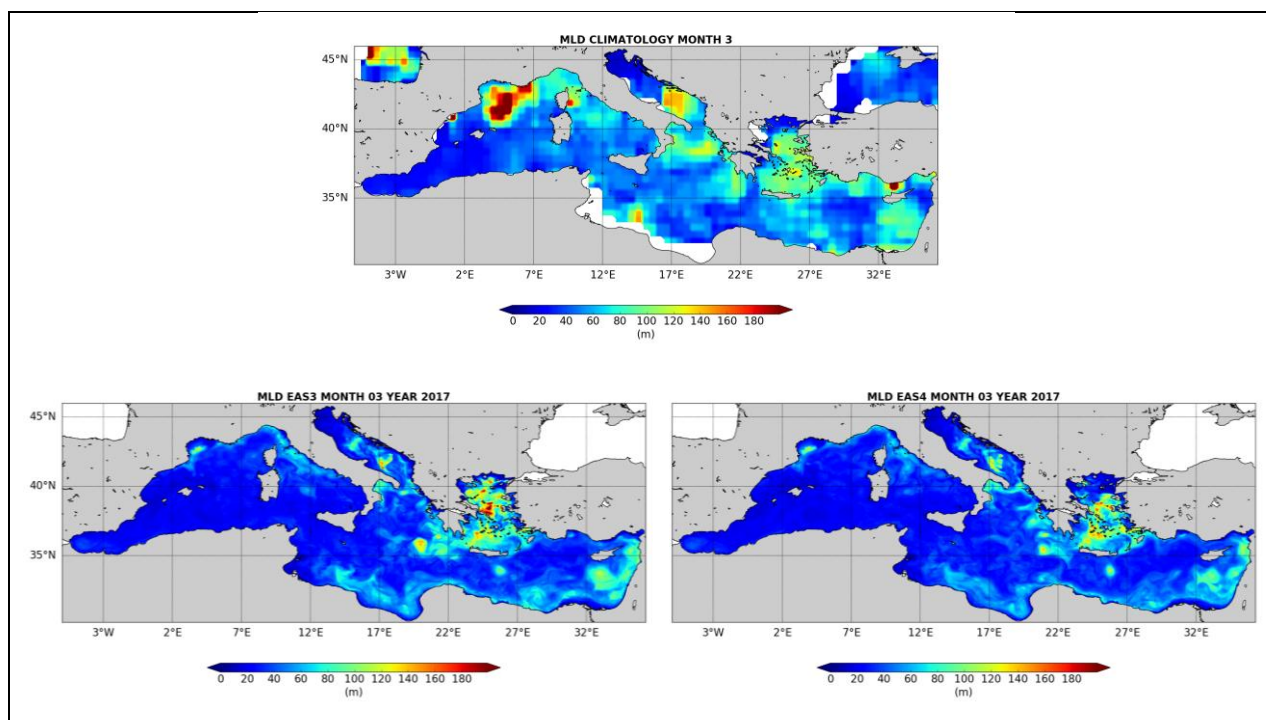


Figure 26: March MLD 2D maps. Top: climatological data from literature; left: March 2017 monthly averaged MLD from MED-Currents EAS3; right: March 2017 monthly averaged MLD from MED-Currents EAS4: MLD-D-CLASS1-CLIM-MEAN_M-MED

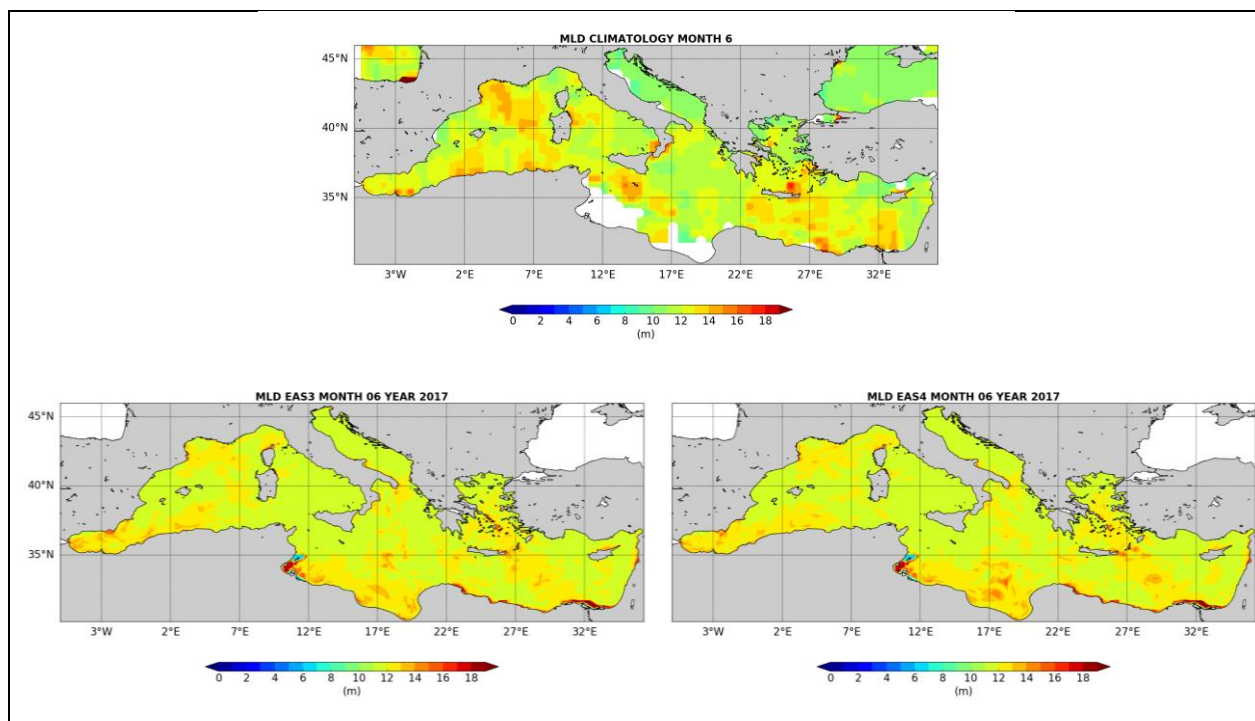


Figure 27: June MLD 2D maps. Top: climatological data from literature; left: June 2017 monthly averaged MLD from MED-Currents EAS3; right: June 2017 monthly averaged MLD from MED-Currents EAS4: MLD-D-CLASS1-CLIM-MEAN_M-MED

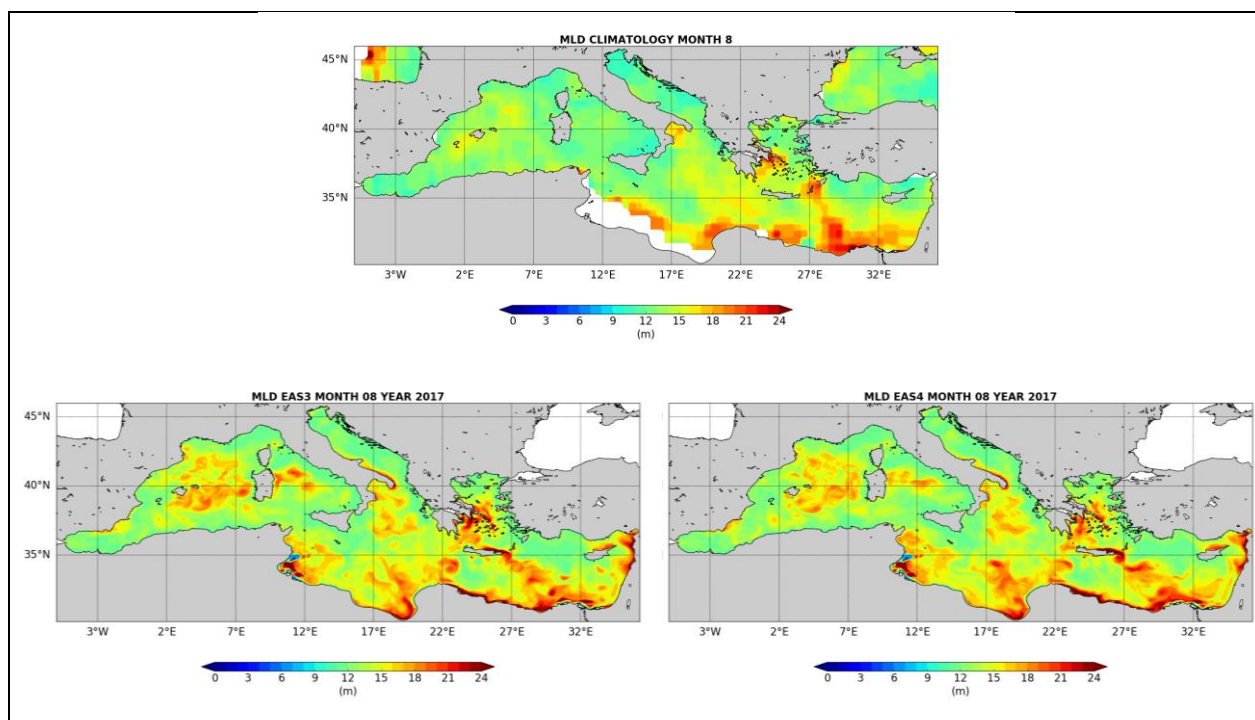


Figure 28: August MLD 2D maps. Top: climatological data from literature; left: September 2017 monthly averaged MLD from MED-Currents EAS3; right: September 2017 monthly averaged MLD from MED-Currents EAS4: MLD-D-CLASS1-CLIM-MEAN_M-MED

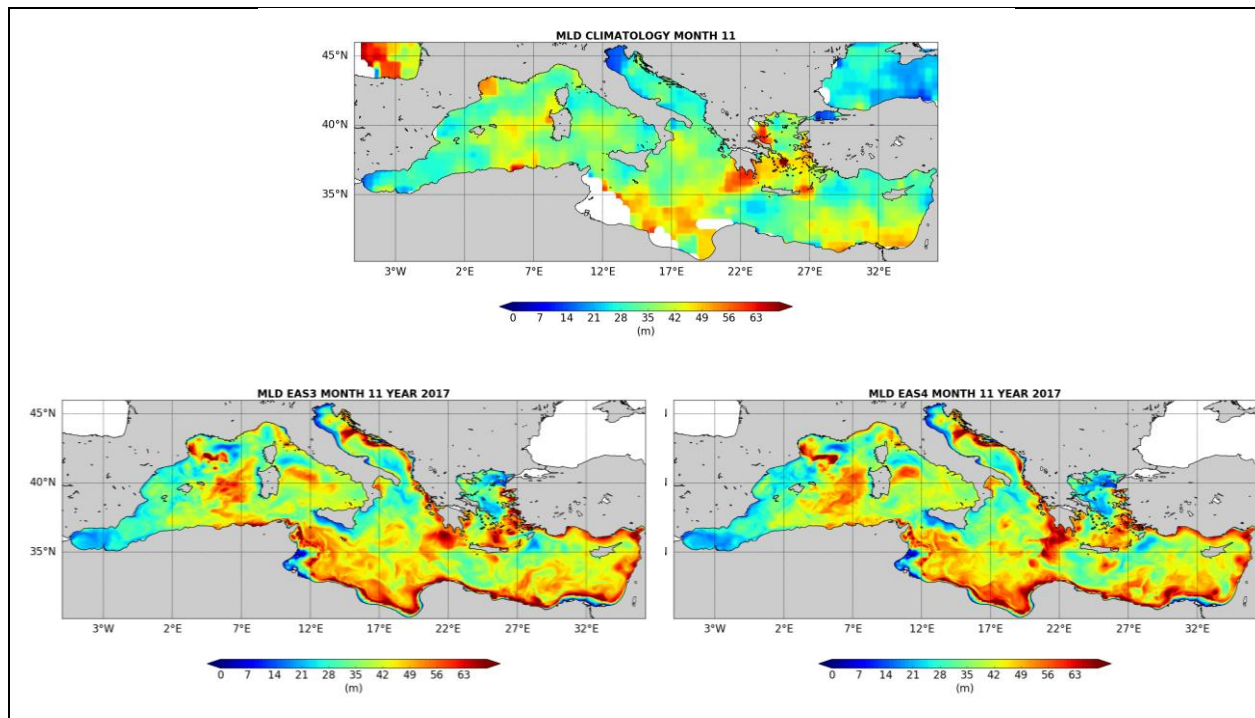


Figure 29: November MLD 2D maps. Top: climatological data from literature; left: November 2017 monthly averaged MLD from MED-Currents EAS3; right: November 2017 monthly averaged MLD from MED-Currents 4: MLD-D-CLASS1-CLIM-MEAN_M-MED

<div> <div>QUID for MED MFC Product</div> <div>MEDSEA_ANALYSIS_FORECAST_PHY_006_013</div> </div>	<div> <div>Ref:</div> <div>CMEMS-MED-QUID-006-013</div> </div> <div> <div>Date:</div> <div>28 January 2019</div> </div> <div> <div>Issue:</div> <div>1.2</div> </div>
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IV

SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

Date	Change/Event description	System version	other

QUID for MED MFC Product MEDSEA_ANALYSIS_FORECAST_PHY_006_013	Ref: Date: Issue:	CMEMS-MED-QUID-006-013 28 January 2019 1.2
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V QUALITY CHANGES SINCE PREVIOUS VERSION

The quality of the product is similar to the one of the previous one.
The models upgrades had no provided a significant impact on the quality of the product.

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