COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE

MED MFC

CMEMS ELEMENT

QUality Information Document for Med Currents analysis and forecast product: MEDSEA_ANALYSIS_FORECAST_PHY_006_001

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CHANGE RECORD

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GLOSSARY AND ABBREVIATIONS

Additional terms:

ALK	Alkalinity
ASSIM	Data Assimilation
CAL/VAL	CALibration/VALidation
CHL	Chloroophyll
CMCC	Centro EuroMediterraneo per i Cambiamenti Climatici
CORR	Correlation
DA	Data Assimilation
DIC	Dissolved Inorganic Carbon
ECMWF	European Centre for Medium range Weather Forecasting
GLO	Global
GODAE	Global Ocean Data Assimilation Experiment
HCMR	Hellenic Centre for Marine Research
INGV	Istituto Nazionale di Geofisica e Vulcanologia
INS	IN-Situ
Med	Mediterranean
MERSEA	Marine Environment and Security for the European Area
MFC	Monitoring and Forecasting System
MonGOOS	Mediterranean Operational Network for the Global Ocean Observing System
NRT	Near Real Time
OBS	Observation
OGS	Istituto Nazionale di Oceanografie e Geofisica Sperimentale
PQ	Product Quality
PQWG	Product Quality Working Group
RMS	Root Mean Square
TAC	Thematic Assembly Center

SLA	Sea Level Anomaly
SSH	Sea Surface Height
SSS	Sea Surface Salinity
SST	Sea Surface Temperature

Applicable and Reference Documents

	Ref	Title	Date / Version
RA 1	Clementi et al., 2013	Clementi E., Oddo P., Korres G., Drudi M. and N. Pinardi, 2013 Coupled wave-ocean modelling system in the Mediterranean Sea. Extended abstract to the 13th Int. Workshop on Wave Hindcasting, Banff, Canada, 2013, 8pp. http://waveworkshop.org/13thWaves/Papers/Clementi_etal_13WAVE_WORKSHOP.pdf	
RA 2	Desroziers et al., 2005	Desroziers, G., Berre, L., Chapnik, B. and Poli, P. (2005), Diagnosis of observation, background and analysis-error statistics in observation space. Q.J.R. Meteorol. Soc., 131: 3385–3396. doi: 10.1256/qj.05.108	
RA 3	Dobricic & Pinardi 2008	Dobricic, S. and N. Pinardi, 2008. An oceanographic three-dimensional variational data ssimilation scheme. Ocean Modelling, 22, 3-4, 89-105.	
RA 4	Dobricic et al., 2007	Dobricic, S., N. Pinardi, M. Adani, M. Tonani, C. Fratianni, A. Bonazzi, and V. Fernandez, 2007. Daily oceanographic analyses by Mediterranean Forecasting System at the basin scale. Ocean Sci., 3, 149-157.	
RA 5	Dobricic et al., 2005	Dobricic, S., 2005. New mean dynamic topography of the mediterranean calculated fron assimilation system diagnostic. GRL, 32.	
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RA 8	Fekete et al., 1999	Fekete, B. M., Vorosmarty, C. J., and Grabs, W.: Global, Composite Runoff Fields Based on Observed River Discharge and Simulated Water Balances, Tech. Rep. 22, Global Runoff Data Cent., Koblenz, Germany, 1999.	
RA 9	Flather, 1976	Flather, R.A., 1976. A tidal model of the northwest European continental shelf. Memories de la Societe Royale des Sciences de Liege 6 (10), 141–164	
RA 10	Gunther et al., 1993	Gunther, H., H. Hasselmann, and Janssen, P.A.E.M.: The WAM model cycle 4, DKRZ report n. 4, 1993.	
RA 11	Hasselmann, 1974	Hasselmann, K.: On the characterization of ocean waves due to white capping, Boundary-Layer Meteorology, 6, 107-127, 1974.	
RA	Hasselmann	Hasselmann, S. and Hasselmann, K.: Computations and	

12	et al., 1985	parameterizations of the nonlinear energy transfer in a gravity wave spectrum. Part I: A new method for efficient computations of the exact nonlinear transfer integral, J. Phys. Ocean., 15, 1369-1377, 1985.	
RA 13	Hasselmann et al., 1985	Hasselmann, S., K. Hasselmann, J. H. Allender, and Barnett, T.P.: Computations and parameterizations of the nonlinear energy transfer in a gravity wave spectrum. Part II: Parameterizations of the nonlinear energy transfer for application in wave models, J. Phys. Ocean., 15, 1378-1391, 1985.	
RA 14	Janssen, 1989	Janssen, P.A.E.M.: Wave induced stress and the drag of air flow over sea wave, J. Phys. Ocean., 19, 745-754, 1989.	
RA 15	Janssen, 1991	Janssen, P.A.E.M.: Quasi-Linear theory of wind wave generation applied to wave forecasting, J. Phys. Ocean., 21, 1631-1642, 1991.	
RA16	Komen et al., 1984	Komen, G. J., S. Hasselmann, and Hasselmann, K.: On the existence of a fully developed windsea spectrum, J. Phys. Ocean., 14, 1271-1285, 1984.	
RA 17	Kourafalou et al., 2003	Kourafalou, V. H. and Barbopoulos, K.: High resolution simulations on the North Aegean Sea seasonal circulation, Ann. Geophys., 21, 251–265, 2003,	
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RA 19	Maraldi et al., 2013	Maraldi C., J. Chanut, B. Levier, N. Ayoub, P. De Mey, G. Reffray, F. Lyard, S. Cailleau, M. Drévillon, E. A. Fanjul, M. G. Sotillo, P. Marsaleix, and the Mercator Research and Development Team, 2013: NEMO on the shelf: assessment of the Iberia–Biscay–Ireland configuration. Ocean Sci., 9, 745–771.	
RA 20	Madec, 2008	Madec G., 2008.NEMO ocean engine, Note du Pole de modelisation, Institut Pierre-Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619.	
RA 21	Oddo et al., 2009	Oddo P., M. Adani N. Pinardi, C. Fratianni, M. Tonani, D. Pettenuzzo, 2009. A Nested Atlantic-Mediterranean Sea General Circulation Model for Operational Forecasting. Ocean Sci. Discuss., 6, 1093-1127.	
RA 22	Oddo et al., 2014	Oddo P., Bonaduce A., Pinardi N. and A. Guarnieri: Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO. Geosci. Model Dev., 7, 3001–3015, 2014.	
RA 23	Pinardi et al., 2003	Pinardi, N., I. Allen, P. De Mey, G. Korres, A. Lascaratos, P.Y. Le Traon, C. Maillard, G. Manzella and C. Tziavos, 2003. The Mediterranean ocean Forecasting System: first phase of implementation (1998-2001). Ann. Geophys., 21, 1, 3-20.	
RA 24	Raicich, 1996	Raicich, F.: On fresh water balance of the Adriatic Sea, J. Mar. Syst., 9, 305–319, 1996.	

RA 25	Rio et al., 2014	Rio, M.-H., A. Pascual, P.-M. Poulain, M. Menna, B. Barceló, and J. Tintoré : Computation of a new mean dynamic topography for the Mediterranean Sea from model outputs, altimeter measurements and oceanographic in situ data. Ocean Science, 10, 731-744, 2014.	
RA 26	Roullet & Madec 2000	Roullet G. and G. Madec, 2000: Salt conservation, free surface, and varying levels: a new formulation for ocean general circulation models. J.G.R., 105, C10, 23,927-23,942.	
RA 27	Tolman, 2009	Tolman H., User Manual and system documentation of WAVEWATCH III version 3.14, 2009. NOAA/NWS/NCEP/MMAB Technical Note 276, 194 pp + Appendices.	
RA 28	Tolman, 2002	Tolman, H.L.: Validation of WAVEWATCH III version 1.15 for a global domain. NOAA / NWS / NCEP / OMB Technical Note 213, 33 pp, 2002.	
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RA 31	Tonani et al., 2008	Tonani, M., N. Pinardi, S. Dobricic, I. Pujol, and C. Fratianni, 2008. A high-resolution free-surface model of the Mediterranean Sea. Ocean Sci., 4, 1-14.	
RA 32	Tonani et al., 2013	M. tonani, S. Simoncelli, A. Grandi and N. Pinardi New gridded climatologies, from in-situ observations, for the Mediterranean Sea Abstract to IMDIS 2013. http://www.google.it/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwiss_HHm_XLAhUCdQ8KHXR1AQ4QFggjMAE&url=http%3A%2F%2Fimdis2013.seadatanet.org%2Fcontent%2Fdownload%2F93851%2F1140805%2Ffile%2FSDN2_D64_WP6_IMDIS2013_proceedings_abstracts.pdf&usg=AFQjCNHnDVXHRCMlaEVd0p7RafnWwWIi0w&bvm=bv.118443451,d.ZWU	

I EXECUTIVE SUMMARY

I.1 Products covered by this document

This document describes the quality of the analysis and forecast nominal product of the physical component of the Mediterranean Sea: MEDSEA_ANALYSIS_FORECAST_PHY_006_001. The product includes:

- 3D daily mean and hourly mean fields of: Potential Temperature, Salinity, Zonal and Meridional Velocity
- 2D daily mean and hourly mean fields of: Sea Surface Height, Mixed Layer Depth, Sea Bed Temperature
- 2D daily mean and hourly mean fields of bottom temperature (temperature of the deepest layer or level)
- 2D daily mean fields and hourly fields of: Surface Zonal and Meridional Stokes drift velocity and wave number. The latter are included in the physical product in order give the possibility to the user to evaluate the 3D Stokes Drift velocity and are not subject to the qualification procedure due to unavailability of data.

Output data are produced at 1/16° horizontal resolution, 72 vertical levels.

I.2 Summary of the results

The quality of the V2 MED-MFC-currents system of analysis and forecast is assed over 2 years period from 01/01/2014 to 31/12/2015 by comparison with insitu and satellite observations and inter-comparison with the CMEMS-Med-MFC-currents V1 version of the system. The MED-MFC-currents system has a 1/16° horizontal resolution and 72 vertical levels.

The main results of the MEDSEA_ANALYSIS_FORECAST_PHY_006_001 quality product assessment are summarized below:

Sea Surface Height: the V2 system presents a relevant better accuracy in terms of sea surface height representation with respect to the previous version. This improvement is mainly due to the use of a changed sing in the DAC applied to SLA dataset and to the use of a 20 years referenced Mean Dynamic Topography. The model skill enhancement is evident when considering the RMS of misfits between model and satellite observations achieving an error decrease of 1 cm (from 4.3 to 3.2 cm).

Temperature: the temperature is accurate with a RMS error always below 1ºC. The error is higher at first layer and lower below 30m. The MED MFC products usually have a cold bias in winter and a warm bias in summer. The accuracy of the temperature at depth has an RMS less than 0.75 above 150m and less than 0.25 below. V2 exhibits a slight decrease in surface temperature skill when compared to V1 system, while little improvements are achieved below 30m depth.

Salinity: the salinity is accurate with RMS EAN values equal or lower than 0.2 PSU. The error is higher in the first 10m, this could be due in part to the fact that the assimilation of the salinity profiles starts at the depth of 8m. The V2 system presents at almost always a better prediction of salinity with respect to V1, this has been achieved by the improvement in data assimilation (grid point EOFs and modified and variable error covariance matrix).

Currents: RMS and bias are evaluated with respect to moored buoys in coastal areas and due to the low number of observations and mainly located in coastal areas the statistical relevance of currents performance is poor.

Bottom temperature: the bottom temperature of V2 system has been compared to SeaDataNet monthly climatology showing a good skill in representing the seasonal variability of the temperature at deepest level and a general underestimation with respect to the climatological dataset especially during spring and autumn seasons with maximum difference of about 0.15 ºC.

Stokes Drift: there are no observations available. The surface Stokes drift is calculated by the wave model (WW3) coupled to the circulation model (NEMO) whose accuracy has been evaluated and described in Clementi et al. 2013 (RA1).

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 floats: INSITU_GLO_NRT_OBSERVATIONS_013_030, INSITU_MED_TS_NRT_OBSERVATIONS_013_035
- vertical profiles of temperature and salinity from moored buoys;
- 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 V1 and V2 systems over 2 years period from January 2014 to December 2015 and are computed over 6 vertical layers (for temperature and salinity) and for 13 sub-regions (Figure **1**): (1) Alboran Sea, (2) South West Med, (3) North West Med, (4) Thyrrenian Sea, (5) Adriatic Sea, (6) North Ionian Sea, (7) South West Ionian Sea, (8) South East Ionian Sea, (9) Aegean Sea, (10) West Levantine, (11) North Central Levantine, (12) South Central Levantine, (13) East Levantine.

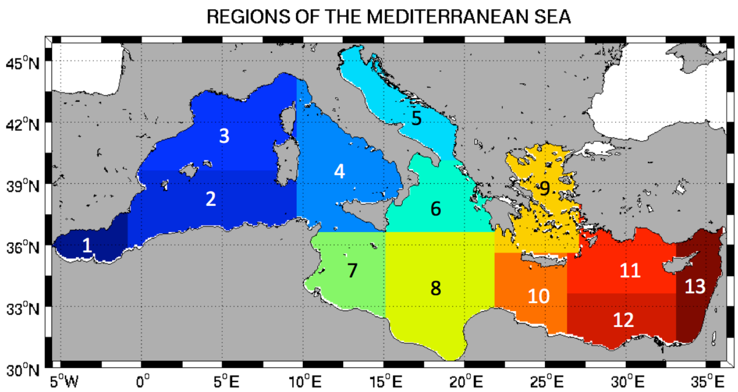


Figure 1. The Mediterranean Sea sub-regions subdivision for validation metrics

T prod - T ref [°C]	V1 system		V2 system	
Layer (m)	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER
0-10	-0.06	0.5	-0.09	0.52
10-30	-0.07	0.75	-0.09	0.76
30-150	0.07	0.57	0.06	0.56
150-300	-0.03	0.25	-0.03	0.24
300-600	-0.03	0.17	-0.03	0.16
600-1000	-0.03	0.12	-0.03	0.1

Table 1: EANs of temperature at different vertical layers evaluated for V1 and V2 systems for the period 2014-2015: T-CLASS4-EAN-MEAN_LAYER and T-CLASS4-EAN-RMS_LAYER in Table 9.

SST prod – SST ref [°C]	V1 system		V2 system	
REGION	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN
MED SEA	0.07	0.51	0.06	0.53
REGION 1	-0.23	0.71	-0.22	0.74
REGION 2	0.06	0.46	0.05	0.46
REGION 3	-0.07	0.52	-0.13	0.56
REGION 4	0.09	0.46	0.08	0.47
REGION 5	0.1	0.61	0.11	0.61
REGION 6	0.11	0.48	0.14	0.53
REGION 7	0.11	0.54	0.09	0.55
REGION 8	0.14	0.42	0.1	0.44
REGION 9	0.15	0.59	0.2	0.65
REGION 10	-0.13	0.45	-0.15	0.47
REGION 11	0.12	0.47	0.12	0.51
REGION 12	0.12	0.4	0.09	0.4
REGION 13	0.16	0.42	0.13	0.45

Table 2: EANs of Sea Surface Temperature evaluated for V1 and V2 systems for the period 2014-2015 for the Mediterranean Sea and 13 regions (see Figure 1): SST-CLASS4-EAN-RMS_BASIN and SST-CLASS4-EAN-MEAN_BASIN in Table 9.

S prod – S ref [PSU]	V1 system		V2 system	
Layer (m)	Mean S-CLASS4-EAN-MEAN_LAYER	RMS S-CLASS4-EAN-RMS_LAYER	Mean S-CLASS4-EAN-MEAN_LAYER	RMS S-CLASS4-EAN-RMS_LAYER
0-10	0.04	0.22	0.05	0.21
10-30	0.01	0.2	0.02	0.19
30-150	-0.01	0.16	0	0.15
150-300	-0.02	0.07	-0.01	0.07
300-600	-0.01	0.05	-0.01	0.04
600-1000	0.01	0.04	0.01	0.03

Table 3: EANs of salinity at different vertical layers evaluated for V1 and V2 systems for the period 2014-2015: S-CLASS4-EAN-MEAN_LAYER and S-CLASS4-EAN-RMS_LAYER in Table 9.

SLA prod – SLA ref [cm]	V1 system	V2 system
REGION	RMS SL-CLASS4-EAN-RMS_BASIN	RMS SL-CLASS4-EAN-RMS_BASIN
MED SEA	4.1	3.6
REGION 1	4.7	4.6
REGION 2	4.3	3.5
REGION 3	3.2	2.8
REGION 4	3.2	2.8
REGION 5	2.6	2.5
REGION 6	2.9	2.7
REGION 7	2.8	2.5
REGION 8	3.3	2.9
REGION 9	3.8	3.7
REGION 10	3.6	3.3
REGION 11	3.4	2.8
REGION 12	3.4	3
REGION 13	3.2	2.8

Table 4: EANs of Sea Level evaluated for V1 and V2 systems for the period 2014-2015 for the Mediterranean Sea and 13 regions (see Figure 1): SL-CLASS4-EAN-RMS_BASIN in Table 9.

The metrics of Table **1** and Table **2** give indications about the accuracy of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 temperature variable along the water column and at the surface for the Mediterranean Sea and 13 sub-regions. The values for all the levels are computed using Argo profiles. The RMS and mean of both systems are higher at the first level and decrease significantly below the third layer. There are some differences between V1 and V2 products: V1 system performs slightly better at the surface while V2 shows improvements at lower layers.

The statistics listed in Table **3** give indications about the accuracy of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 salinity product. The values for all the levels are computed using Argo profiles. The performance of the new system is slightly increased with RMSs values lower than the ones evaluated for V1 system. This has been achieved by improving the data assimilation with grid point EOFs and the modification in the background covariance matrix (details in section II.3). Below the third layer the RMS and mean values decrease significantly with respect to surface values.

The metrics shown in Table **2** define the accuracy of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 sea level anomaly. The statics are computed along the satellite track. Statistics show relevant improvement in the new V2 version of the system with enhanced ability to reproduce the sea surface height with respect to the previous system V1. This improvement has been achieved by correcting the use of Dynamic Atmospheric Correction when assimilating SLA data and using a 20 years referenced MDT (details in section II.3).

II PRODUCTION SUB-SYSTEM DESCRIPTION

II.1 Production centre details

PU: INGV

Production chain: Med-MFC-currents

External product: temperature (3D), salinity (3D), meridional and zonal currents (3D), sea surface height (2D), Mixed Layer Depth (2D), bottom temperature (2D), meridional and zonal Stokes drift velocity (2D), wave number (2D)

Frequency of model output: daily (24-hr averages) and hourly (1-hr averages)

Geographical coverage: 15°W → 36.25°E ; 30.19°N → 45.94°N (Gulf of Biscay is excluded)

Horizontal resolution: 1/16°

Vertical coverage: From surface to 5334 m (72 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 physical analysis and forecasts for the Mediterranean Sea are produced by the INGV Production Unit by means of the 3DVAR-NEMO-WW3 model system (described below).

Analyses and forecasts for Med-Currents are 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**: Top: Scheme of the analysis and forecast MyO-FO Med-MFC processing chain; Bottom: Sketch of the coupling mechanism between WW3 and NEMO.

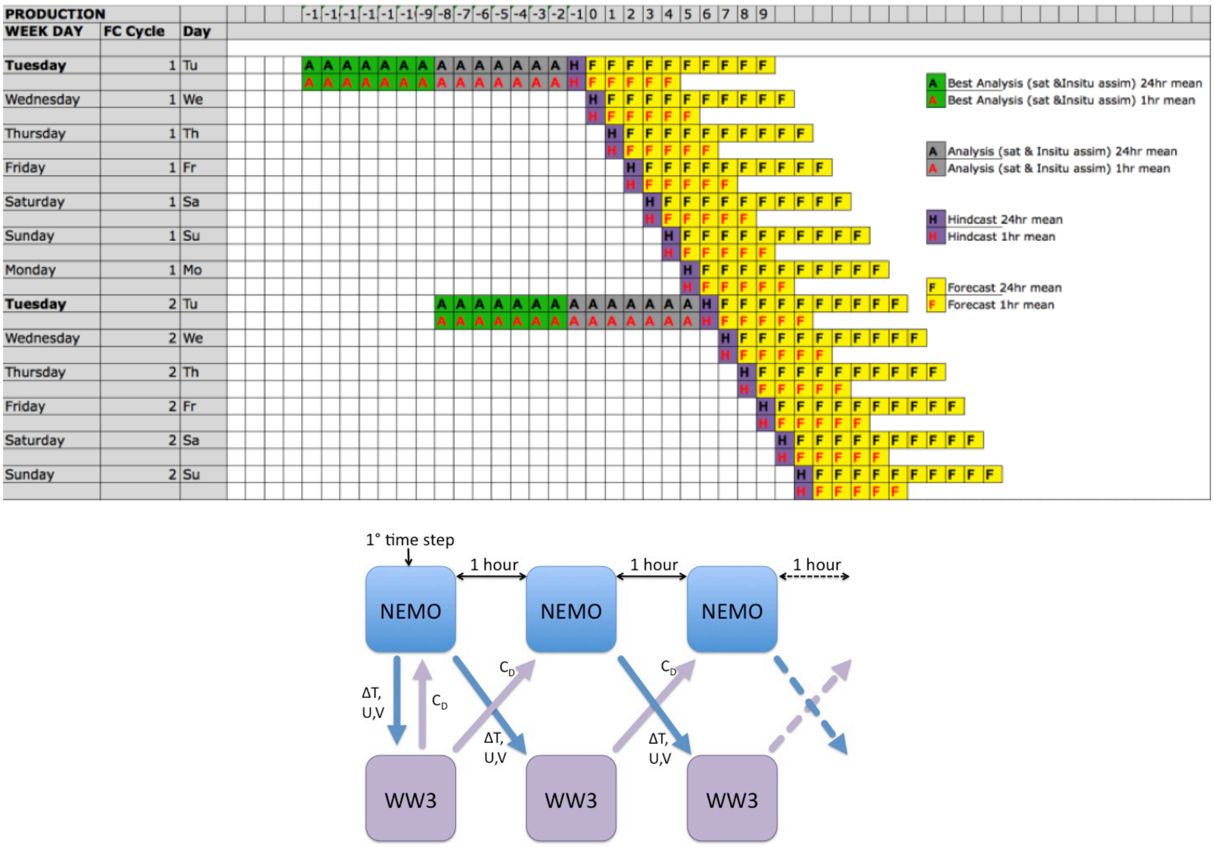


Figure 2. Top: Scheme of the analysis and forecast CMEMS Med-MFC processing chain. Bottom: Sketch of the coupling mechanism between WW3 and NEMO. When the simulation starts, models exchange information after the first time step (10 min), while later they communicate every hour. NEMO inputs WW3 with air-sea temperature differences (ΔT) and current fields (U,V), while WW3 passes to NEMO the wind stress drag coefficient.

The Med-MFC-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 code is coupled with WW3 model to produce one day of hindcast and 10-day forecast.
3. Analysis/Hindcast (only on Tuesday): NEMO code is combined with OceanVar in order to produce the best estimation of the sea (i.e. analysis). The NEMO+WW3+OceanVar system is running for 15 days into the past in order to use the best available along tack SLA products. The latest days 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.2 Description of the 3DVAR-NEMO-WW3 model system

Med-currents model system

The Mediterranean Forecasting System, MFS, (Tonani et al 2014, Dombrowsky et al. 2009) is the physical component of the Mediterranean Forecasting System (Med-currents) and is providing since year 2000 short term forecast for the Mediterranean. It is a coupled hydrodynamic-wave model implemented over the whole Mediterranean Basin. The model horizontal grid resolution is 1/16˚ (ca. 6km) and has 72 unevenly spaced vertical levels.

The hydrodynamics are supplied by the Nucleous for European Modelling of the Ocean (NEMO) 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 3.4 (Madec et al 2008). The code is developed and maintained by the NEMO-consortium. The model solves the primitive equations in spherical coordinates.

NEMO has been implemented in the Mediterranean at 1/16° x 1/16° horizontal resolution and 72 unevenly spaced vertical levels (Oddo et al., 2009) with time step of 300sec. The model covers the whole Mediterranean Sea and also extend 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. Also the atmospheric pressure effect has been introduced in the model dynamic (Oddo et al., 2014). The horizontal eddy diffusivity coefficient for tracers and the horizontal bilaplacian eddy viscosity has been set respectively equal to -6.e8 [m4/s] and -1.e9 [m4/s]. Moreover at the bottom, a quadratic bottom drag coefficient with a logarithmic formulation has been used according to Maraldi et al. (2013).

The hydrodynamic model is nested, in the Atlantic, within the Global analysis and forecast system GLO-MFC daily data set (1/12° horizontal resolution, 50 vertical levels) that is interpolated onto the Med-MFC model grid. Details on the nesting technique and major impacts on the model results are in Oddo et al., 2009. The model uses vertical partial cells to fit the bottom depth shape.

The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae using the 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) 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 forecast data, while the runoffs are provided by monthly mean datasets: the Global Runoff Data Centre dataset (Fekete et al., 1999) for the Ebro, Nile and Rhone and the dataset from Raicich (Raicich, 1996) for the Adriatic rivers (Po, Vjosë, Seman and Bojana). The Dardanelles inflow is parameterized as a river and the climatological net inflow rates are taken from Kourafalou and Barbopoulos (2003).

Wave model component (WW3)

The Wave dynamic is solved by a Mediterranean implementation of the WaveWatch-III code version 3.14 (Tolman 2009). WaveWatch covers the same domain and follows the same horizontal discretization of the circulation model (1/16° x 1/16°) with a time step of 600 sec. The wave model uses 24 directional bins (15° directional resolution) and 30 frequency bins (ranging between 0.05Hz and 0.7931 Hz) to represent the wave spectral distribution.

WW3 has been forced by the same 1/8 degree horizontal resolution ECMWF atmospheric forcings 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., 2013.

The surface Stokes Drift and the mean wavenumber are evaluated through the WW3 model and made available to the users so the vertical component can be calculated; it has to be noticed that the 3D current velocity released to the users (and evaluated by the circulation model NEMO) are not modified by the Stokes Drift. The wave-current model coupling has been implemented since MyOcean V3 and has not been modified in the following versions.

Description of Data Assimilation scheme

The data assimilation system is the OCEANVAR scheme developed by Dobricic and Pinardi (2008). The background error correlation matrix, B, is estimated from 12 years time series of Sea Level Anomaly, Temperature and Salinity from MyOcean Reanalysis datasets. Tri-variate Background Error Correlation matrices are defined monthly and for each grid point deeper than 75m in the Mediterranean Sea. Observation Error Correlation Matrix, R, has a monthly and z-dependent variability evaluated from Desrozier's relationship (Desrozier et al. 2005).

The mean dynamic topography used in the assimilation of SLA has been computed by Rio et al (2014). The assimilated data include: sea level anomaly, sea surface temperature (nudging), in situ temperature profiles by VOS XBTs (Voluntary Observing Ship-eXpandable Bathythermograph), in situ temperature and salinity profiles by ARGO floats, in situ temperature and salinity profiles from GLIDER (Conductivity-Temperature-Depth). Concerning SLA data a dedicated satellite product accounting for Dynamic Atmospheric Correction is used. Satellite OA-SST (Objective Analyses-Sea Surface Temperature) data are used for the correction of surface heat fluxes with the relaxation constant of 40 W m-2 K-1.

II.3 New features of the Med-MFC-currents V2 system

The new features of the Med-MFC V2 physical component are mainly due to data assimilation (D.A.) improvements and use of daily ECMWF precipitations instead of climatological values. The main differences between the CMEMS Med-MFC-currents V1 and V2 systems are summarized in Table **5** and described hereafter.

SYSTEM	IC	D.A. Vertical Background error covariance matrix (B)	D.A. Observational error covariance matrix (R)	D.A. Sign correction in SLA DAC	D.A. Mean Dynamic Topography MDF after 2014-03-24	Precipitation dataset
CMEMS Med-MFC curents **V2** (EAS1)	From restart file of V1 (01/12/2012)	30 EOFs for each grid point	z-dependent with monthly variability	AVISO+DAC (14km)	20 yrs MDT 1993-2013 (Rio et al 2014)	Daily ECMWF
CMEMS Med-MFC currents **V1** (SYS4e)	SDN Clim T/S (01/01/2011)	20 EOFs 13 Regions Seasonal	Constant and uniform: T: 0.05ºC S: 0.02 PSU SLA: 0.02m	AVISO-DAC (14km)	7 yrs MDT	CMAP monthly climatology

Table 5: Differences between CMEMS Med-MFC-currents V2 and V1 systems.

1. Data Assimilation (D.A) improvements

- Grid point EOFs and error covariance matrix

  The data assimilation scheme used in the Med-MFC V1 operational system is the OceanVar based on a variational scheme where the vertical covariances are represented by 20 seasonally and regionally variable empirical orthogonal functions (EOFs) of surface elevation and vertical profiles of temperature and salinity (Dobricic et al, 2005).

  Since these EOFs cannot represent the whole variability of the vertical structure of the background-error variance in the Mediterranean Sea and in order to assimilate vertical profiles also in the deeper part of the water column below 2000m, new grid-point EOFs have been implemented in the Med-MFC assimilation V2 system. 30 grid point EOFs have been evaluated starting from Med-MFC reanalysis product (1987-2013) over a box of 8x8 grid cells around the target point and retaining only points deeper than the target point. The correlation matrix from the input profiles has been normalized with the standard deviation evaluated removing the yearly mean. Since the resulting Vertical Background error covariance matrix (B) is 2 orders of magnitude bigger than the one evaluated in case of regional EOFs, the corresponding observational error covariance matrix (R) has been increased using the Desrozier's relationship (Eq. 1).

  Starting from 2 years simulation misfits, a z-dependent error has been found balancing the following formulation:

  $$E(d_b^o d_b^{OT}) = R + \alpha HBH^T \qquad (1)$$

  where $E(d_b^o d_b^{OT})$ is the expected variance of the misfits, *H* is the linear observation operator for the interpolation of model state variables into observational positions and α has been set equal to 0.5. The domain average value has been subtracted to each month in order to evaluate the unbiased estimate of misfits variance, so R is constant in space but z-dependent with monthly variability.

- The SLA assimilation in the MED-MFC is achieved by using data from along-track SL-TAC to which the DAC (Dynamic Atmospheric Correction) evaluated by TAPAS dataset is applied. A correction in the sign of the DAC in applied in V2 system.
- Since from 24-03-2014 the sea level data are computed with respect to a twenty-year mean (1993-2012), a new Mean Dynamic Topography (MDT) released in 2014 has been used for the SLA assimilation.

2. Implementation of daily ECMWF precipitations

   The CMAP (Climate Prediction Centre Merged Analysis of Precipitation) monthly climatology precipitations are replaced by the ECMWF daily precipitations in the V2 system.

II.4 Upstream data and boundary condition of the 3DVAR-NEMO-WW3 model

The CMEMS MED-MFC-currents system uses the following upstream data:

1. Atmospheric forcing (including precipitatin): 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, Seman, and Buna-Bojana
3. Data assimilation:
   - Temperature and Salinity vertical profiles from Copernicus INSITU TAC
     - INSITU_MED_NRT_OBSERVATIONS_013_035
     - INSITU_GLO_NRT_OBSERVATIONS_013_030
   - Satellite along track Sea Level Anomaly from Copernicus SL TAC:
     - SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021
     - SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019
   - Satellite SST from Copernicus OSI TAC (nudging):
     - SST_MED_SST_L4_NRT_OBSERVATIONS_010_004
4. Initial conditions are those of the CMEMS Med-MFC V1 analysis and forecast system at 1st December 2012.
5. Laterl boundary conditions from Copernicus Global Analysis and Forecast system: GLOBAL_ANALYSIS_FORECAST_PHYS_001_002 at 1/12° horizontal resolution, 50 vertical levels. In particular for the lateral boundary condition the following conditions are considered:
   1. The radiative phase velocity (Cx and Cy) is computed at the open boundaries (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

III VALIDATION FRAMEWORK

In order to evaluate and assure the quality of the MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 product of the CMEMS Med-MFC-currents version V2, a simulation experiment has been performed using the system described in section II, that will be operational at V2 version, and covering 3 years period from December 2012-December 2015.

In particular the qualification task has been carried out over 2 years period, from January 2014 to December 2015, based on MERSEA Class 4 diagnostics (model and observational data comparisons).

The performance of the V2 Med-currents system has been assessed by using external products, i.e. temperature, salinity, sea level and currents, using quasi-independent satellite and in-situ observations and independent moored buoys in compliance with the Scientific PreOperational Qualification Plan (ScQP).

Quasi-independent data are all the observations (Satellite SLA and SST and in situ vertical profiles of temperature and salinity from XBT, Argo and Glider) that are assimilated into the system. Diagnostic in term of RMS of the misfits and/or bias is computed. The independent in-situ observations are delivered by a network of 13 institutes from Copernicus INSITU TAC (Puertos del Estado, IFREMER, CNR-IAMC-ISSIA-ISMAR, HCMR, OC-UCY, CSIC, OGS, ISPRA, NIB-MBS) and MonGOOS partners (IOLR, UMT-IOI-POU, IASA-UAT, IMS-METU) and are downloaded operationally on a daily basis by the Med-MFC operational centre at INGV.

The datasets of observations used for the qualification task are listed below: in Table **6** and in Table **7** there is respectively the list of the used quasi-independent and independent data with the corresponding CMEMS product names. In

INDEPENDENT DATA		
	AVAILABILITY	
	IN 2014	IN 2015
TEMPERATURE	20	11
SALINITY	11	10
SEA LEVEL ANOMALY	42	51
CURRENTS	7	7
SST	16	11

Table **8** there are the numbers of all the available independent moored buoys, for the year 2014 and 2015 and Figure 3 shows the locations of moored buoys.

QUASI-INDEPENDENT DATA	
TYPE	CMEMS PRODUCT NAME
ARGO XBT CTD& GLIDER	INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035

SLA	SEALEVEL_MED_SLA_ASSIM_L3_NRT_OBSERVATIONS_008_021 SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019
SST	SST_MED_SST_L4_NRT_OBSERVATIONS_010_004_a

Table 6: list of the quasi-independent observations

INDEPENDENT DATA	
TYPE	**CMEMS PRODUCT NAME**
MOORED BUOYS	INSITU_MED_NRT_OBSERVATIONS_013_035

Table 7: list of the independent observations

INDEPENDENT DATA		
	AVAILABILITY	
	IN 2014	**IN 2015**
TEMPERATURE	20	11
SALINITY	11	10
SEA LEVEL ANOMALY	42	51
CURRENTS	7	7
SST	16	11

Table 8: Availability and Numbers of the independent data (moored buoy)

Figure 3: Locations of moored independent in-situ data in the Mediterranean Sea.

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 previous V1 system is presented in Table **9** in accordance to the Scientific PreOperational Qualification Plan.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of Med-MFC-Currents using semi-independent data: Estimate Accuracy Numbers				
T-CLASS4-EAN-RMS_LAYER	Temperature vertical profiles comparison with Copernicus INSITU TAC and MonGOOS moored buoys data at 6 layers for the Mediterranean basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners (for the first layer only)	Temperature daily RMSs of the difference between model and insitu observations averaged over the qualification testing period (Jan 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for 6 different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m)
T-CLASS4-EAN-MEAN_LAYER	Temperature vertical profiles comparison with Copernicus INSITU TAC and MonGOOS moored buoys data at 6 layers for the Mediterranean basin.	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners (for the first layer only)	Temperature daily mean differences between model and insitu observations averaged over the qualification testing period (Jan 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for 6 different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m)
S-CLASS4-EAN-RMS_LAYER	Salinity vertical profiles comparison with Copernicus INSITU TAC and MonGOOS moored buoys data at 6 layers for the Mediterranean basin.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners (for the first layer only)	Salinity daily RMSs of the difference between model and insitu observations averaged over the qualification testing period (Jan 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are evaluated for 6 different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m)
S-CLASS4-EAN-MEAN_LAYER	Salinity vertical profiles comparison with Copernicus INSITU TAC and MonGOOS moored buoys data at 6 layers for the Mediterranean	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035	Salinity daily mean differences between model and insitu observations averaged over the qualification testing period (Jan 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and are

	basin.		Moored buoys from MonGOOS partners (for the first layer only)	evaluated for 6 different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m)
SL-CLASS4-EAN-RMS_BASIN	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	Sea level daily RMSs of the difference between model and satellite observations averaged over the qualification testing period (Jan 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
SST-CLASS4-EAN-RMS_BASIN	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 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
SST-CLASS4-EAN-MEAN_BASIN	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 2014-Dec 2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
NRT evaluation of Med-MFC-Currents using semi-independent data. Daily comparison				
T-CLASS4-RMS_LAYER_BASIN	Temperature vertical profiles comparison with Copernicus INSITU TAC data at 6 layers for the Mediterranean basin and selected sub-basins	Temperature	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 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 (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins, and are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m).
T-CLASS4-BIAS_LAYER_BASIN	Temperature vertical profiles comparison with Copernicus INSITU TAC	Temperature	Argo floats from the Copernicus INSITU TAC products:	Time series of daily bias (difference between model and insitu observations) computed for temperature evaluated over the

	data at 6 layers for the Mediterranean basin and selected sub-basins		INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035	qualification testing period (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins, and are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m).
S-CLASS4-RMS_LAYER_BASIN	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 6 layers for the Mediterranean basin and selected sub-basins	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 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 (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins, and are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m).
S-CLASS4-BIAS_LAYER_BASIN	Salinity vertical profiles comparison with Copernicus INSITU TAC data at 6 layers for the Mediterranean basin and selected sub-basins	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035	Time series of daily bias (difference between model and insitu observations) computed for temperature evaluated over the qualification testing period (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins, and are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m).
SL-CLASS4-RMS_BASIN	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	Time series of sea level anomaly daily RMSs of the difference between model and satellite observations evaluated over the qualification testing period (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
SST-CLASS4-RMS_BASIN	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	Time series of sea surface temperature daily RMSs of the difference between model and satellite observations evaluated over the qualification testing period (2014-2015). This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
SST-CLASS4-BIAS_BASIN	Sea Surface Temperature comparison with SST Copernicus OSI TAC L4	Sea Surface Temperature	SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_01	Time series of daily bias (difference between model and satellite observations) computed for sea surface temperature evaluated over the qualification testing period (2014-2015).

	(satellite) data for the Mediterranean basin and selected sub-basins.		0_004	This quantity is evaluated on the model analysis. The statistics are defined for all the Mediterranean Sea and selected sub-basins.
NRT evaluation of Med-MFC-Currents using semi-independent data. Weekly comparison of misfits				
T-CLASS4-RMS_DEPTH	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_GLO_NRT_OBSERVATIONS_013_030 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 (2014-2015). 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-CLASS4-RMS_DEPTH	Salinity vertical profiles comparison with assimilated Copernicus INSITU TAC data at 5 specified depths.	Salinity	Argo floats from the Copernicus INSITU TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 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. 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.
SL-CLASS4-RMS	Sea level anomaly comparison with assimilated Copernicus Sea Level TAC satellite along track data for the Mediterranean basin.	Sea Level Anomlay	Satellites (Jason1, Jason2, Envisat, 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. 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.
SST-CLASS4-RMS	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 weekly RMSs of the difference between model and satellite observations evaluated over the qualification testing period. Together with the time series, the average value of weekly RMSs is evaluated over the qualification testing period.

				This quantity is evaluated on the model analysis
SST-CLASS4-BIAS	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 weekly bias (difference between model and satellite observations) evaluated over the qualification testing period. Together with the time series, the average value of weekly bias is evaluated over the qualification testing period. This quantity is evaluated on the model analysis
NRT evaluation of Med-MFC-Currents using independent data. Daily comparison with moored buoys				
T-CLASS4-RMS-INDEPENDENT	Temperature comparison with Copernicus INSITU TAC and MonGOOS data.	Temperatue	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	Time series of daily temperature of insitu observations and model outputs evaluated for the surface layer (0-3 m) 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.
T-CLASS4-BIAS-INDEPENDENT	Temperature comparison with Copernicus INSITU TAC and MonGOOS data.	Temperatue	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	Time series of daily temperature of insitu observations and model outputs evaluated for the surface layer (0-3 m) 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.
S-CLASS4-RMS-INDEPENDENT	Salinity comparison with Copernicus INSITU TAC and MonGOOS data.	Salinity	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	Time series of daily salinity of insitu observations and model outputs evaluated for the surface layer (0-3 m) 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.
S-CLASS4-BIAS-INDEPENDENT	Salinity comparison with Copernicus INSITU TAC and MonGOOS data.	Salinity	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	Time series of daily salinity of insitu observations and model outputs evaluated for the surface layer (0-3 m) 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.

SL-CLASS4-RMS-INDEPENDENT	Sea Level comparison with Copernicus INSITU TAC and MonGOOS data.	Sea Level	Tide-gauges from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Tide-gauges from MonGOOS partners	Time series of daily sea surface height 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.
SL-CLASS4-BIAS-INDEPENDENT	Sea Level comparison with Copernicus INSITU TAC and MonGOOS data.	Sea Level	Tide-gauges from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Tide-gauges from MonGOOS partners	Time series of daily sea surface height 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.
UV-CLASS4-RMS-INDEPENDENT	Surface currents comparison with Copernicus INSITU TAC and MonGOOS data.	Currents	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	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-CLASS4-BIAS-INDEPENDENT	Surface currents comparison with Copernicus INSITU TAC and MonGOOS data.	Currents	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners	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.
T-CLASS4-RMS-SURF_INDEPENDENT	Sea Surface Temperature comparison with Copernicus INSITU TAC and MonGOOS data, and with Copernicus OSI TAC L4 (satellite) data.	Sea Surface Temperature	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030 INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	Time series of daily sea surface temperature 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.
T-CLASS4-BIAS-SURF_INDEPENDENT	Sea Surface Temperature comparison with Copernicus INSITU TAC	Sea Surface Temperature	Moored buoys from Copernicus InSitu TAC products: INSITU_GLO_NRT_OBSERVATIONS_013_030	Time series of daily sea surface temperature of insitu observations and model outputs evaluated over the qualification testing period. Together with the time series, the average value of daily bias is

	and MonGOOS data, and with Copernicus OSI TAC L4 (satellite) data.		INSITU_MED_NRT_OBSERVATIONS_013_035 Moored buoys from MonGOOS partners SST satellite data from Copernicus OSI TAC L4 product: SST_MED_SST_L4_NRT_OBSERVATIONS_010_004	evaluated over the qualification testing period. This quantity is evaluated on the model analysis.

Table 9: List of metrics for Med_MFC-Currents evaluation using in-situ and satellite observations.

IV VALIDATION RESULTS

In the following tables, there is synthesis of the values of bias and Root Mean Square (RMS), calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 product with: quasi-independent data assimilated by the system (ARGO, CTD, XBT, glider and Satellite SLA & SST) (Table **10** and Table **11**); independent in-situ data from the available buoys in the Mediterranean Sea (Figure 3), for Temperature, Salinity, Sea Level, SST and currents (Table **12**).

The synthesis is based on 2 years period (2014-2015). In Table **10** there are the RMS and Bias (only for SST) computed comparing the Med-MFC-currents V2 system with the quasi-independent data for SST, T and S.

Variables/estimated accuracy:	Metrics		Depth	Observation
SEA SURFACE TEMPERATURE (°C)	**RMS** SST-CLASS4-RMS	**BIAS** SST-CLASS4-BIAS		
	0.53±0.09	-0.06 ± 0.12	0	Satellite SST
TEMPERATURE (°C):	**RMS** T-CLASS4-RMS_DEPTH		**Depth**	**Observation**
	0.54±0.18		8	Argo, CTD
	0.85±0.51		30	Argo, CTD
	0.29±0.05		150	Argo, CTD
	0.23±0.05		300	Argo, CTD
	0.13±0.03		600	Argo, CTD
	0.74±0.14		8	XBT
	0.74±0.22		30	XBT
	0.35±0.25		150	XBT
	0.17±0.09		300	XBT
	0.06±0.03		600	XBT
	0.25±0.14		8	GLIDER
	0.2±0.07		30	GLIDER
	0.17±0.06		150	GLIDER
	0.07±0.07		300	GLIDER
	0.07±0.06		600	GLIDER
SALINITY (psu)	S-CLASS4-RMS_DEPTH		**Depth**	**Observation**
	0.21±0.05		8	Argo, CTD
	0.19±0.04		30	Argo, CTD
	0.1±0.02		150	Argo, CTD
	0.05±0.01		300	Argo, CTD
	0.03±0.01		600	Argo, CTD
	0.16±0.12		8	GLIDER
	0.1±0.1		30	GLIDER
	0.09±0.05		150	GLIDER
	0.05±0.04		300	GLIDER
	0.02±0.01		600	GLIDER

Table 10: Quasi-independent validation. Analysis evaluation based over 2 years time series (2014-2015): SST-CLASS4-RMS, SST-CLASS4-BIAS, T-CLASS4-RMS_DEPTH, S-CLASS4-RMS_DEPTH.

In Table **11** there are the RMS for the Sea Level Anomaly calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 product with each available satellite from January 2014 to December 2015.

SEA LEVEL ANOMALIES (cm)	RMSE SL-CLASS4-RMS	Availability
All Satellites	3.2	01/01/2014-31/12/2015
ALTIKA	3.2	01/01/2014-31/12/2015
CRYOSAT	3.5	01/01/2014-31/12/2015
JASON 2	2.9	01/01/2014-31/12/2015

Table 11: Analysis evaluation based over 2 years time series (2014-2015) for the Sea Level Anomaly for each available satellite: SL-CLASS4-RMS.

The following figures (Figure **4**) show the time series of weekly RMSs of temperature misfits at 5 depths (8, 30, 150, 300, 600 m), T-CLASS4-RMS_DEPTH, for the CMEMS Med-MFC-currents V1 system (blue line) and the V2 system (red line) (observation minus model value transformed at the observation location and time). The differences between V2 and V1 systems are always very small. The new system presents a slightly higher error at surface and better performances at lower levels if compared to V1 system. The temperature error is generally higher above 150 m and presents a clear seasonal variability with higher values during warm seasons, then the error decrease significantly lower 150 m.

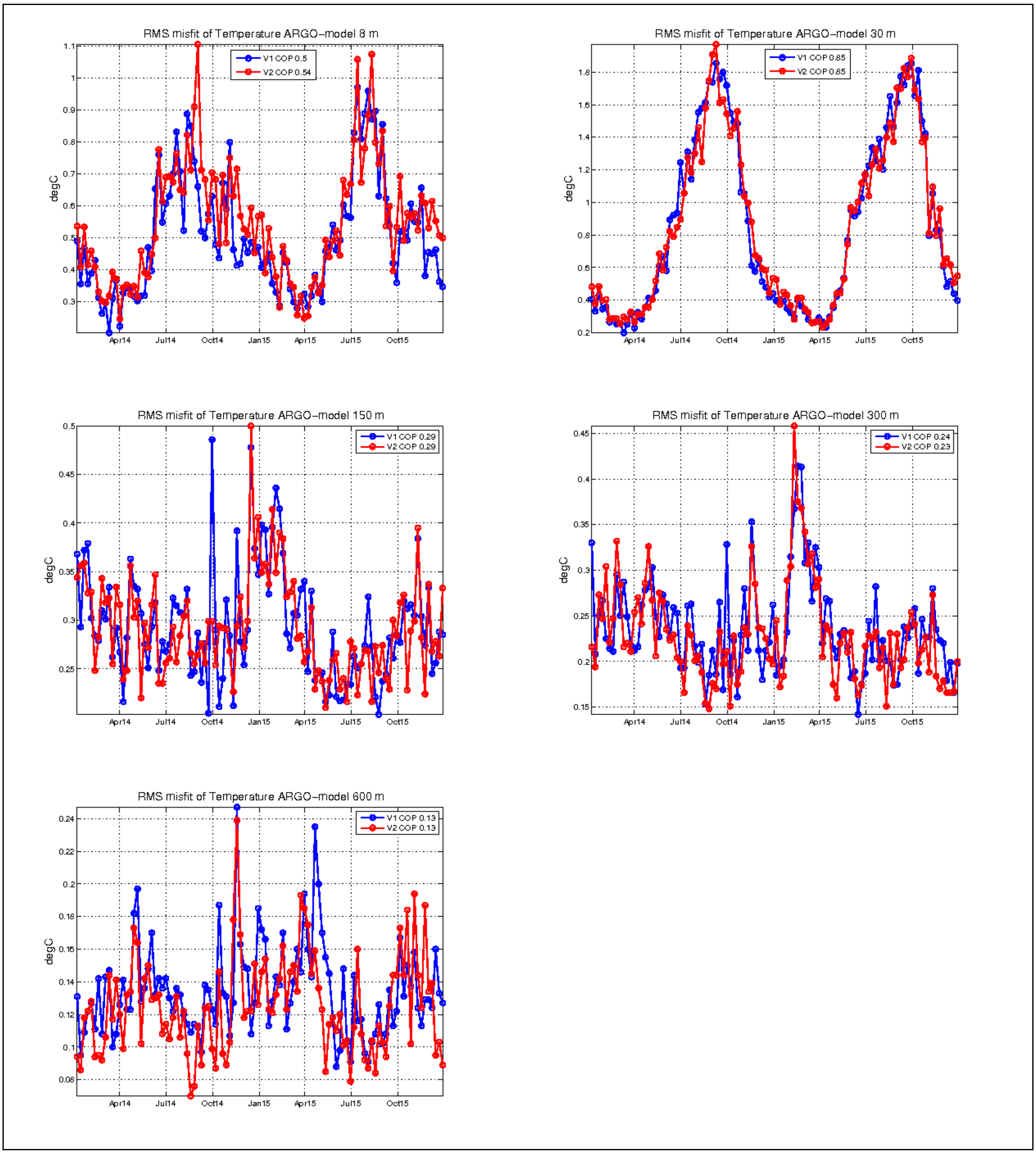


Figure 4: RMS misfit of temperature ARGO-Model at 8, 30, 150, 300 and 600 m (T-CLASS4-RMS_DEPTH)

The following figures (Figure **5**) show the time series of weekly RMSs of salinity misfits at 5 depths (8, 30, 150, 300, 600 m), S-CLASS4-RMS_DEPTH, for the CMEMS Med-MFC-currents V1 system (blue line) and the V2 system (red line) (observation minus model value transformed at the observation location and time).

The differences between V2 and V1 systems are always very small. The new system presents slightly better performances at lower levels if compared to V1 system. The salinity error is generally higher above 150 m with values around 0.2 PSU and better skill below 300 m. It presents a seasonal variability at first layers with higher values during warm seasons.

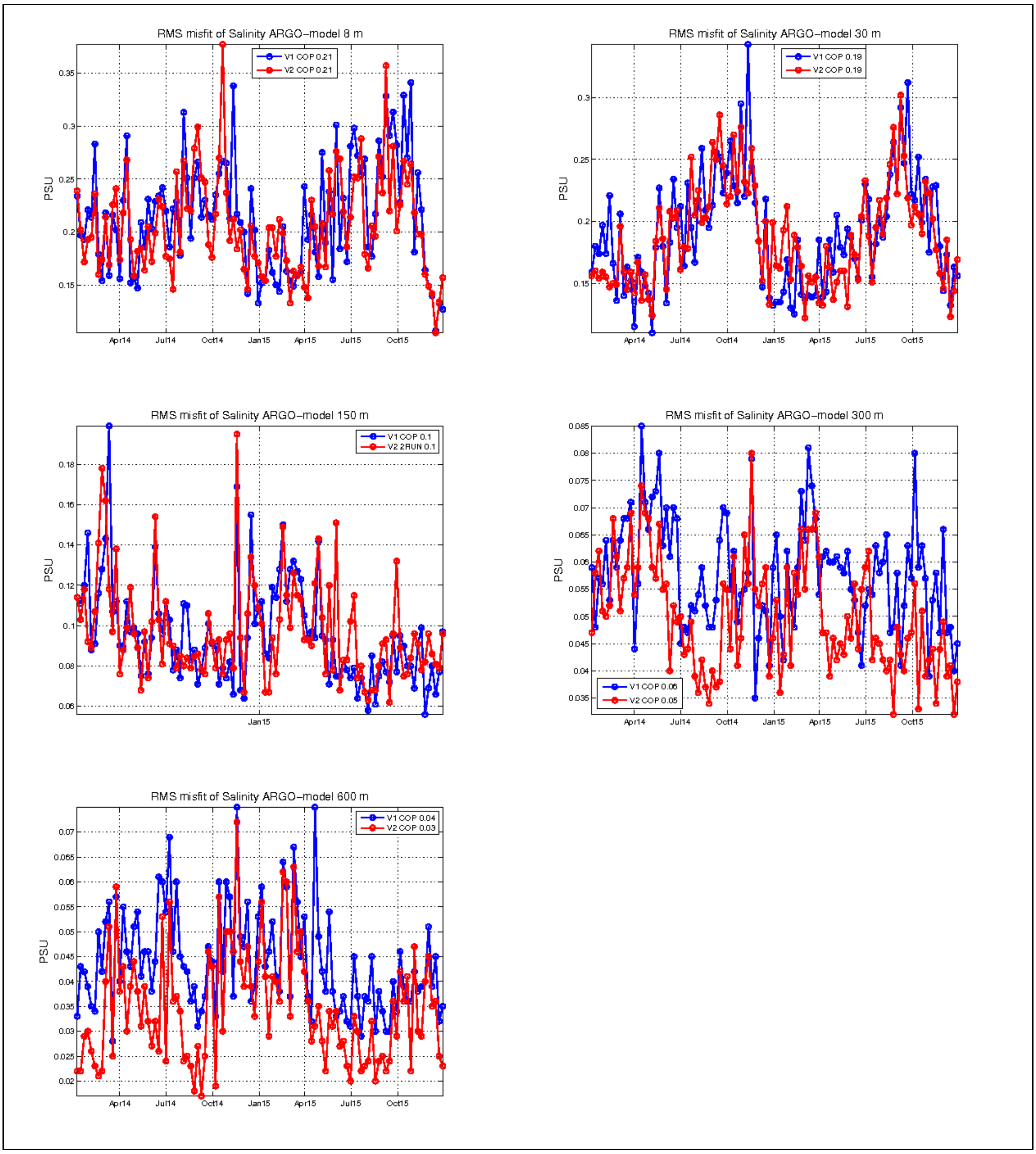


Figure 5: RMS misfit of salinity ARGO-Model at 8, 30, 150, 300 and 600 m (S-CLASS4-RMS_DEPTH)

The following figures (Figure **6**) show the time series of weekly RMSs of sea level anomaly misfits at surface, SL-CLASS4-RMS, for the CMEMS Med-MFC-currents V1 system (blue line) and the V2 system (red line) (observation minus model value transformed at the observation location and time).

The differences between V2 and V1 systems are relevant. The new system presents a better performance if compared to V1 system for each of the available satellite decreasing the error with observations in average of 1 cm (from 4.3 to 3.3cm considering all the satellites in the validation period 201-2015). The V2 enhanced skill is generated by data assimilation improvements terms of DAC (assimilated with correct sign) and use of a 20 years based MDT.

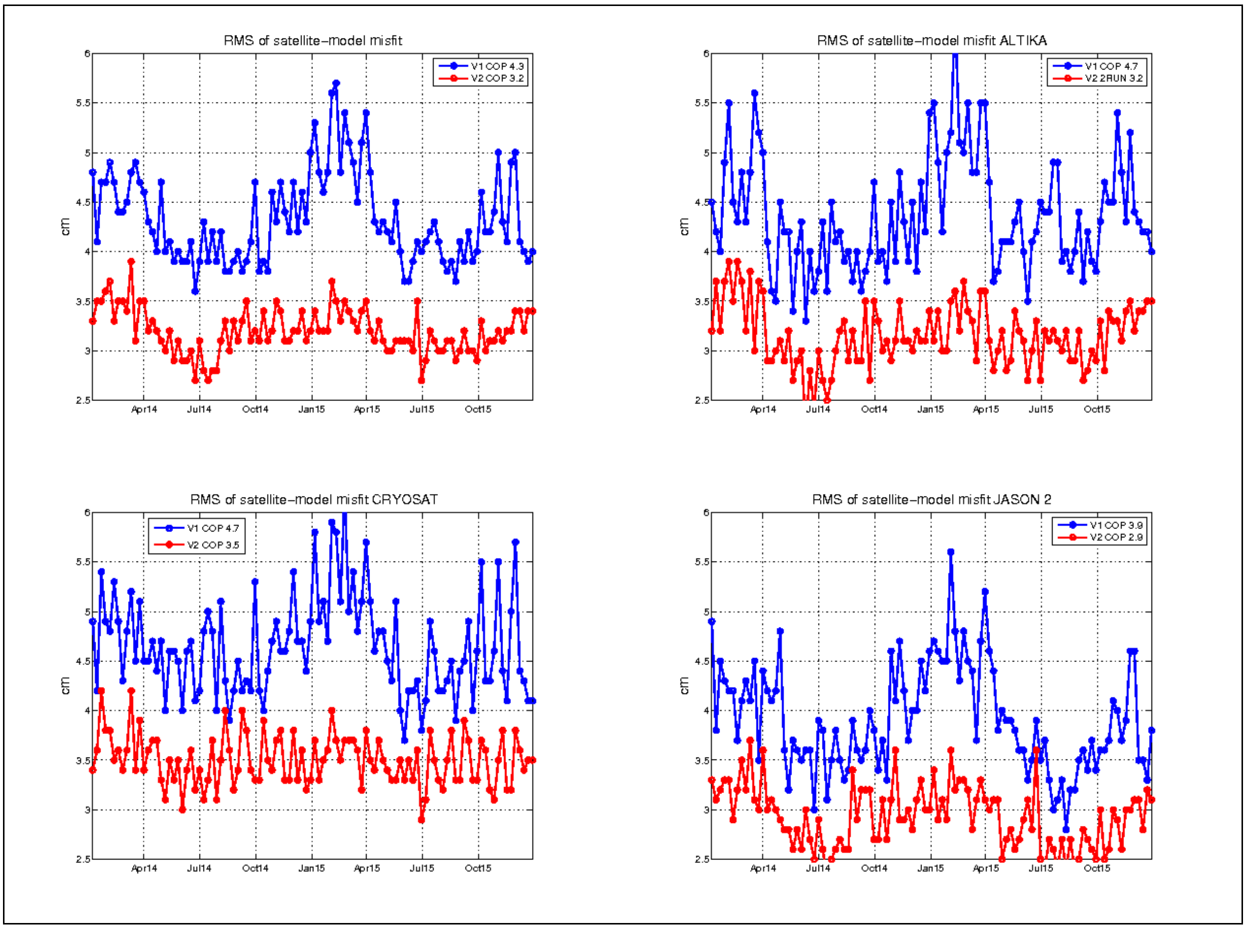


Figure 6 Weekly RMS misfit of satellite-model along SLA data track for all the satellite (panel top-left), for Altika (panel top-right), for Cryosat (panel bottom-left) and for Jason2 (panel bottom-right) (SL-CLASS4-RMS).

The following figures (Figure **7**) show the time series of temperature daily RMSs of the difference between model output and observations evaluated over the qualification testing period (2014-2015). The statistics are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m): T-CLASS4-RMS_LAYER_BASIN.

The differences between V2 and V1 systems are very small. The new system presents a slightly higher error at surface and better performances at lower levels if compared to V1 system. The average value of RMS over the entire period is the one listed in Table **1**. The temperature error is generally higher above 150 m and presents a clear seasonal variability with higher values during warm seasons, then the error decreases significantly below 150 m.

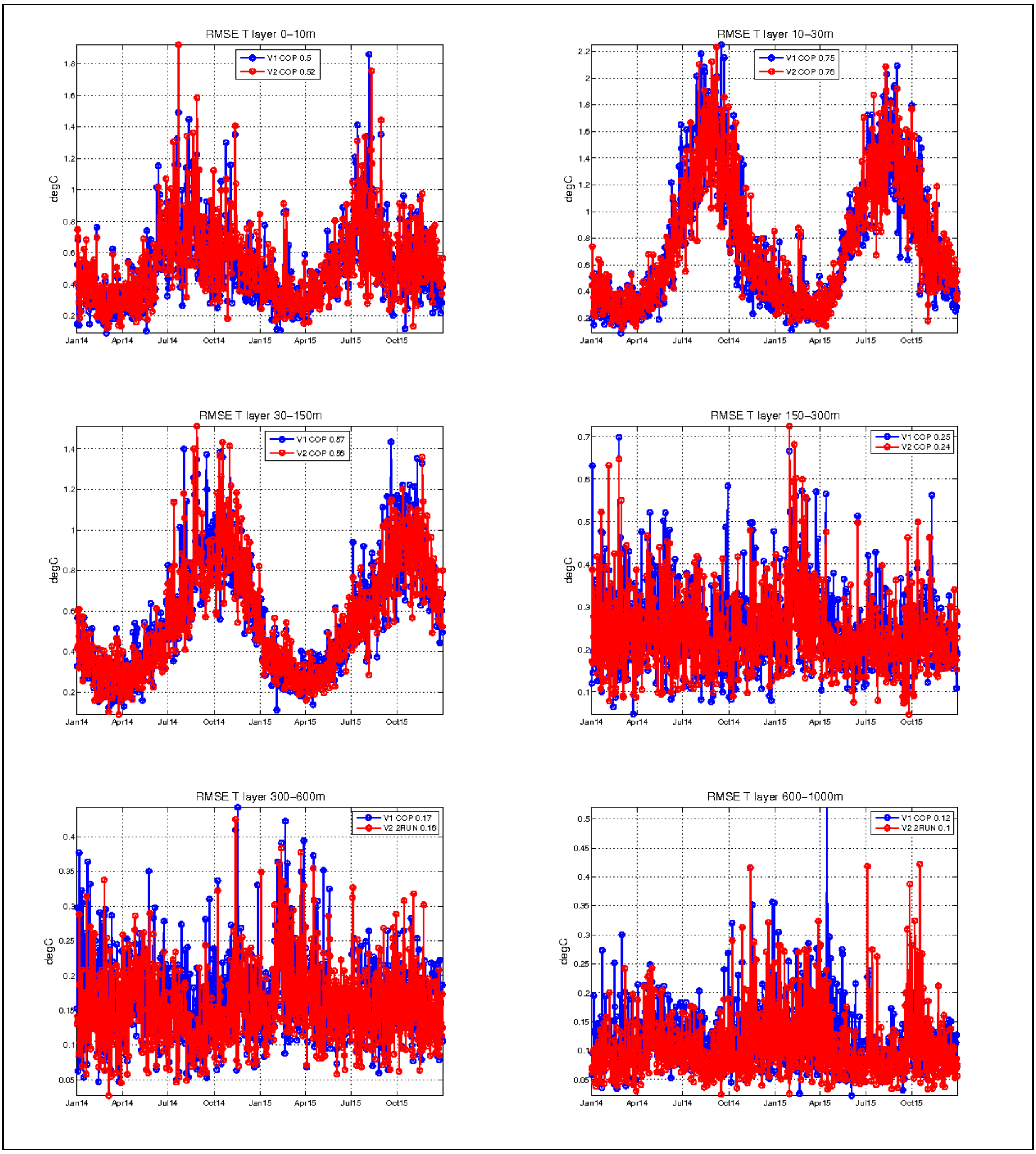


Figure 7: Time series of daily RMS of temperature at different vertical layers for V1 and V2 systems (T-CLASS4-RMS_LAYER_BASIN)

The following figures (Figure **8**) show the time series of salinity daily RMSs of the difference between model output and observations evaluated over the qualification testing period (2014-2015): S-CLASS4-RMS_LAYER_BASIN. The statistics are evaluated for seven different layers (0-10, 10-30, 30-150, 150-300, 300-600, 600-1000 m).

The differences between V2 and V1 systems are very small. The new system presents slightly better performances at almost all levels if compared to V1 system. The average value of RMS over the entire period is the one listed in Table **1**. The salinity error is generally higher above 150 m then the error decreases significantly below 150 m.

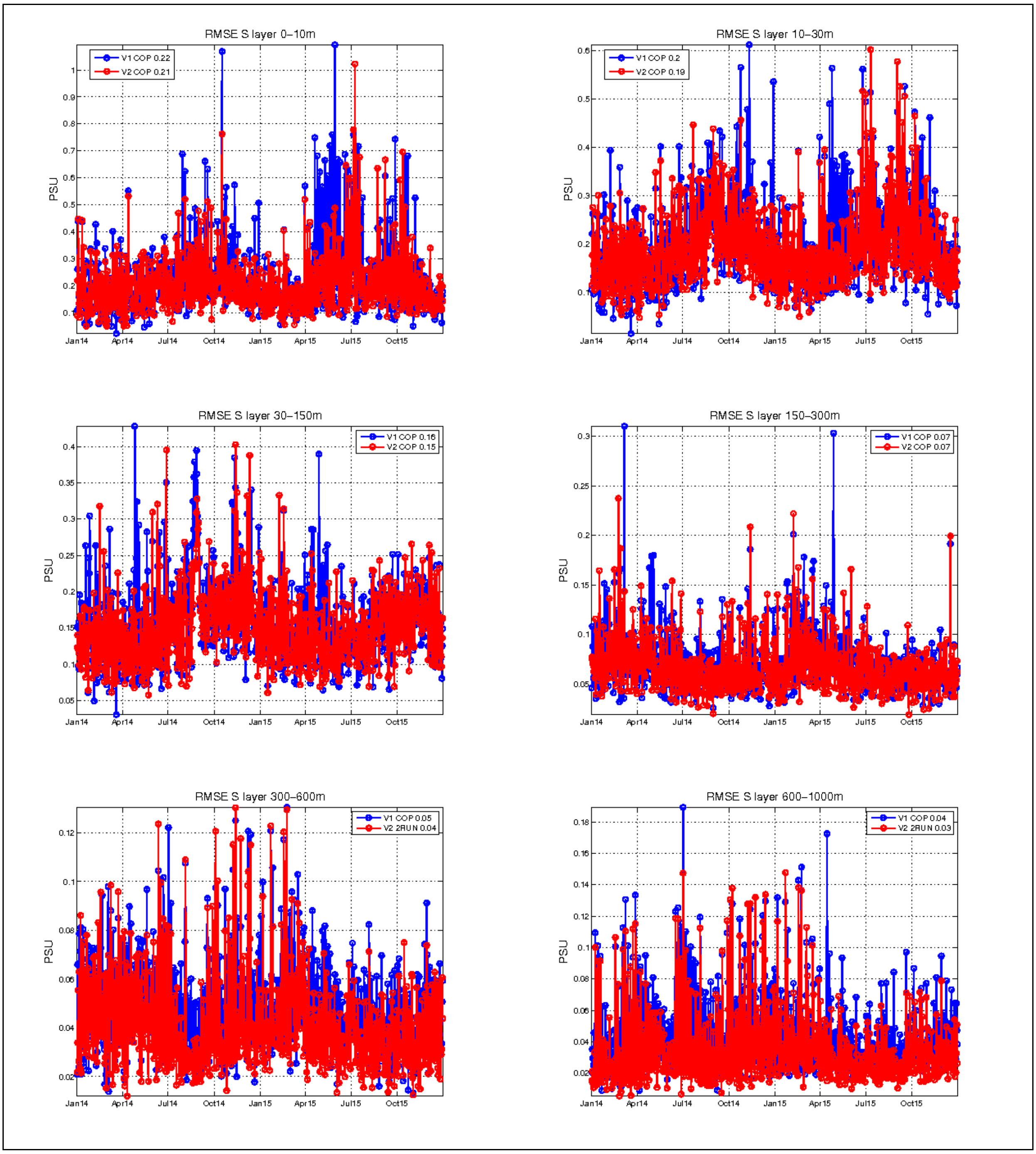


Figure 8: Time series of daily RMS of salinity at different vertical layers for V1 and V2 systems (S-CLASS4-RMS_LAYER_BASIN)

Figure 9 shows the time series of Sea Surface Temperature daily RMSs of the difference between model output and observations evaluated over the qualification testing period (2014-2015): SST-CLASS4-RMS_BASIN.

The differences between V2 and V1 systems are small and confirms a slightly higher error of the V2 system with respect to V1. In general the SST RMS is higher during warm period and autumn while it decreases during spring season.

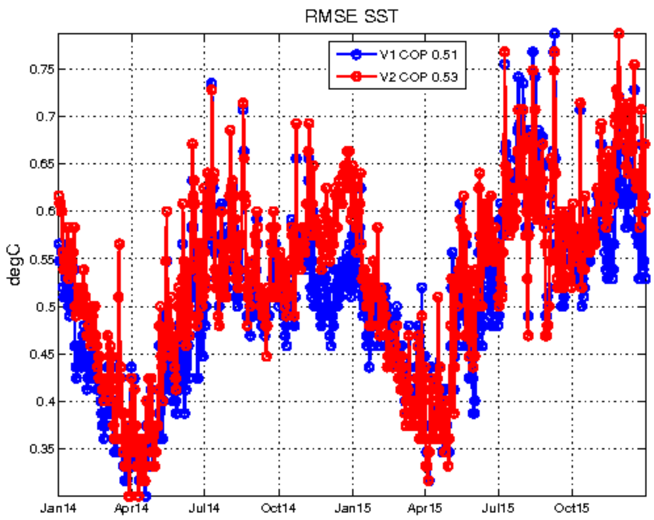


Figure 9: Time series of daily RMS of Sea Surface Temperature for V1 and V2 systems (SST-CLASS4-RMS_BASIN)

Figure **10** shows the time series of Sea Level Anomaly daily RMSs of the difference between model output and observations evaluated over the qualification testing period (2014-2015): SL-CLASS4-RMS_BASIN. The new system (red line) presents better performances during all the simulated period if compared to V1 system (blue line). The average value of RMS decreases of about 0.5 cm (from 4.1 to 3.6 cm) as a consequence of data assimilation improvements.

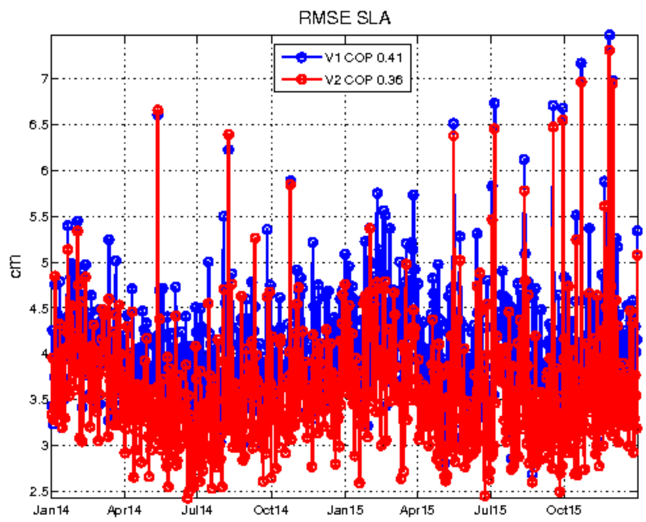


Figure 10: Time series of daily RMS of Sea Level Anomaly for V1 and V2 systems (SL-CLASS4-RMS_BASIN)

Table **12** summarizes the RMS and the Bias calculated comparing the analysis of MEDSEA_ANALYSIS_FORECAST_PHYS_006_001 product with the independent in-situ data (MB: moored buoys) for the year 2014 and 2015 as well as considering metrics averaged over both years.

Variables/estimated accuracy:	RMSE	Bias	Depth	Obs	n. of Obs.
	T-CLASS4-RMS-INDEPENDENT	T-CLASS4-BIAS-INDEPENDENT			
TEMPERATURE (°C) year 2014	0.77	-0.24	0-3	MB	20
TEMPERATURE (°C) year 2015	0.66	0.08	0-3	MB	11
TEMPERATURE (°C) years 2014-2015	0.73	-0.18	0-3	MB	
	S-CLASS4-RMS-INDEPENDENT	S-CLASS4-BIAS-INDEPENDENT			
SALINITY (psu) year 2014	0.80	0.50	0-3	MB	11
SALINITY (psu) year 2015	0.77	0.48	0-3	MB	10
SALINITY (psu) years 2014-2015	0.78	0.49	0-3	MB	
	SL-CLASS4-RMS-INDEPENDENT	SL-CLASS4-BIAS-INDEPENDENT			
SLA (cm) year 2014	5.54	-0.21	0-3	MB	42
SLA (cm) year 2015	5.92	-1.10	0-3	MB	51
SLA (cm) years 2014-2015	5.75	-0.68	0-3	MB	
	T-CLASS4-RMS-SURF_INDEPENDENT	T-CLASS4-BIAS-SURF_INDEPENDENT			
SST (°C) year 2014	0.69	-0.01	0-3	MB	16
SST (°C) year 2015	0.54	0.1	0-3	MB	11
SST (°C) years 2014-2015	0.63	0.04	0-3	MB	
	UV-CLASS4-RMS-INDEPENDENT	UV-CLASS4-BIAS-INDEPENDENT			
Zonal Current (cm/s) year 2014	9.2	0.84	0-3	MB	7
Zonal Current (cm/s) year 2015	13.21	-0.81	0-3	MB	6
Zonal Current (cm/s) years 2014-2015	11.06	0.07	0-3	MB	
Meridional Current (cm/s) year 2014	14.25	3.99	0-3	MB	7
Meridional Current (cm/s) year 2015	15.35	-2.27	0-3	MB	6
Meridional Current (cm/s) years 2014-2015	14.76	1.09	0-3	MB	

Table 12: Independent observation evaluation based on 2 years time series (2014-2015) of analysis and Moored Buoys observations: T-CLASS4-RMS-INDEPENDENT, T-CLASS4-BIAS-INDEPENDENT, S-CLASS4-RMS-INDEPENDENT, S-CLASS4-BIAS-INDEPENDENT, SL-CLASS4-RMS-INDEPENDENT, SL-CLASS4-BIAS-INDEPENDENT, UV-CLASS4-RMS-INDEPENDENT, UV-CLASS4-BIAS-INDEPENDENT, T-CLASS4-RMS-SURF_INDEPENDENT, T-CLASS4-BIAS-SURF_INDEPENDENT

Figure **11** to Figure **14** show the daily temperature, salinity, sea level, zonal currents and meridional currents time series of V1 (blue line) and V2 (red line) model outputs against specified moored buoys (green line) for the year 2014 (top) and 2015 (bottom). In general the two systems present small differences with similar skill. Some examples are shown hereafter considering temperature at Tarragona buoy (Fig 11), Salinity (Fig 12), Sea Level (Fig 13) and Currents (Fig 14) at Valencia buoy. The V1 and V2 modelling systems exhibit a good ability in representing the measurements and only little differences can be inferred by the two timeseries. In particular currents at Valencia buoy evaluated by the V2 system show an improvement with respect to V1 that could be achieved by the improved SLA; but considering metrics evaluated at all buoys, not a clear improvement can be assessed.

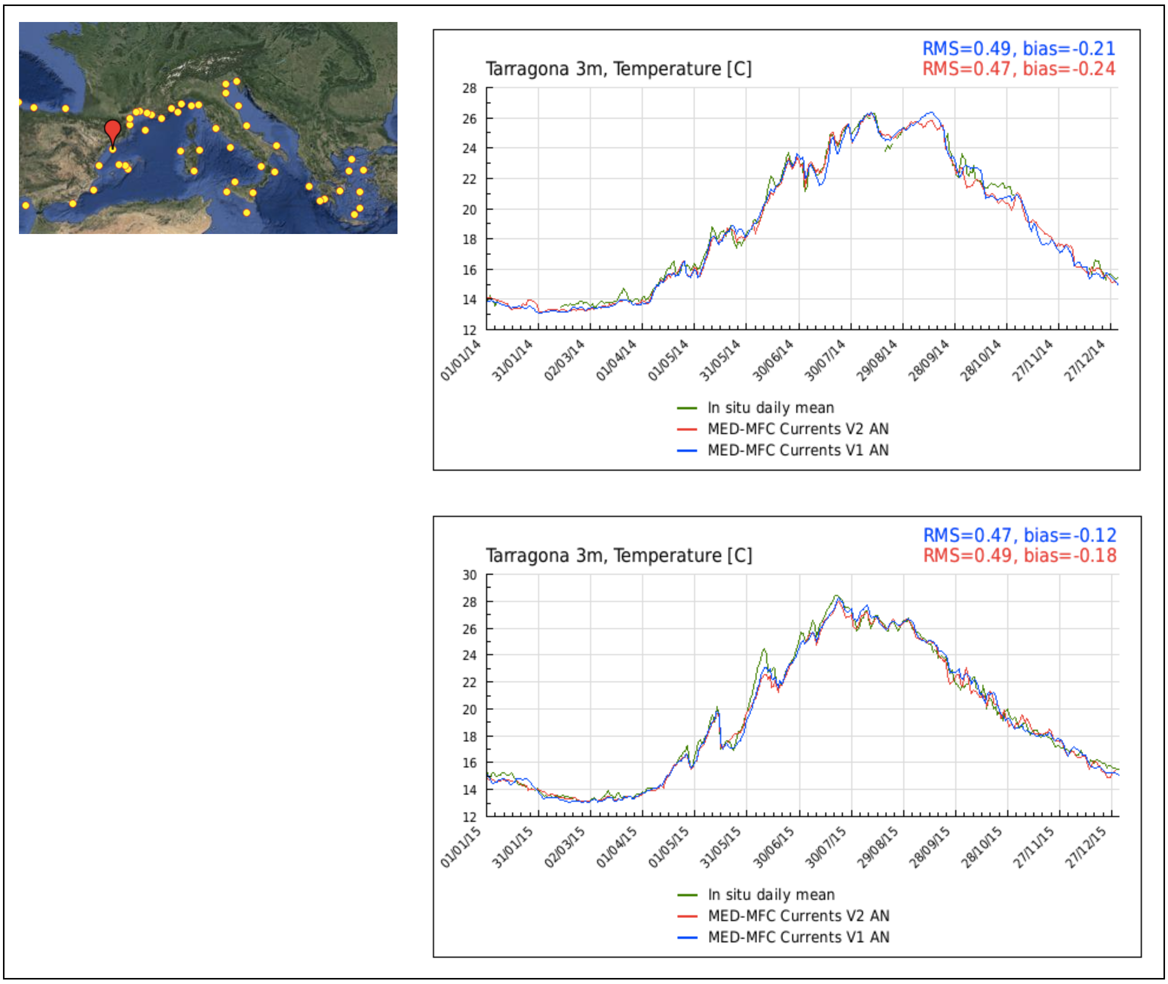


Figure 11: Time series of daily surface temperature at Tarragona buoy. Comparison between observations (green line), V1 model output (blue line) and V2 model output (red line). Top left: buoy location. Top right: year 2014. Bottom: year 2015. RMS and bias averaged over each year are included in the plot (T-CLASS4-RMS-INDEPENDENT, T-CLASS4-BIAS-INDEPENDENT).

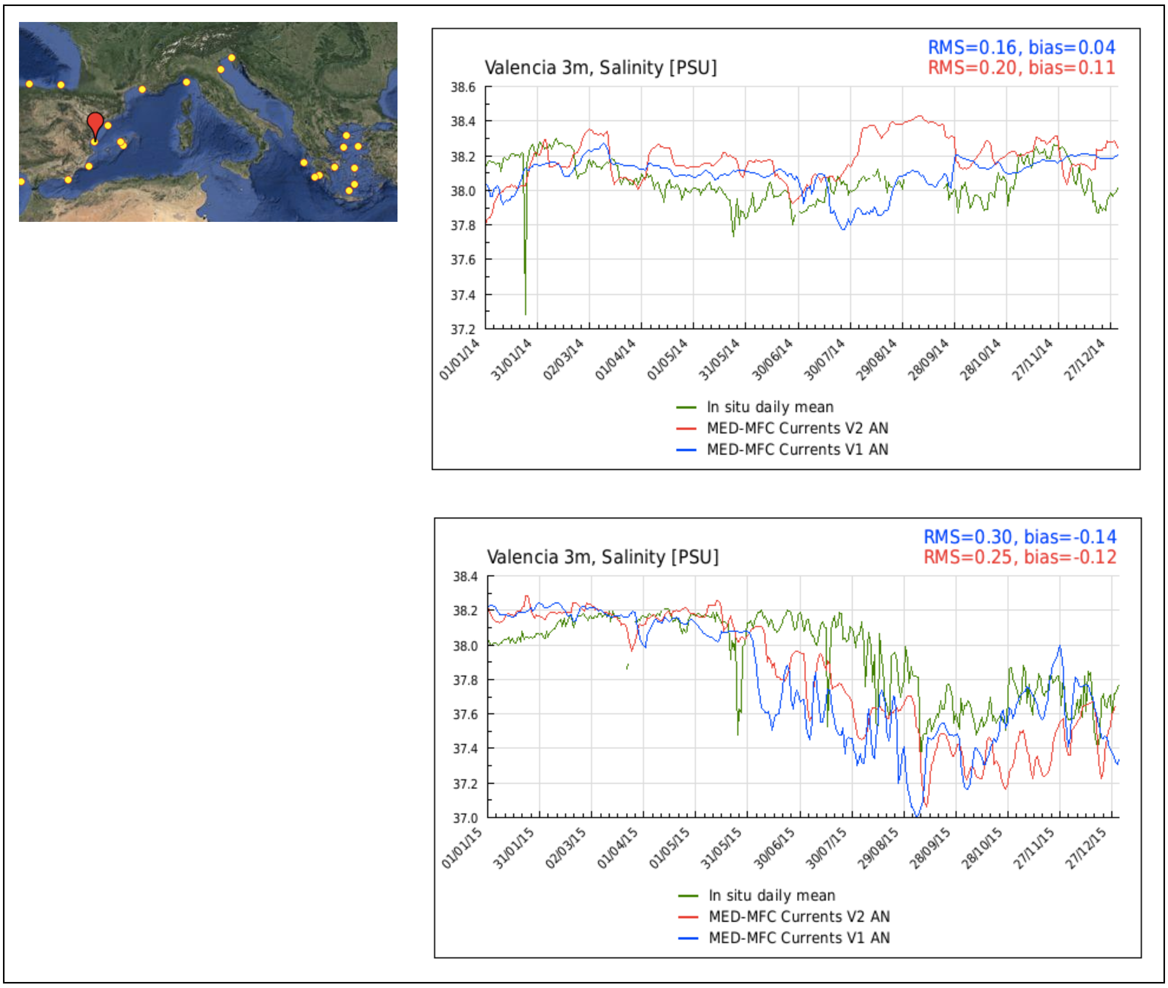


Figure 12: Time series of daily surface salinity at Valencia buoy. Comparison between observations (green line), V1 model output (blue line) and V2 model output (red line). Top left: buoy location. Top right: year 2014. Bottom: year 2015. RMS and bias averaged over each year are included in the plot (S-CLASS4-RMS-INDEPENDENT, S-CLASS4-BIAS-INDEPENDENT).

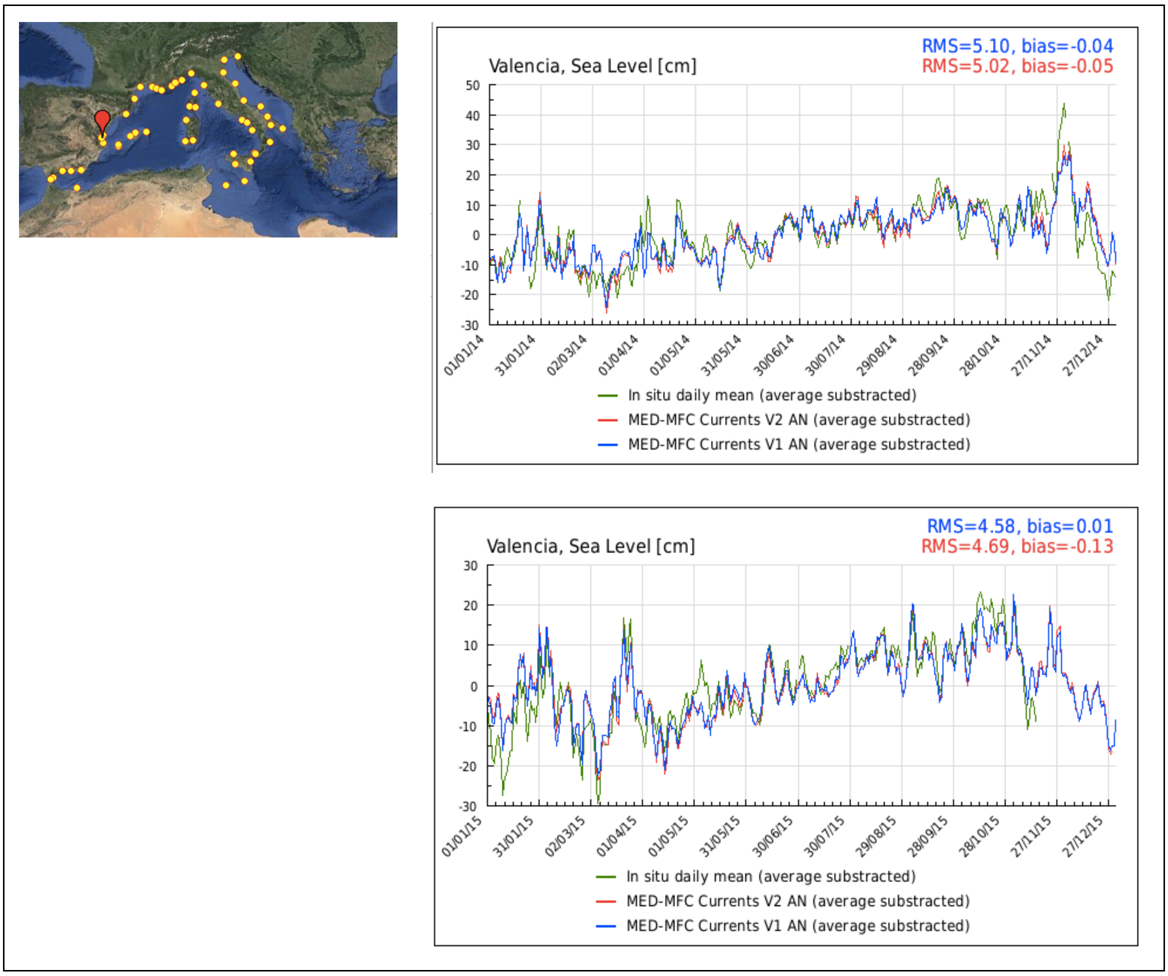


Figure 13: Time series of daily sea level at Valencia buoy. Comparison between observations (green line), V1 model output (blue line) and V2 model output (red line). Top left: buoy location. Top right: year 2014. Bottom: year 2015. RMS and bias averaged over each year are included in the plot (SL-CLASS4-RMS-INDEPENDENT, SL-CLASS4-BIAS-INDEPENDENT).

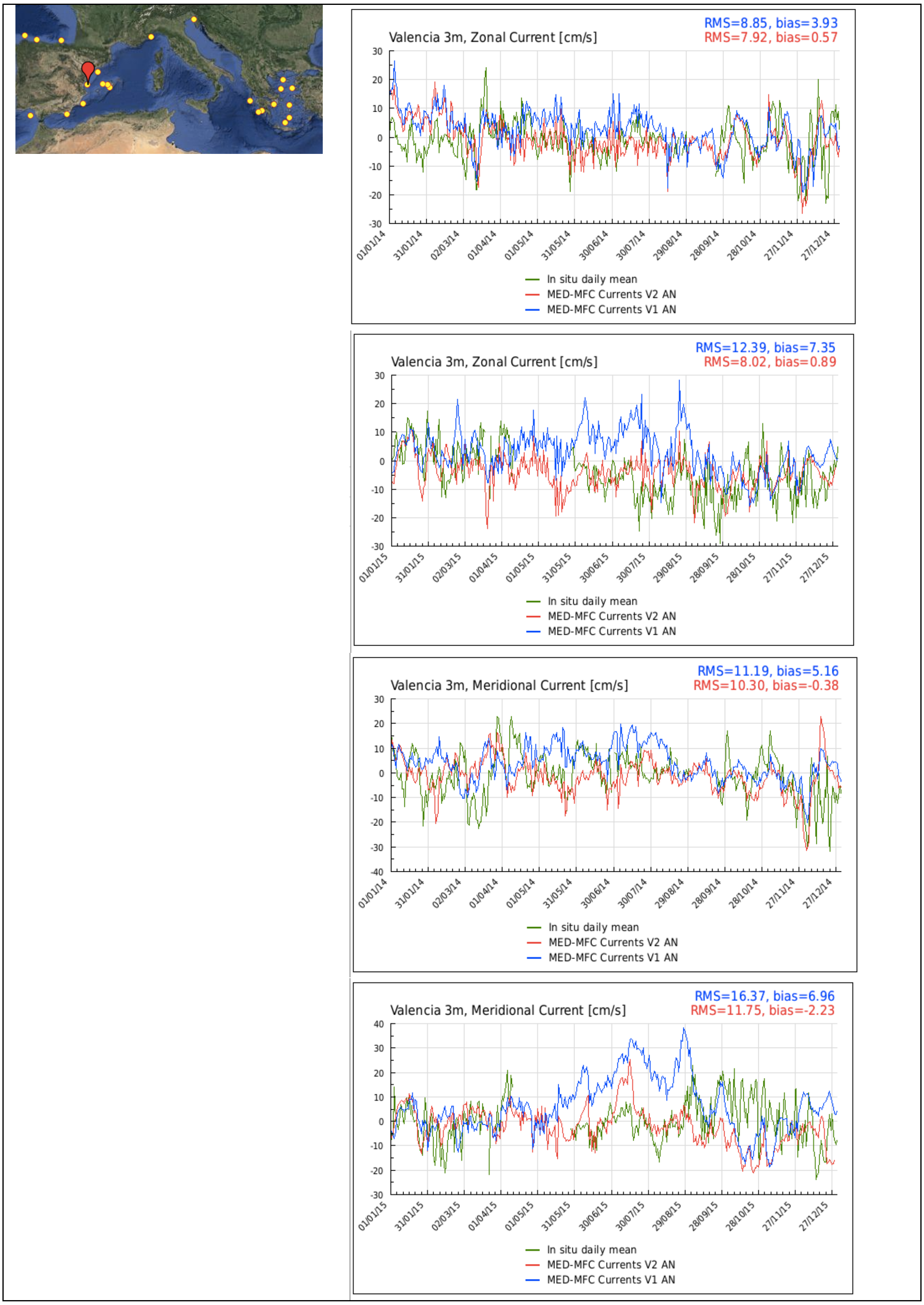


Figure 14: Time series of daily sea surface currents at Valencia buoy. Comparison between observations (green line), V1 model output (blue line) and V2 model output (red line). Top left: buoy location. Right: Zonal current 2014, Zonal current 2015, Meridional current 2014, Meridional current 2015. RMS and bias averaged over each year are included in the plot (UV-CLASS4-RMS-INDEPENDENT, UV-CLASS4-BIAS-INDEPENDENT).

Figure 15 and Figure 16 show 2D maps of SST comparison respectively between 2014 and 2015 annual mean computed from Med-MFC-currents V2 system and from satellite observations and their differences. The V2 system is able to well reproduce the spatial pattern of satellite observation and the largest differences are located in the shallow water, where: the atmospheric forcing, wind in particular, is less accurate and not enough resolved; the coastline and the coastal processes (upwelling) are not well resolved.

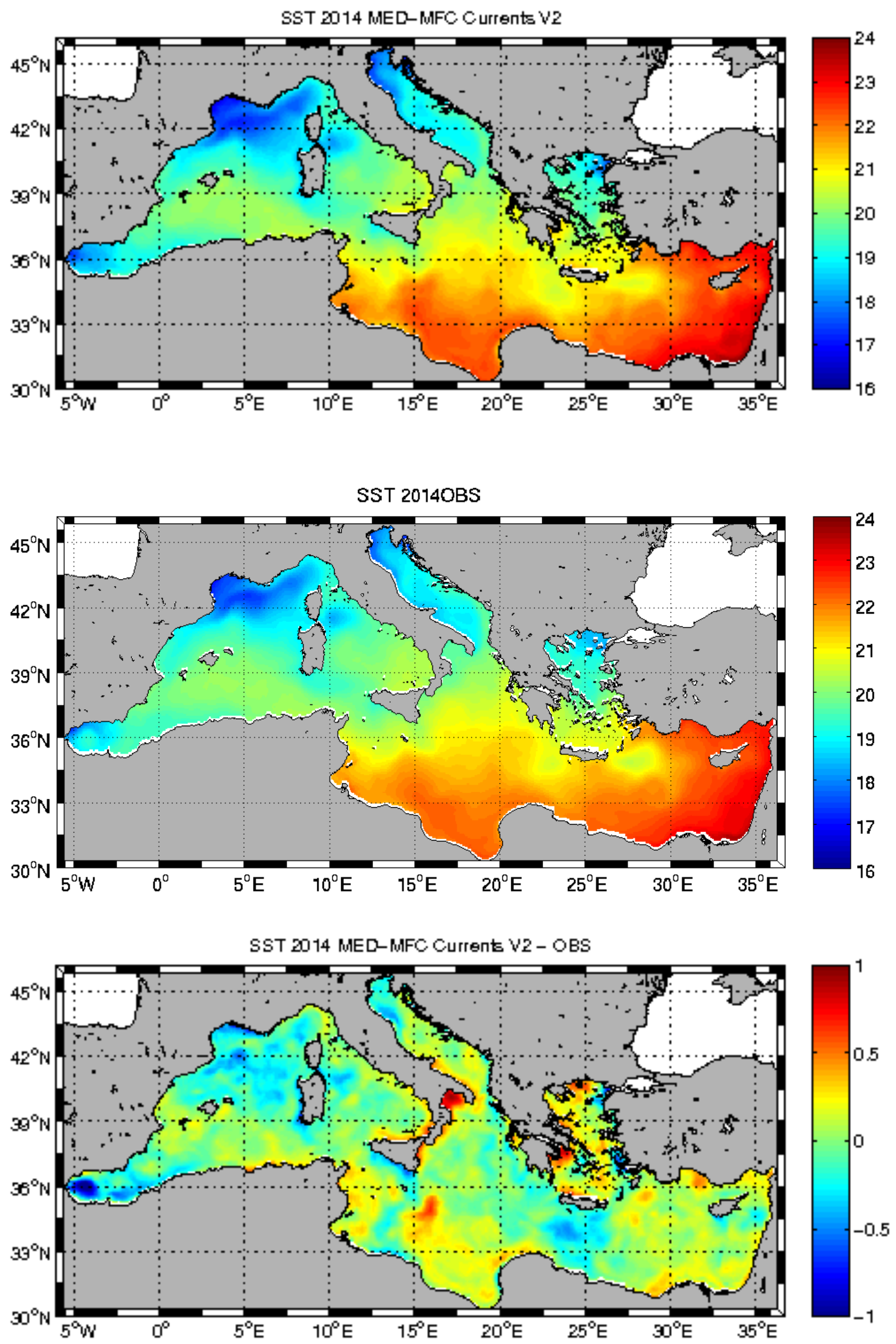


Figure 15: Maps of mean annual (2014) SST computed for V2 system (top), satellite observations (middle) and difference between model and observations (bottom).

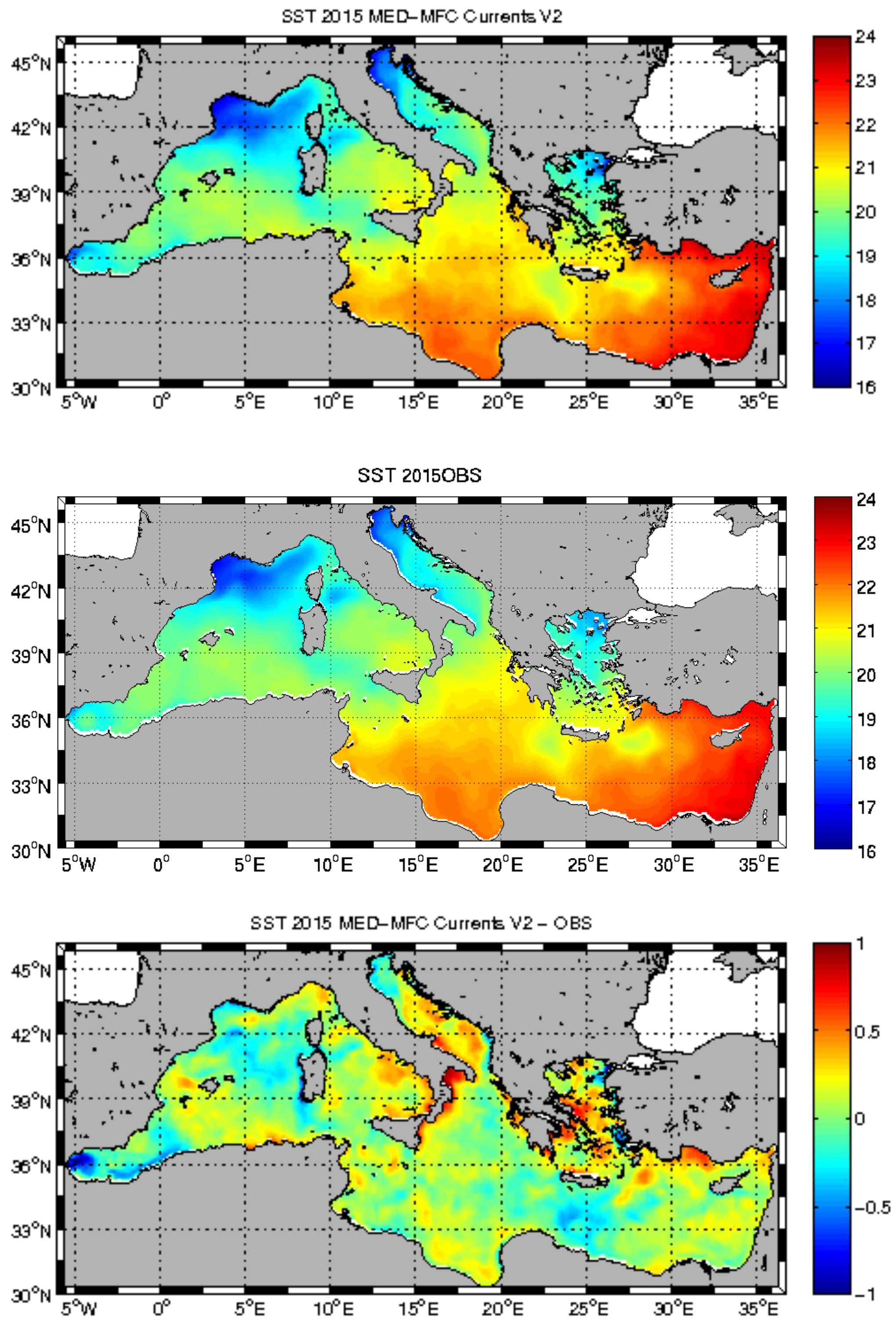


Figure 16: Maps of mean annual (2015) SST computed for V2 system (top), satellite observations (middle) and difference between model and observations (bottom).

The bottom temperature, that is the temperature of the deepest layer or level of the circulation model, has been compared to SeaDataNet dataset (see Tonani et al., 2013 for more details) for the years 2014 and 2015. Figure 17 shows the climatology (green line), the 2014 (blue line) and 2015 (red line) model results as monthly averages along the year. It can be seen that the system is able to reproduce the seasonal variability of the bottom temperature; it generally underestimates the climatological dataset especially during spring and autumn periods with a maximum difference of about 0.1degC in 2014 and 0.15degC in 2015.

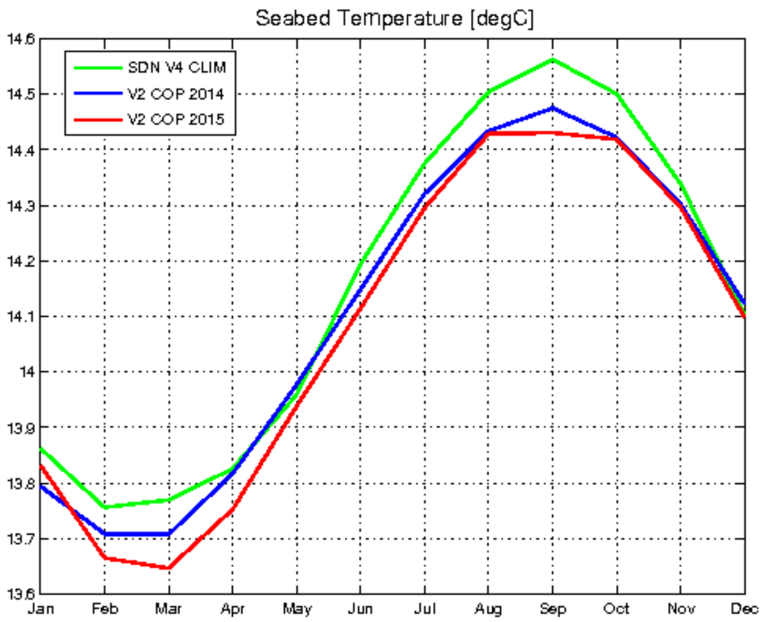


Figure 17: Time series of bottom temperature monthly climatologies from SeaDataNet dataset (green line) against 2014 (blue line) and 2015 (red line) V2 system numerical results.

V QUALITY CHANGES SINCE PREVIOUS VERSION

V.1 Changes since CMEMS Med-Currents V1

The CMEMS MED-MFC-currents V2 system presents some improvements with respect to V1 version achieved through new implemented developments and mainly related to data assimilation and to the use of daily precipitations (instead of climatology); all the new features are described in section II.3.

Main improvements are achieved considering sea level anomaly with a decrease in the model error of about 1 cm, also the salinity field is better reproduced by V2 system at almost all vertical layers considered. A slightly increase in the V2 error has been highlighted at surface temperature, while a better skill is achieved at lower levels.

V.2 Update on 22nd November 2016: impact on Med-Currents due to update on GLO-MFC AN-FC product

The product MEDSEA_ANALYSIS_FORECAST_PHY_006_001 is updated from 22nd November 2016: the system is now nested in the Atlantic Ocean with the new GLO-MFC high resolution physical system for analysis and forecast (GLOBAL_ANALYSIS_FORECAST_PHY_001_024).

One year experiment reproducing the operational system at CMEMS V2 has been carried out for the year 2015 nesting the Med-Currents system with the new GLO-MFC product.

Qualification activities have been performed producing EAN and weekly RMS of misfits for Temperature, Salinity and SLA of CMEMS V2 and CMEMS V2 with new OBC systems showing that the new forcings have negligible impacts on the quality of the physical product. Despite product quality is not significant affected by the OBC change, users have to take into account that a discontinuity in the mean SSH is produced due to the change in the data imposed as lateral boundary condition in the Atlantic (SSH differences ~ -3cm on average; estimations derived from year 2015).

V.2.1 Estimate 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 tables.

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 floats: INSITU_GLO_NRT_OBSERVATIONS_013_030, INSITU_MED_TS_NRT_OBSERVATIONS_013_035
- vertical profiles of temperature and salinity from moored buoys;
- 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 V2 and V2-newOBC systems over 1 year period from January 2015 to December 2015 and are computed over 6 vertical layers (for temperature and salinity) and for 13 sub-regions (Figure **1**):

T prod - T ref [ºC]	V2 system		V2-newOBC system	
Layer (m)	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER	Mean T-CLASS4-EAN-MEAN_LAYER	RMS T-CLASS4-EAN-RMS_LAYER
0-10 (*)	-0.04	0.57	-0.04	0.58
10-30	0	0.91	0	0.91
30-150	0.06	0.63	0.06	0.63
150-300	-0.04	0.24	-0.04	0.24
300-600	-0.03	0.16	-0.03	0.15
600-1000	-0.02	0.10	-0.02	0.09

Table 13: EANs of temperature at different vertical layers evaluated for V2 and V2-newOBC systems for the year 2015: T-CLASS4-EAN-MEAN_LAYER and T-CLASS4-EAN-RMS_LAYER in Table 9.

SST prod – SST ref [ºC]	V2 system		V2-newOBC system	
REGION	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN	Mean SST-CLASS4-EAN-MEAN_BASIN	RMS SST-CLASS4-EAN-RMS_BASIN
MED SEA	0.08	0.57	0.08	0.58
REGION 1	-0.17	0.86	-0.19	0.88
REGION 2	0.07	0.52	0.08	0.52
REGION 3	-0.05	0.58	-0.06	0.58
REGION 4	0.16	0.52	0.16	0.52
REGION 5	0.2	0.71	0.2	0.70
REGION 6	0.19	0.54	0.19	0.54
REGION 7	0.1	0.55	0.1	0.55
REGION 8	0.1	0.44	0.1	0.44
REGION 9	0.25	0.72	0.25	0.72
REGION 10	-0.13	0.47	-0.12	0.47
REGION 11	0.16	0.57	0.16	0.57
REGION 12	0.09	0.41	0.1	0.41
REGION 13	0.17	0.50	0.17	0.50

Table 14: EANs of Sea Surface Temperature evaluated for V2 and V2-newOBC systems for the year 2015 for the Mediterranean Sea and 13 regions (see Figure 1): SST-CLASS4-EAN-RMS_BASIN and SST-CLASS4-EAN-MEAN_BASIN in Table 9.

The metrics of Table **13** and Table **14** give indications about the accuracy of temperature along the water column and at the surface, respectively, for the Mediterranean Sea and 13 sub-regions. The values for all the levels are computed using Argo profiles. The RMS and mean of both V2 and V2-newOBC systems are higher at the first levels and decrease significantly below the third layer. In general there are no significant differences between the 2 systems, only little decrease in SST skill is noticed for the whole basin and few sub-regions, while lower layers temperature skill is slightly increased when considering the updated system nested with new GLO-MFC product.

S prod – S ref [PSU]	V2 system		V2-newOBC system	
Layer (m)	**Mean** S-CLASS4-EAN-MEAN_LAYER	**RMS** S-CLASS4-EAN-RMS_LAYER	**Mean** S-CLASS4-EAN-MEAN_LAYER	**RMS** S-CLASS4-EAN-RMS_LAYER
0-10 (*)	0.05	0.3	0.05	0.3
10-30	0.03	0.25	0.03	0.25
30-150	0.02	0.18	0.02	0.18
150-300	-0.01	0.1	-0.01	0.1
300-600	-0.01	0.07	-0.01	0.07
600-1000	0.01	0.06	0.01	0.06

Table 15:EANs of salinity at different vertical layers evaluated for V2 and V2-newOBC systems for the year 2015: S-CLASS4-EAN-MEAN_LAYER and S-CLASS4-EAN-RMS_LAYER in Table 9.

The statistics listed in Table **15** give indications about the accuracy of salinity along the water column. The values for all the levels are computed using Argo profiles. The performance of the system using new GLO-MFC product is the same of the V2 system.

SLA prod – SLA ref [cm]	V2 system	V2-newOBC system
REGION	**RMS** SL-CLASS4-EAN-RMS_BASIN	**RMS** SL-CLASS4-EAN-RMS_BASIN
MED SEA	3.9	3.9
REGION 1	4.9	5.0
REGION 2	4.1	4.2
REGION 3	3.4	3.5
REGION 4	3.2	3.2
REGION 5	3.1	3.1
REGION 6	3.3	3.4
REGION 7	3.3	3.3

REGION 8	3.3	3.3
REGION 9	6.3	6.4
REGION 10	4.7	4.7
REGION 11	3.3	3.3
REGION 12	3.8	3.8
REGION 13	2.9	2.9

Table 16: EANs of Sea Level evaluated for V2 and V2-newOBC systems for the year 2015 for the Mediterranean Sea and 13 regions (see Figure 1): SL-CLASS4-EAN-RMS_BASIN in Table 9

The metrics shown in Table **16** define the accuracy of sea level anomaly. The statics are computed along the satellite track. Statistics show only small differences between the 2 systems in some of the sub-regions, but no significant skill modification is detected.

V.2.2 *Quasi-independent Validation*

In the following tables, there is synthesis of the values of bias and RMS, calculated comparing the experiment V2-newOBC for year 2015 with quasi-independent data assimilated by the system (ARGO, CTD, XBT, glider and Satellite SLA & SST) for SST, temperature and salinity at different depths (Table **17**) and SLA (Table **18**).

Variables/estimated accuracy:	Metrics		Depth	Observation
SEA SURFACE TEMPERATURE (°C)	**RMS** SST-CLASS4-RMS	**BIAS** SST-CLASS4-BIAS		
	0.58±0.09	-0.04±0.10	0	Satellite SST
TEMPERATURE (°C):	**RMS** T-CLASS4-RMS_DEPTH		**Depth**	**Observation**
	0.55±0.19		8	Argo, CTD
	0.87±0.51		30	Argo, CTD
	0.29±0.06		150	Argo, CTD
	0.23±0.06		300	Argo, CTD
	0.13±0.03		600	Argo, CTD
	0.37±0.22		8	XBT
	0.37±0.27		30	XBT
	0.21±0.12		150	XBT
	0.14±0.11		300	XBT
	0.08±0.06		600	XBT
	0.19±0.08		8	GLIDER
	0.17±0.06		30	GLIDER
	0.17±0.08		150	GLIDER
	0.10±0.05		300	GLIDER
	0.07±0.05		600	GLIDER
SALINITY (psu)	S-CLASS4-RMS_DEPTH		**Depth**	**Observation**
	0.2±0.05		8	Argo, CTD
	0.18±0.04		30	Argo, CTD

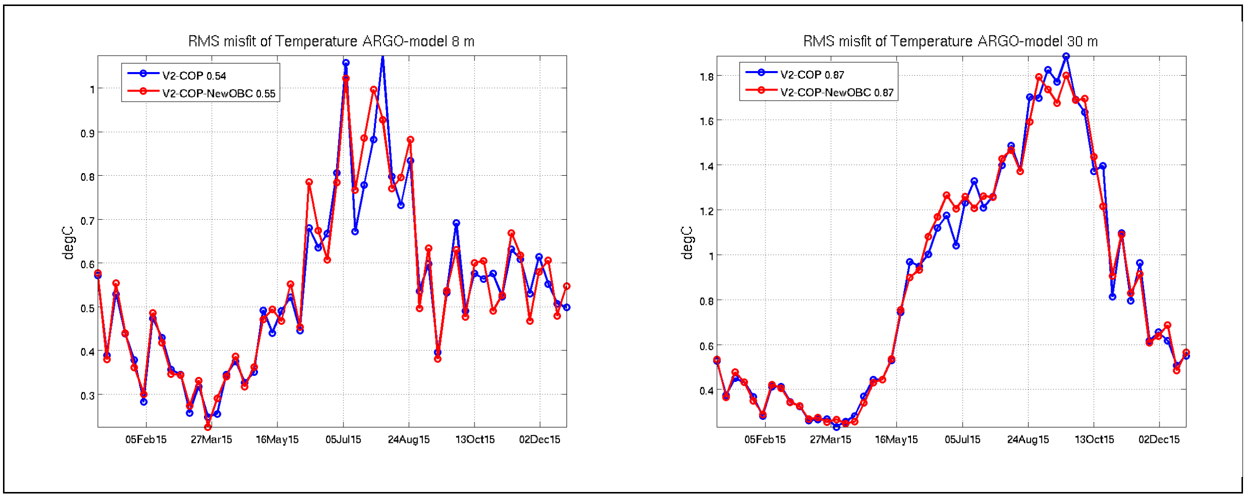
	0.09±0.02	150	Argo, CTD
	0.05±0.01	300	Argo, CTD
	0.03±0.01	600	Argo, CTD
	0.16±0.14	8	GLIDER
	0.12±0.13	30	GLIDER
	0.08±0.04	150	GLIDER
	0.05±0.04	300	GLIDER
	0.02±0.01	600	GLIDER

Table 17: Quasi-independent validation. Analysis evaluation based over year 2015: SST-CLASS4-RMS, SST-CLASS4-BIAS, T-CLASS4-RMS_DEPTH, S-CLASS4-RMS_DEPTH.

SEA LEVEL ANOMALIES (cm)	**RMSE** **SL-CLASS4-RMS**	**Availability**
All Satellites	3.2	01/01/2015-31/12/2015
ALTIKA	3.2	01/01/2015-31/12/2015
CRYOSAT	3.5	01/01/2015-31/12/2015
JASON 2	2.9	01/01/2015-31/12/2015

Table 18: Analysis evaluation based over year 2015 for the Sea Level Anomaly for each available satellite: SL-CLASS4-RMS.

The following figures (Figure **18**) show the time series of weekly RMSs of temperature misfits at 5 depths (8, 30, 150, 300, 600 m), T-CLASS4-RMS_DEPTH, for the CMEMS Med-MFC-currents V2 system (blue line) and the V2 system with new OBC (red line) (observation minus model value transformed at the observation location and time). The differences between V2 and V1 systems are always negligible.



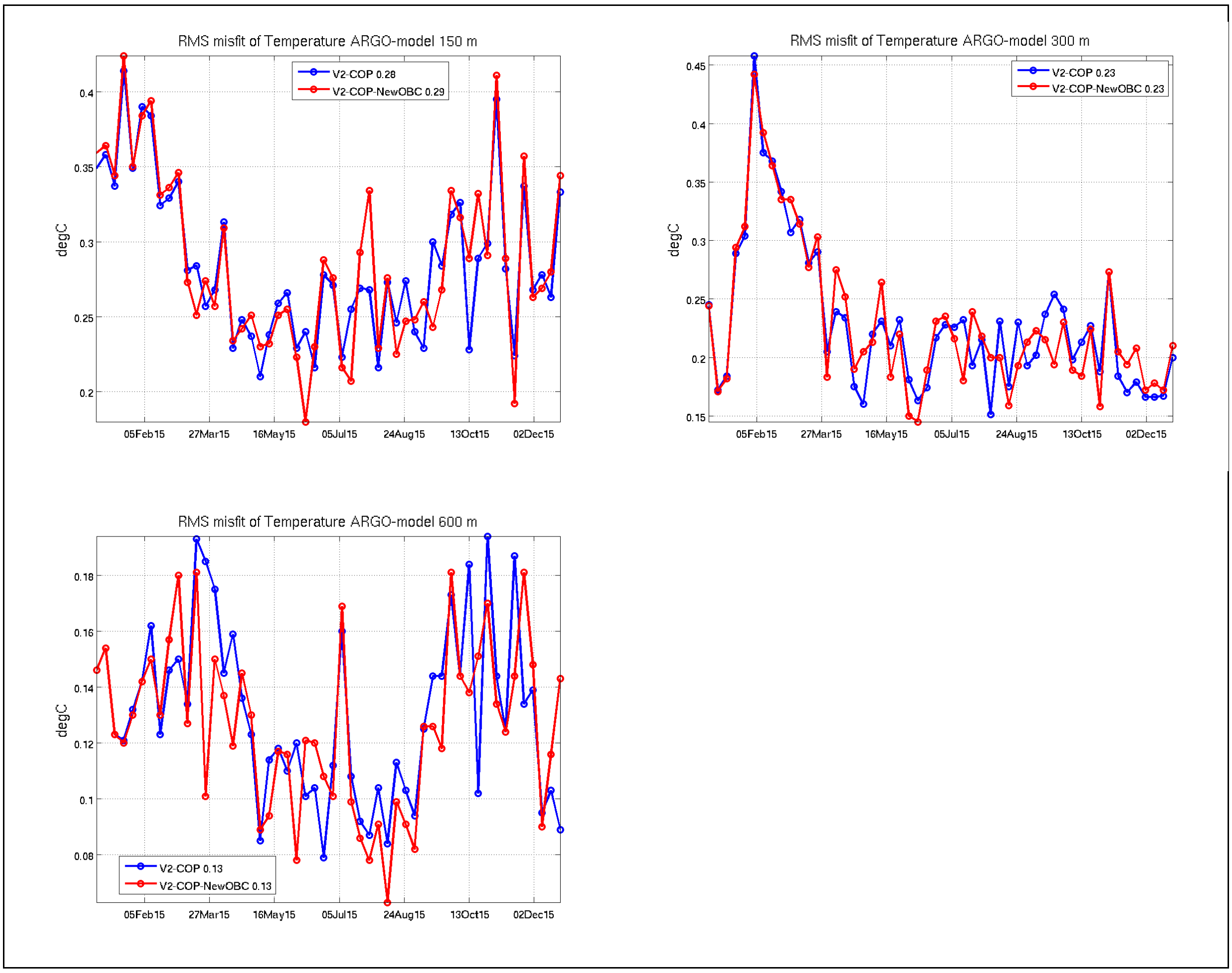
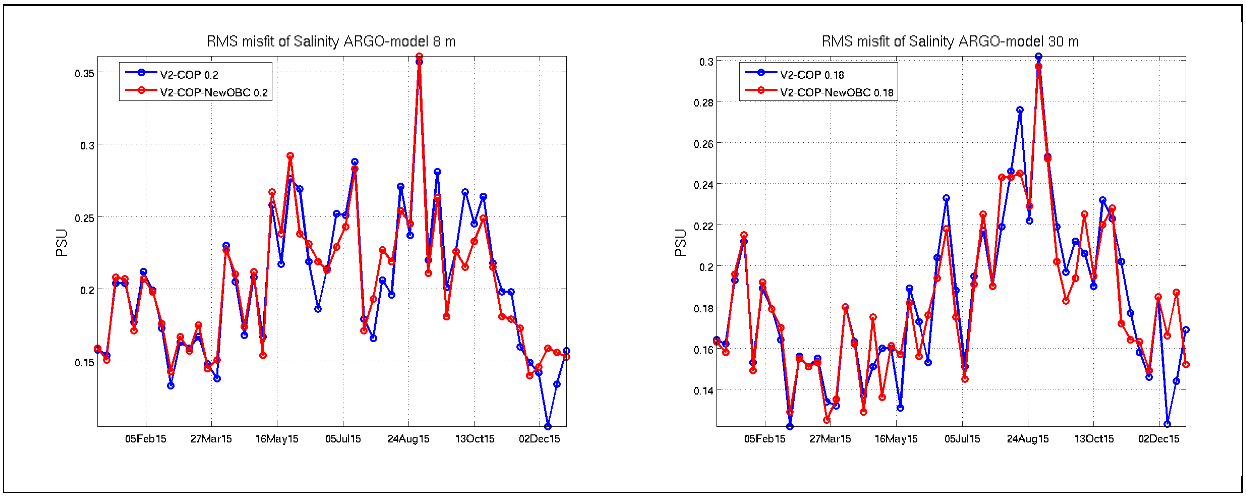


Figure 18: RMS misfit of temperature ARGO-Model at 8, 30, 150, 300 and 600 m (T-CLASS4-RMS_DEPTH)

The following figures (Figure **19**) show the time series of weekly RMSs of salinity misfits at 5 depths (8, 30, 150, 300, 600 m), S-CLASS4-RMS_DEPTH, for the CMEMS Med-MFC-currents V2 system (blue line) and the V2 system with new OBC (red line) (observation minus model value transformed at the observation location and time).

The differences between the two systems are always negligible.



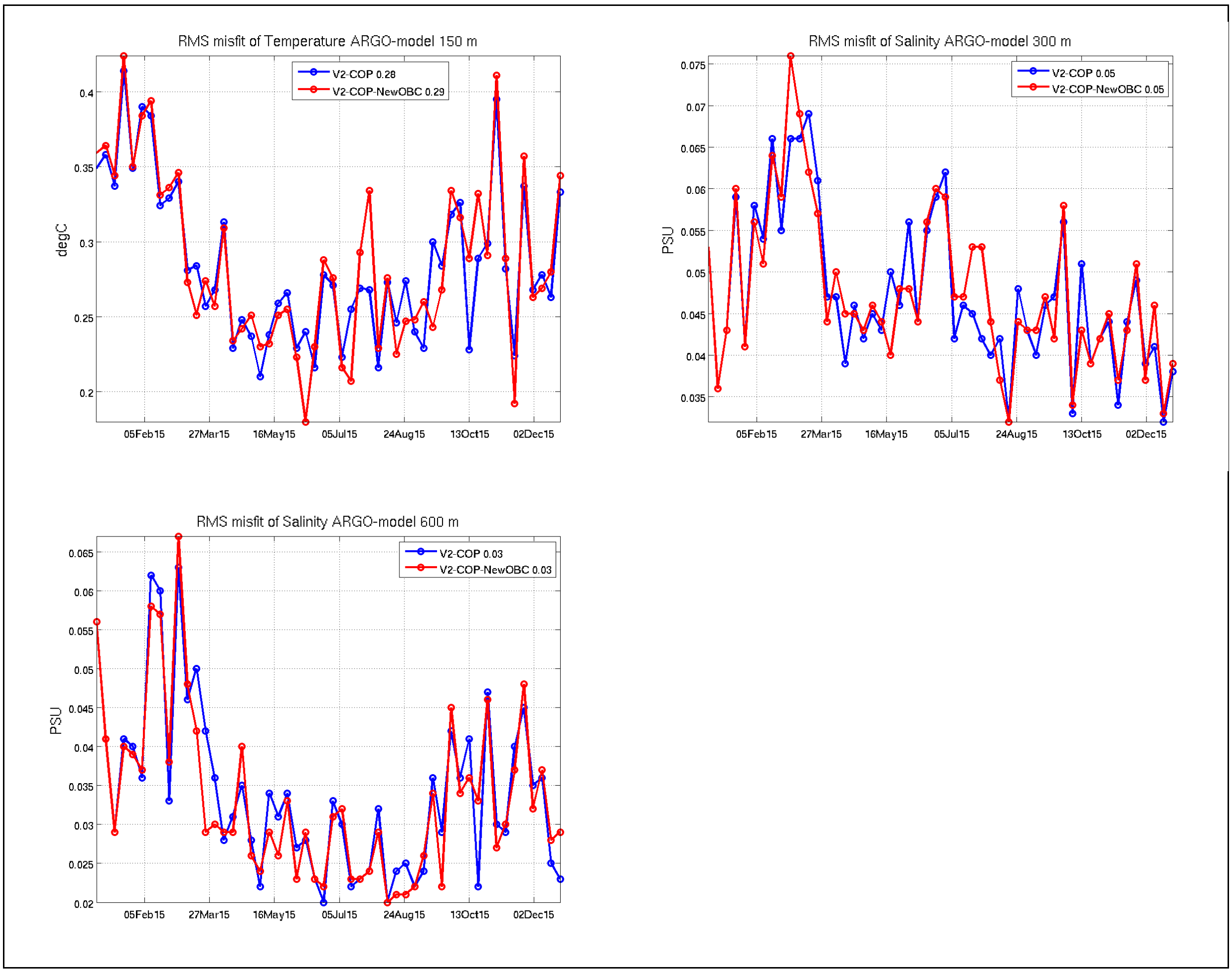


Figure 19: RMS misfit of salinity ARGO-Model at 8, 30, 150, 300 and 600 m (S-CLASS4-RMS_DEPTH)

The following figures (Figure **20**) show the time series of weekly RMSs of sea level anomaly misfits at surface, SL-CLASS4-RMS, for the CMEMS Med-MFC-currents V2 system (blue line) and the V2 system with new OBC (red line) (observation minus model value transformed at the observation location and time).

The differences between V2 and V1 systems are always negligible when considering comparison with single satellite and all the available satellites for year 2015.

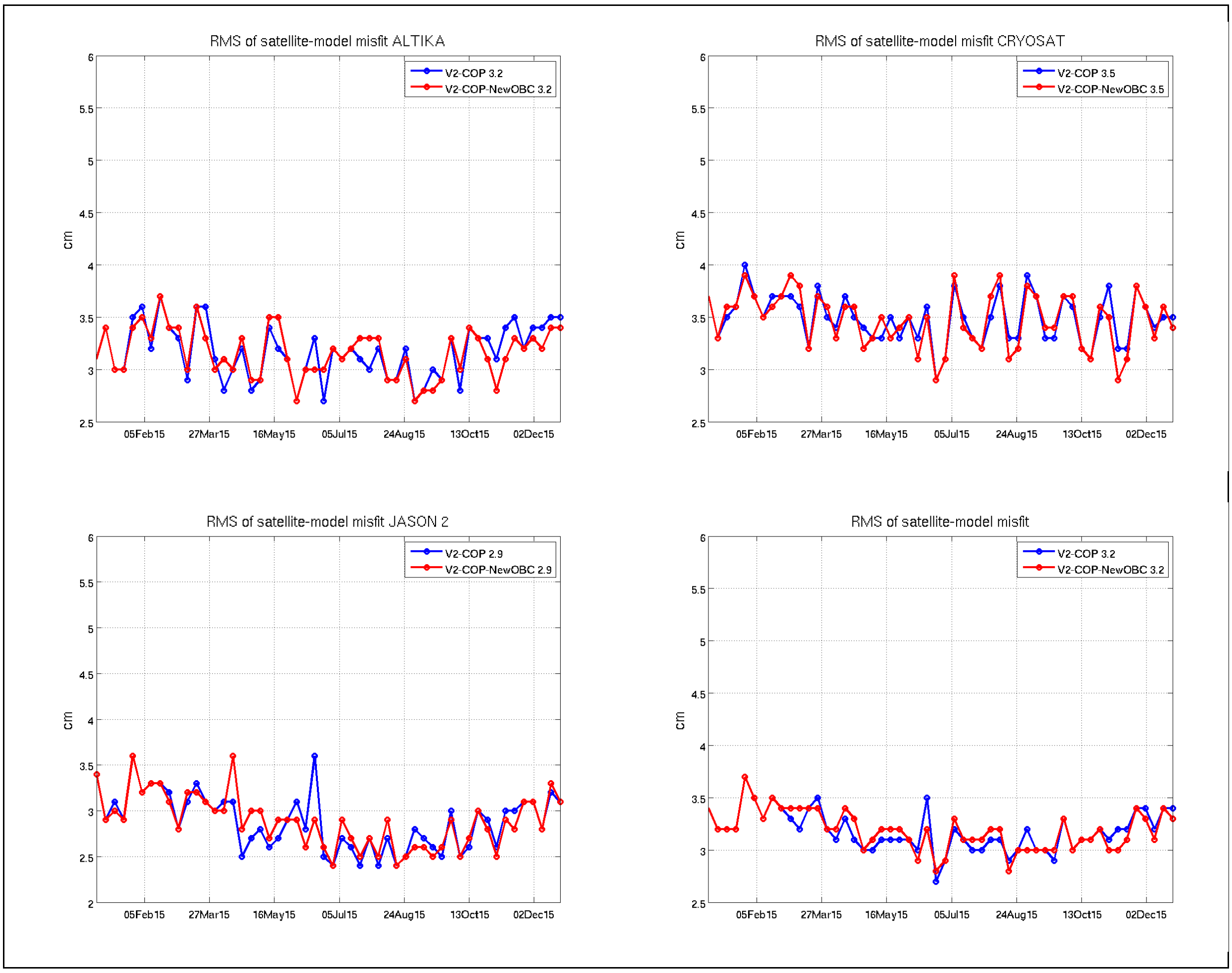


Figure 20 Weekly RMS misfit of satellite-model along SLA data track for Altika (panel top-left), for Cryosat (panel top-right), for Jason2 (panel bottom-left) and for all the satellites (panel bottom-right) (SL-CLASS4-RMS).