QUality Information Document for Med Physics reanalysis product: MEDSEA_REANALYSIS_PHYS_006_004

Issue: 1.5

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CHANGE RECORD

Issue	Date	§	Description of Change	Author	Validated By
1.0	26 January 2016	All	First version of the document at CMEMS V1	Claudia Fratianni	
1.1	04 April 2016	All	Second version of the document after V2 Acceptance Review	Claudia Fratianni	
1.2	11 January 2017	All	Third version of the document	Claudia Fratianni	
1.3	12 February	All	Update version for for CMEMS EIS V4	Claudia Fratianni	
1.4	21 January 2019	VI	Update version 2017 time-series extension	Emanuela Clementi	
1.5	10 September 2019	VI	Update version 2018 time-series extension	Emanuela Clementi	

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I EXECUTIVE SUMMARY

I.1 Products covered by this document

This document describes the quality of the product MEDSEA_REANALYSIS_PHYS_006_004, the reanalysis product of the physical state of the Mediterranean Sea, which includes 2D daily/monthly fields of sea surface height and 3D daily/monthly fields of temperature, salinity, meridional and zonal currents at 1/16° horizontal resolution and 72 vertical levels.

The aim of the MEDSEA_REANALYSIS_PHYS_006_004 is to provide an integrated set of information consistent across space-time dimension, using both observations and model, covering the period 1987-2018.

I.2 Summary of the results

The quality of the MEDSEA_REANALYSIS_PHYS_006_004 has been assessed for the 1987 to 2016 period by comparing results with observations, climatology and literature. The extended time-series up to December 2018 has no provided significant changes with respect to the previous period. The results are grouped by ocean state variable and detailed as follows:

- **Sea Surface Temperature (SST):** SST RMS and BIAS with respect to daily satellite SST maps are presented as time series and as horizontal maps. The evolution of SST error shows a seasonality, with error higher during summer period, during which the system shows a warm bias, and a mean value of 0.56°C. The SST quality might be considered of comparable quality of satellite optimally interpolated maps (*Marullo et al., 2008*).
- **Temperature (T):** The temperature RMS and BIAS with respect to in-situ data assimilated by the system are presented as profiles averaged over the whole domain (up to 1000 m) over the entire reanalysis period. RMS errors along the water column is on average 0.33°C with a peak at about 30 m of depth (less than 0.8°C). Temperature BIAS exhibits maximum positive values up to 150 m of depth, where the seasonal thermocline evolves, while below 150 m the values are negative.
- **Salinity (S):** The salinity RMS and BIAS with respect of in-situ data assimilated by the system are presented as profiles averaged over the whole domain (up to 1000 m) and over the entire time period. RMS errors along the water column is on average 0.09 psu, with the maximum at the surface (0.3 psu), where the atmospheric and land forcing are crucial. Salinity BIAS is negative in the first 400 m of the water column and positive below.

- **Sea Level Anomaly (SLA):** the SLA RMS with respect to along-track data assimilated oscillates from about 3 to 4.5 cm with a mean of ~3.6 cm, which is comparable with the RMS of observations.

I.3 Estimated Accuracy Numbers

The results for each variable assessed are presented in Table 1

Parameter	Metrics	Units	Decimal places
Sea Surface Temperature	MEAN BIAS	°C	0.18 ± 0.25
Sea Surface Temperature	MEAN RMS	°C	0.56 ± 0.13
Temperature	MEAN BIAS	°C	-0.02 ± 0.0
Temperature	MEAN RMS	°C	0.33 ± 0.02
Salinity	MEAN BIAS	PSU	0.0 ± 0.003
Salinity	MEAN RMS	PSU	0.09 ± 0.01
Sea Level Anomaly	MEAN BIAS	cm	0.08 ± 0.13
Sea Level Anomaly	MEAN RMS	cm	3.55 ± 0.59

Table 1 Summary of MEDSEA_REANALYSIS_PHYS_006_004 performance for different parameters over the entire time period (1987 - 2016).

II PRODUCTION SYSTEM DESCRIPTION

- Production Centre Name: Med-MFC
- Production subsystem Name: Med-MFC Currents Reanalysis
- Production Unit: INGV

The MEDSEA_REANALYSIS_PHYS_006_004 has been produced by Physics PU at INGV by combining, every day, the output of the ocean model, forced by atmospheric surface fluxes and relaxed to SST, and quality controlled ocean observations, through the data assimilation scheme.

II.1 Brief overview of V3 Mediterranean Sea Physical Reanalysis System (MED REA)

The Mediterranean Physical Reanalysis system relies on three main components:

1. **ocean model**: is a hydrodynamic model, supplied by Nucleus for European Modelling of the Ocean (NEMO);
2. **data assimilation scheme**: is a variational data assimilation scheme (OceanVar) for temperature and salinity profiles and satellite Sea Level Anomaly along track data;
3. **assimilated data**: are in-situ temperature and salinity profiles and Sea Level Anomaly along track satellite data.

II.1.1 Description of the circulation model system

The OGCM used to produce the MEDSEA_REANALYSIS_PHYS_006_004 are NEMO version 3.2 for the period 1987-2013 and NEMO version 3.4 from year 2014. The two codes were used with the same physical settings. Some tests were done in order to align the two codes during a common period and no relevant differences have been highlighted. Moreover, the validation performed on the entire time series didn't show any change in the quality of the product due to the updating.

The model solves the primitive equations in spherical coordinated and has been implemented in the Mediterranean at 1/16°x1/16° horizontal resolution and 72 unevenly spaced vertical layers (*Oddo et al., 2009*). The model covers the Mediterranean Basin and also extends into the Atlantic in order to better resolve the exchanges with the Atlantic Ocean at the Strait of Gibraltar.

The NEMO model is nested in the Atlantic within the monthly mean climatological fields computed from ten years of daily output of the 1/4° x 1/4° degrees PSY3 global model provided by MERCATOR (*Drevillon et al., 2008*). 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, 0.75° horizontal-resolution ERAInterim reanalysis fields (*Dee et al. 2011*) 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*). Atmospheric variables used are: air temperature at 2 m, dew point temperature at 2 m, mean sea level pressure, total cloud cover, 10 m wind u and v components. Satellite SST is used to correct interactively the computed heat flux at air-sea interface with a relaxation constant of 60 W/m²/K.

Water balance is computed as Evaporation minus Precipitation and Runoff. The evaporation is derived from the latent heat flux. Runoff is 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). Precipitations are from ERAInterim reanalysis (6-h, 0.75° horizontal-resolution).

II.1.2 Description of data assimilation scheme

The data assimilation system is the three-dimensional variation scheme called OceanVar, set up by *Dobricic and Pinardi* (2008), that allows to correct model fields for the dynamic variables. The vertical covariance matrix are represented by 20 seasonally and regionally vertical EOFs of surface elevation and vertical profiles of temperature and salinity, estimated from the temporal variability of parameters in a historical model simulation (*Dobricic et al., 2005*). The MDT used for SLA data assimilation has been computed by *Dobricic et al., 2005*.

The assimilation cycle is daily and both in-situ and satellite data are jointly assimilated to estimate the initial condition for numerical model.

II.1.3 Description of assimilated data

The assimilated data consist of satellite SLA data and in-situ temperature and salinity profiles.

The SLA dataset used to produce MEDSEA_REANALYSIS_PHYS_006_004 is a concatenation of:

- **SEALEVEL_MED_SLA_L3_REP_OBSERVATION_008_020** updated on June 2014 completing the time series till the end of 2013;
- **SEALEVEL_MED_SLA_L3_REP_OBSERVATION_008_020** updated at the latest version released on June 2016 completing the time series till the end of 2015;
- **SEALEVEL_MED_PHY_L3_REP_OBSERVATIONS_008_049** updated at the latest version released on April 2018 completing the time series till the end of 2018;

The dataset differ in terms of the temporal mean used to compute the sea surface heights, respectively seven-year mean and twenty-year mean. All the missions are homogenized with respect to a reference mission, which is currently Jason2. This product is computed with an optimal and centred computation time window (6 week before and after the date). The time coverage depends on the duration of the missions and starts from 1992.

The in situ temperature and salinity profiles considered for the MED REA production belong from different instrumental data type: CTDs, XBTs, MBTs, bottles, ARGO floats. In situ data sets have been collected from European Marine databases and have been archived in a specific format to be assimilated. They were downloaded from different sources: 1) SeaDataNet European infrastructure (DG-Research-FP6); 2) MEDAR-MEDATLAS dataset covering the period 1985-1999 (*Maillard et al. 2005*); 3) MFS (Mediterranean Forecasting System) operational observation infrastructure based on Enea and Coriolis data centers,4) MyOcean In situ TAC and 5) CMEMS INS-TAC. Potential duplicates were thus identified and excluded from successive usage and analysis. The decrease of the number of observations for the recent years due to a time lag between the sampling and the insertion of the data inside the SDN infrastructure is a common characteristic of historical databases. This required the use of MFS, MyOcean and CMEMS in situ TAC operational observations to integrate the SDN data set in the recent period. We intend for MFS operational observations, near real time (NRT) observations collected in the Mediterranean Sea within different precursor projects spanning a time period from 1999 to April 2009 when MyOcean Project started:

- MFSPP (Mediterranean ocean Forecasting System Pilot Project) 1998-2001 EU-MAST project MA 53-CT98-0171
- MFSTEP (Mediterranean ocean Forecasting System Towards Environmental Prediction) 2003-2005 DG-Research – FP5 EU Contract Number EVK3-CT-2002-00075;

The SST dataset are not assimilated but they are used to correct the surface heat flux by a relaxation of the numerical model surface layer temperature towards the observed SST. This dataset is a time concatenation of SST products characterized by horizontal maps already optimally interpolated:

1. SST reprocessed data (1985-July 2008) at 1/16° of the recent AVHRR Pathfinder SST (*Marullo et al., 2008*);
2. SST Reconstruction DT data at 1/16° from 2008 to August 2010 (*Marullo et al. 2007*)
3. SST_MED_SST_L4_HR: Level 4 (L4) products covering Mediterranean corresponds to daily (night-time) gridded super-collated (multi-sensor) and optimally interpolated satellite SST estimates at High spatial Resolution (HR), i.e. at 1/16° (*Buongiorno Nardelli et al. 2013*).

Table 2 summarizes the atmospheric forcing and data assimilated in the reanalysis system.

DATA TYPE	EXTERNAL PRODUCTS
ATMOSPHERIC FORCING	ECMWF ERAInterim Atmospheric Reanalysis
SLA	SEALEVEL_MED_SLA_L3_REP_OBSERVATIONS_008_020 SEALEVEL_MED_SLA_L3_NRT_OBSERVATIONS_008_019 SEALEVEL_MED_PHY_L3_REP_OBSERVATIONS_008_049
ARGO	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030
XBT	MEDATLAS, MFS (Enea), INSITU_MED_NRT_OBSERVATIONS_013_035
CTD	SeaDataNet, MEDATLAS,MFS (Enea), INSITU-TAC dataset in-situ SeaDataNet product (FREE access temperature Salinity Observations) in-situ SeaDataNet product (RESTRICTED access temperature Salinity Observations) MEDAR MEDATLAS (Historical data)
SST	GOS-CNR-SST-HR-RAN-MEDITERRANEAN GOS-CNR-SST-HR-DT-MEDITERRANEAN SST_MED_SST_L4_NRT_OBSERVATIONS_010_004

Table 2 Atmospheric forcing and data assimilated details.

The Mediterranean Sea Physical reanalysis has been initialized by a temperature and salinity monthly climatology (named SDN_V2aa) produced within the framework of SeaDataNet FP6 Project. It has been calculated utilizing the extensive historical in situ data set from 1900 to 1987. We considered only observations before 1987 to compute the initial condition because we did not want the climatology to be affected by the Eastern Mediterranean Transient (EMT). The EMT (*Roether et al. 1996*) is a large climatic event evolved between the late eighties and early nineties that showed for the first time the contribution of the Aegean Sea to the Eastern Mediterranean deep waters formation, in particular the Cretan Deep Water (CWD), which started to be formed in 1987, reaching its maximum rate (1Sv) in 1992-1993 and since 1996 decayed permanently. EMT changed consistently the water mass characteristics of the Mediterranean Basin thanks to the subsequent spread of saltier and warmer waters towards the Adriatc Sea and the Western basin (*Pinardi et al. 2015*). Mediterranean observations have been blended to the World Ocean Atlas climatology (WOA) in the Atlantic Box. The climatology has been computed with DIVA software tool (Data-Interpolating Variational Analysis), which allows to spatially interpolate observations onto a regular grid in an optimal way (modb.oce.ulg.ac.be/mediawiki/index.php/DIVA).

The Mediterranean Sea Physical reanalysis has been initialized on the 1st of January 1985 and run till the 31st of December 2018. The first two years are considered the period of model spin up.

III VALIDATION FRAMEWORK

The performance of the MEDSEA_REANALYSIS_PHYS_006_004 has been evaluated for the period 1 January 1987-31 December 2016 (the 2017-2018 skill is compliant with the previous period) considering a set of standardized metrics grouped by ocean state variables and applied in order to assess different aspect that can affect the quality of the products.

All confrontations were undertaken from an "in-situ point of view", where the observational dataset were kept on their original position and the corresponding model estimates are interpolated to the sensor position.

The EANs have been computed using the misfits (*Adani et al., 2011; Tonani et al., 2008*). The observation operator h is used to interpolate the model fields x^f to the location in time and space of the observations, y. This enables calculation of innovation or misfits:

$$m = [y - h(x^f)]$$

Misfits have been calculated before the data are inserted via data assimilation and the data can be considered as independent since the data are mostly sparse in space and time. The deviations between the datasets are quantified in terms of RMSD and BIAS, where RMSD provides estimates of the model precision while the BIAS indicates possible systematically errors in the model reanalysis, assuming that the observational dataset is correct. The RMSD and BIAS from temperature and salinity misfits are presented as monthly mean time series over 5 layers: L1) 0-30 m; L2) 30-150 m; L3) 150-300 m; L4) 300-600 m; L5) 600-1000 m and as mean profile computed over the entire domain and the entire time period. A deeper layer 1000-3000 m has not been considered because scares data availability in time and space below 1000 m that does not provide enough statistical significance.

IV VALIDATION RESULTS

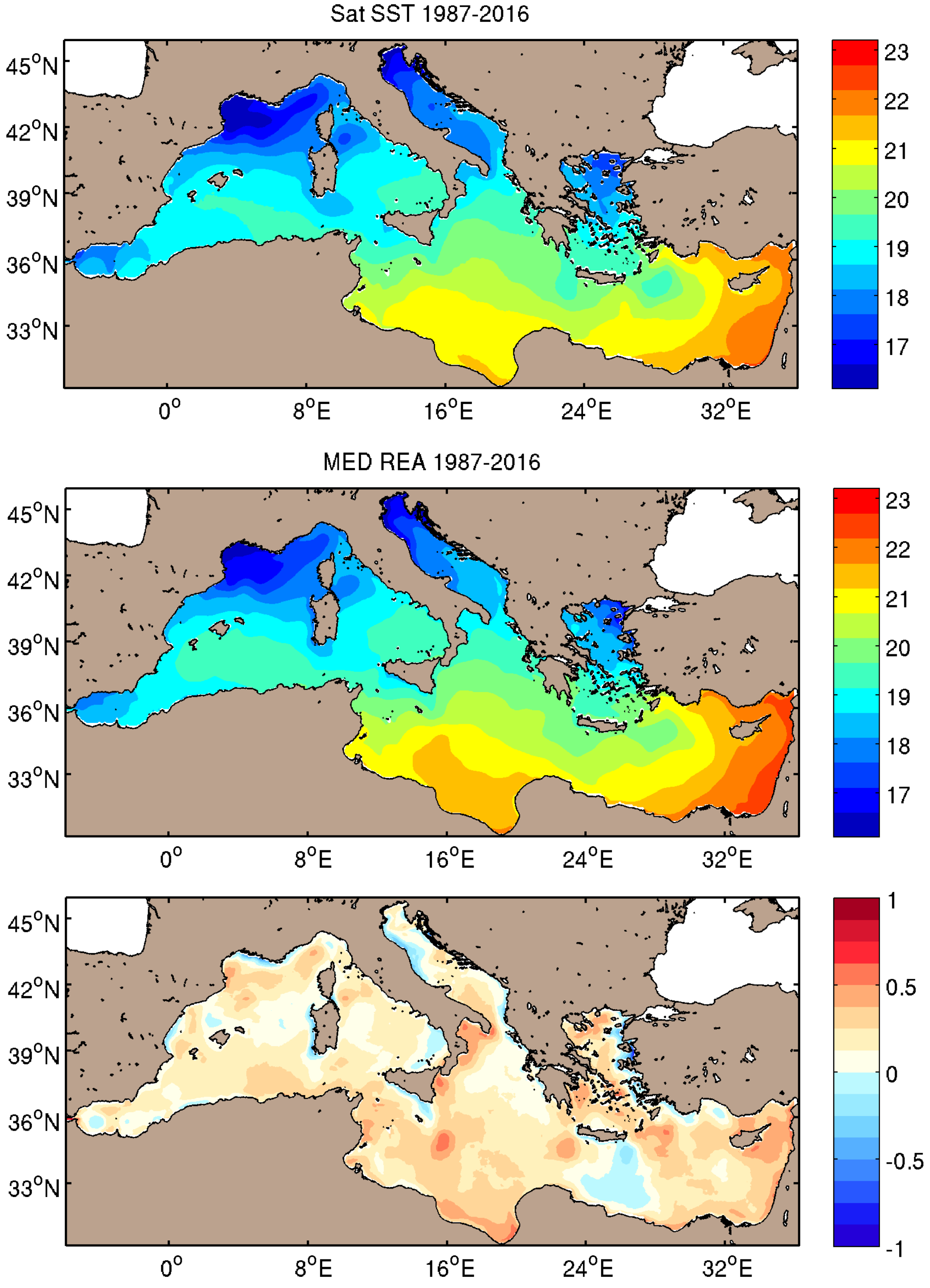
IV.1 SST

Table 3 summarizes the metrics and the observations used in the assessment of Sea Surface Temperature.

Name	**Reference dataset**	**Quantity**
SST-CLASS1-MEAN	Daily satellite estimates from OC TAC of SST	Maps of long-term annual mean from reanalysis product and reference dataset and differences between reference dataset and reanalysis product
SST-CLASS4-RMS-DAILY	Daily satellite estimates from OC TAC of SST	Time series of RMS of reference dataset minus reanalysis product on daily basis
SST-CLASS4-BIAS-DAILY	Daily satellite estimates from OC TAC of SST	Time series of BIAS of reference dataset minus reanalysis product on daily basis
SST-CLASS1-RMS	Daily satellite estimates from OC TAC of SST	Maps of annual mean RMS of reference dataset minus reanalysis product on daily basis
SST-CLASS1-BIAS	Daily satellite estimates from OC TAC of SST	Maps of annual mean BIAS of reference dataset minus reanalysis product on daily basis
SST-CLASS3-2DMEAN	Daily satellite estimates from OC TAC of SST	Time series of domain averaged monthly SST computed from reanalysis product and reference dataset
QNET-CLASS3-2DMEAN	QNET as computed from *Pettenuzzo et al., 2010*	Time series of domain averaged monthly surface heat flux computed from reanalysis product

Table 3 Metrics and observations used to assess the SST.

Figure 1 (SST-CLASS1-MEAN) shows maps of long term annual mean SST computed from satellite observations and reanalysis product. The MED REA is able to well reproduce the spatial pattern of satellite observations and the largest differences are located where the role of atmospheric forcing and coastal processes play a crucial role.



Sat SST 1987-2016

MED REA 1987-2016

Figure 1: SST-CLASS1-MEAN Maps of long term annual mean from Satellite SST (upper panel), reanalysis product (middle panel) and differences: model - observations (bottom panel).

Figure 2 (**SST-CLASS4-RMS-DAILY** and **SST-CLASS4-BIAS-DAILY**) shows SST RMSD and BIAS of the differences between reanalysis product and satellite observations computed from daily estimates over the period 1987-2016. Both RMS and BIAS are characterized by a strong seasonal cycle with the lowest values during the winter months and the highest values during the summer months. Multi-year mean RMSD value is 0.56°C while multi-year mean BIAS is 0.18°C.

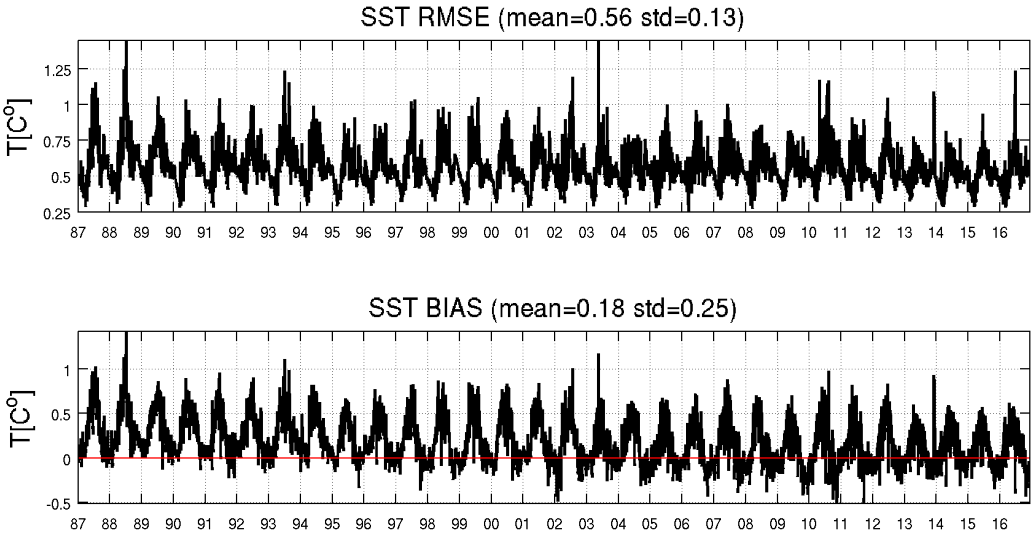


Figure 2: SST-CLASS4-RMS-DAILY (upper panel) and SST-CLASS4-BIAS-DAILY (bottom panel) computed from reanalysis product and satellite reference dataset on daily basis.

Figure 3 (**SST-CLASS1-RMS and SST-CLASS1-BIAS**) shows SST RMSD and BIAS maps computed over the whole time period 1987-2016. The largest RMSD values are located along the Eastern Gulf of Lion, Western Adriatic coast, the Turkish and Tunisian coasts. The BIAS spatial pattern highlights the areas where atmospheric forcing, numerical model approximations and topography deficiencies are located: cold BIAS values are located mainly along Aegean coast and Ierapetra gyre, while warm BIAS values are located in the Gulf of Taranto, around Cyprus and Rhode Island, South West of Crete and along Libyan coast.

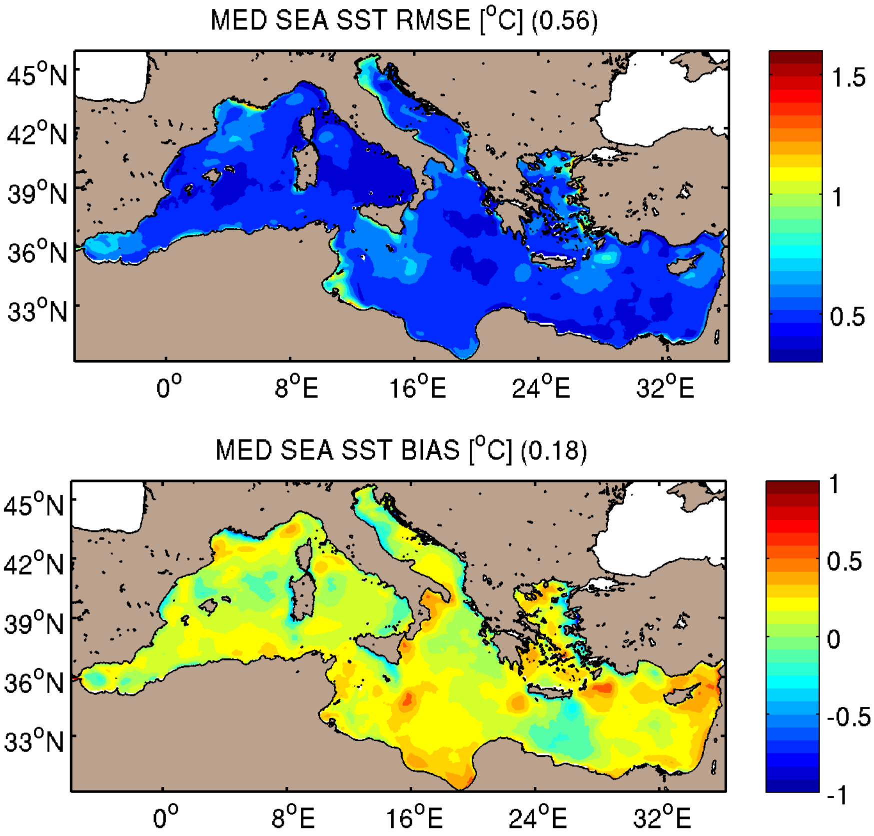


Figure 3: SST-CLASS1-RMS (upper panel) and SST-CLASS1-BIAS (Reanalysis-Observations) (bottom panel) computed from reanalysis product and satellite observations for the whole reanalysis period (1987-2016).

Figure 4 (**SST-CLASS3-2DMEAN**) shows the time series of domain averaged monthly SST computed from reanalysis product and from satellite observations over the whole period. The multiyear mean for the reanalysis product is 20.3°C, while for the observations is 20°C.

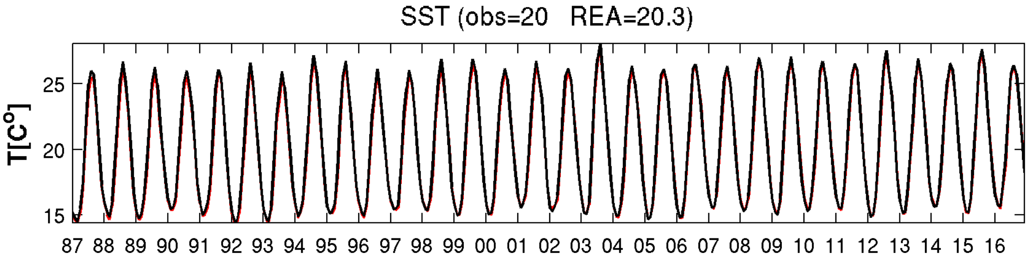


Figure 4: SST-CLASS3-2DMEAN Domain averaged monthly SST computed from reanalysis product (black line) and from satellite observations (red line).

Figure 5 **QNET-CLASS3-2DMEAN**) shows the multiyear monthly mean net heat flux, ranging from -275 W/m^2 to 190 W/m^2. The net heat budget is equal to -2 W/m^2, that is lower with respect to the literature values (-6±3 W/m^{2}in *Pettenuzzo et al., 2010*).

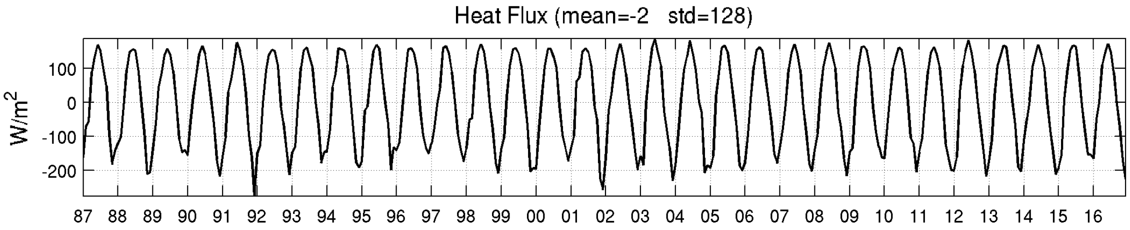


Figure 5: QNET-CLASS3-2DMEAN Domain averaged surface heat flux computed from reanalysis product.

IV.2 Temperature

Table 4 summarizes the metrics and the observations used in the assessment of Temperature.

Name	**Reference dataset**	**Quantity**
T-CLASS1-MEAN-DEPTHS	Targeted monthly mean gridded climatology from SDN	Maps of long-term annual mean from reanalysis product and reference dataset and differences at different depths
T-CLASS3-BIAS	Targeted monthly mean gridded climatology from SDN	Monthly climatology and monthly basin averaged profiles comparison against reference dataset
T-CLASS3-LAYERS	None	Time series of temperature computed from reanalysis product at different layers
T-CLASS3-IC-CHANGE	Targeted monthly mean gridded climatology from SDN	Water column differences between monthly basin averaged reanalysis temperature profiles and the IC
T-CLASS4-RMS-LAYERS	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Time series of RMS computed from misfits in different layers
T-CLASS4-BIAS-LAYERS	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Time series of BIAS computed from misfits in different layers
T-CLASS4-RMS-DEPTH	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Mean RMS profiles
T-CLASS4-BIAS-DEPTH	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Mean BIAS profiles

Table 4: Metrics and observations used to assess the Temperature.

Figure 6 - (**T-CLASS1-MEAN-DEPTHS**) shows the temperature annual mean computed for different depths (15-100-350-1000 m) from SDN climatology, reanalysis products and their differences. SDN climatology was computed considering observations from 1900 to 2009 and applying a 2° of correlation length in the mapping procedure.

At 15 m of depth (Figure 6), the major positive differences are located in the proximity to the Po river plume in the Northern Adriatic Basin, where the reanalysis appears warmer than the climatology. This is due the absence of the signal of the Po river in the climatology dataset.

The major negative differences are located instead in the areas where upwelling events occur, such as South West of Sicily and West of Sardinia.

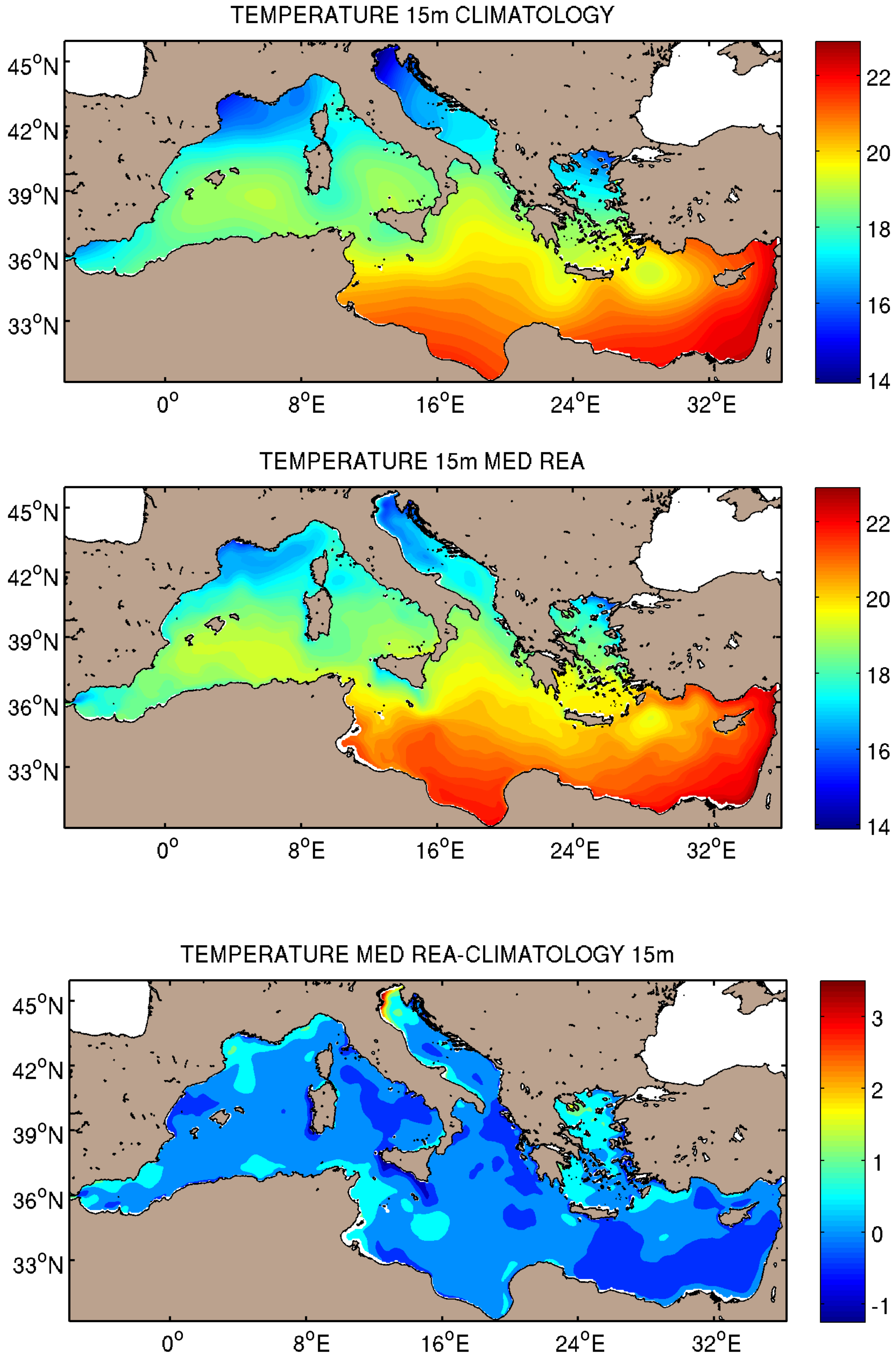
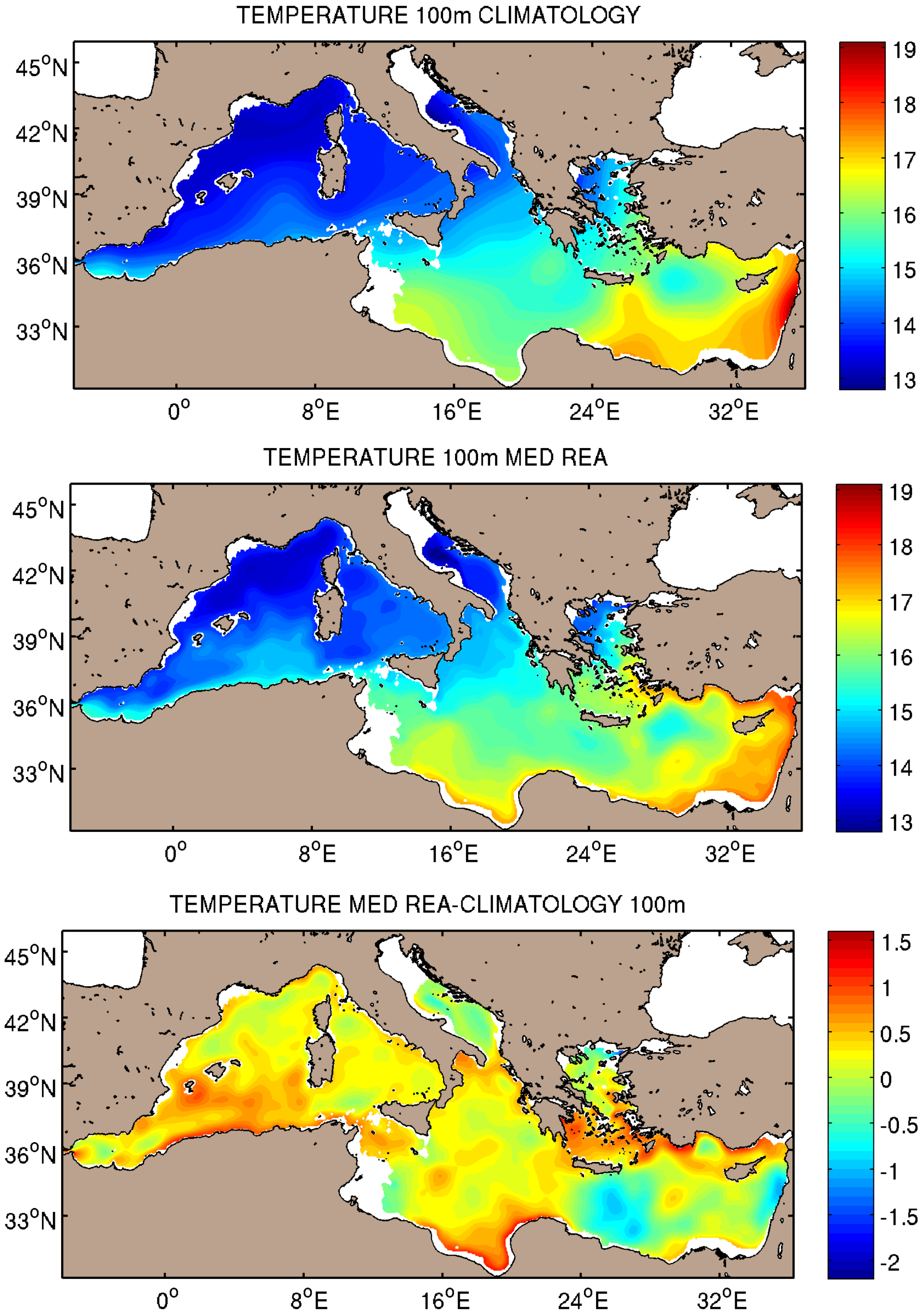


Figure 6 T-CLASS1-MEAN-DEPTHS Annual mean maps of temperature at 15 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

At 100 m of depth (Figure 7), the largest negative differences are at the Dardanelles inflow, in the south-east of Crete and north east of the Levantine basin, while positive differences appear in correspondence of the areas where the main currents form (*Pinardi et al., 2015*): along coast of Algeria (Algerian Current), Tunisia (Sicily Strait Tunisian Current) and Turkey (Asia Minor Current).



TEMPERATURE 100m CLIMATOLOGY

TEMPERATURE 100m MED REA

TEMPERATURE MED REA-CLIMATOLOGY 100m

Figure 7 T-CLASS1-MEAN-DEPTHS Annual mean maps of temperature at 100 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

At 350 m of depth (Figure 8), negative differences are located in the Levantine basin, where are located also the largest positive differences along the northern coasts.

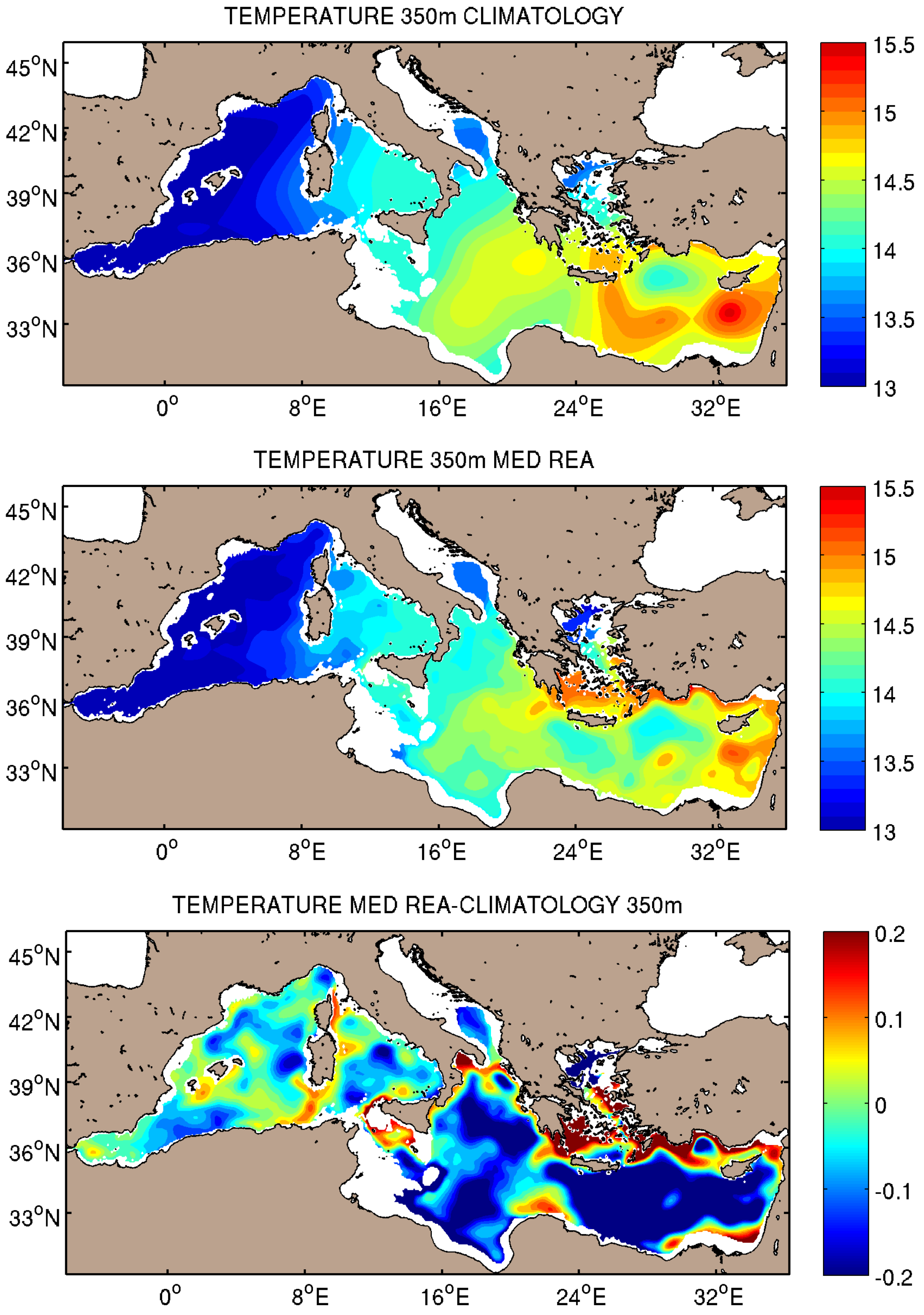


Figure 8 T-CLASS1-MEAN DEPTHS Annual mean of temperature at 350 m of depth computed from SDN climatology (upper panel), reanalyisis products (middle panel) and differences (bottom panel).

At 1000 m of depth (Figure 9), reanalysis and climatology match quite well with maximum negative differences in the Southern Tyrrhenian basin and along the Ionian coast of Greece.

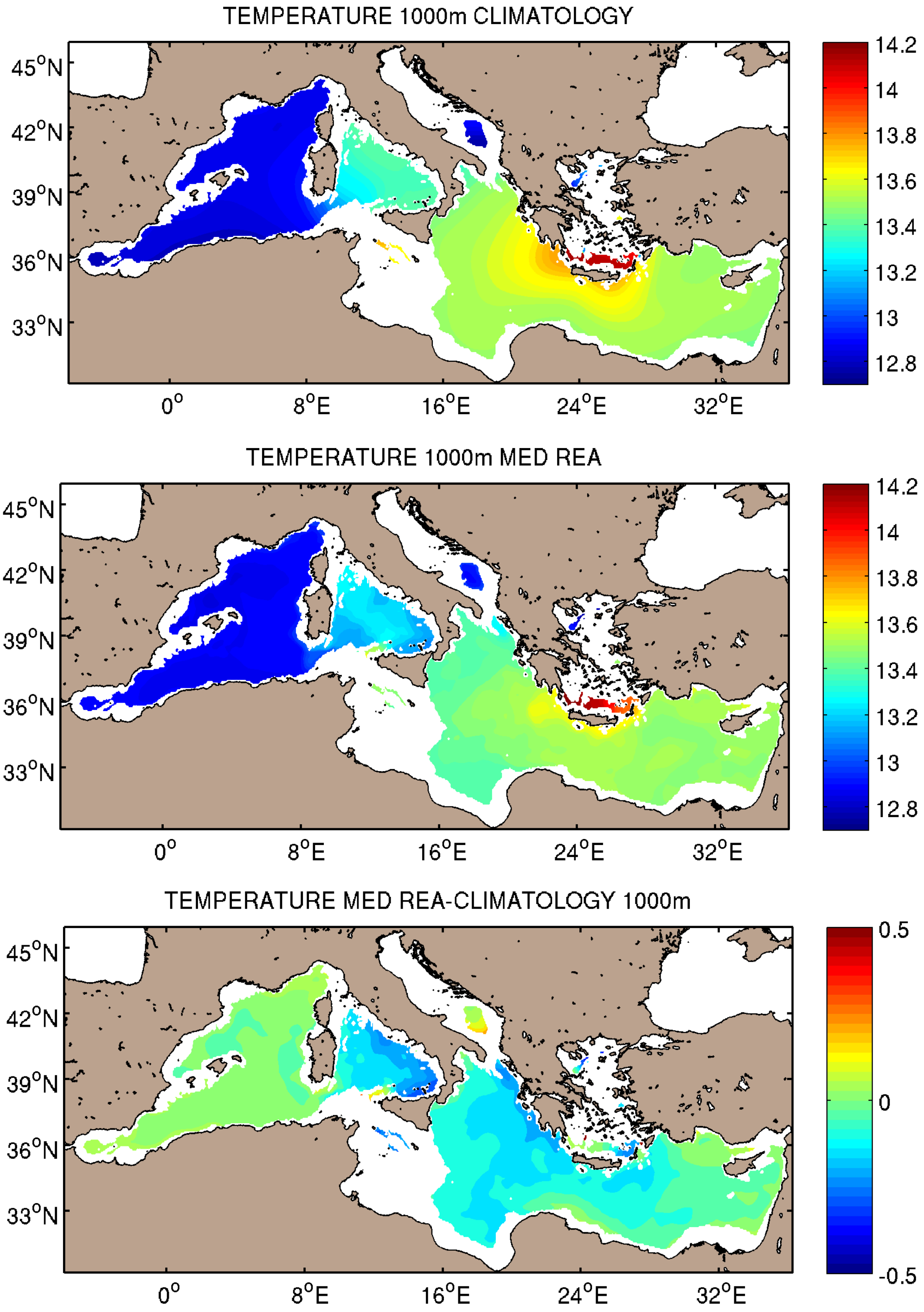


Figure 9 T-CLASS1-MEAN-DEPTHS Annual mean maps of temperature at 1000 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

Figure 10 (**T-CLASS3-BIAS**) shows the temperature monthly climatology and monthly basin averaged profiles comparison against SDN climatology as a function of depth, up to 1000 m. Starting from the surface, and considering the differences as monthly climatology, from May to September reanalysis product is warmer (~0.3 °- 0.8°C) than the SDN climatology within the first 15 m, while is colder (~0.2°C) between 15-50 m. From September to December, the major positive differences, indicating that the reanalysis is warmer than the SDN climatology, are located between 20-50 m. Over all the months, from 200 to 1000 m SDN climatology is slightly warmer (~0.1°C) than reanalysis.

The differences between reanalysis and SDN climatology as monthly basin averaged profiles (Figure 10 – bottom panel), highlight the interannual variability: the years 2003, 2012 and 2015 present, during summer the highest positive differences reaching within the first 20 m values of ~2°C and 1.5°C respectively. After 1990, positive anomalies within the first 150 m are evident during winters 2000-2001, 2001-2002, 2002-2003, 2006-2007 and starting from 2014 became deeper until 500 m.

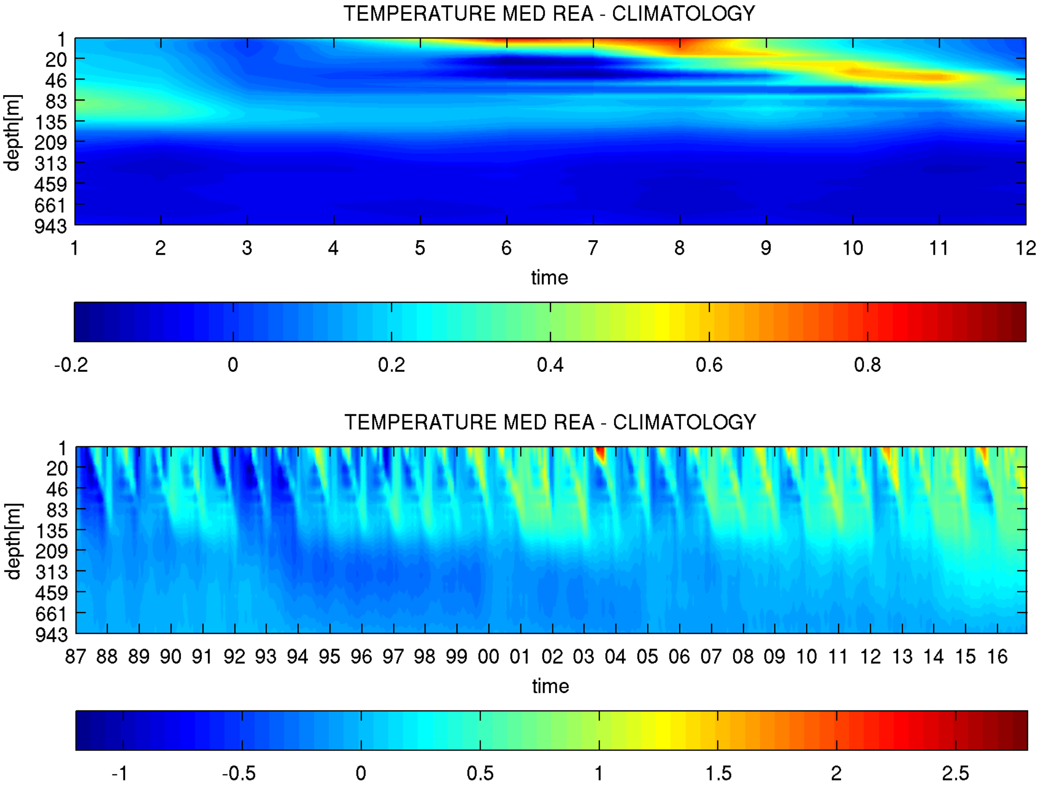
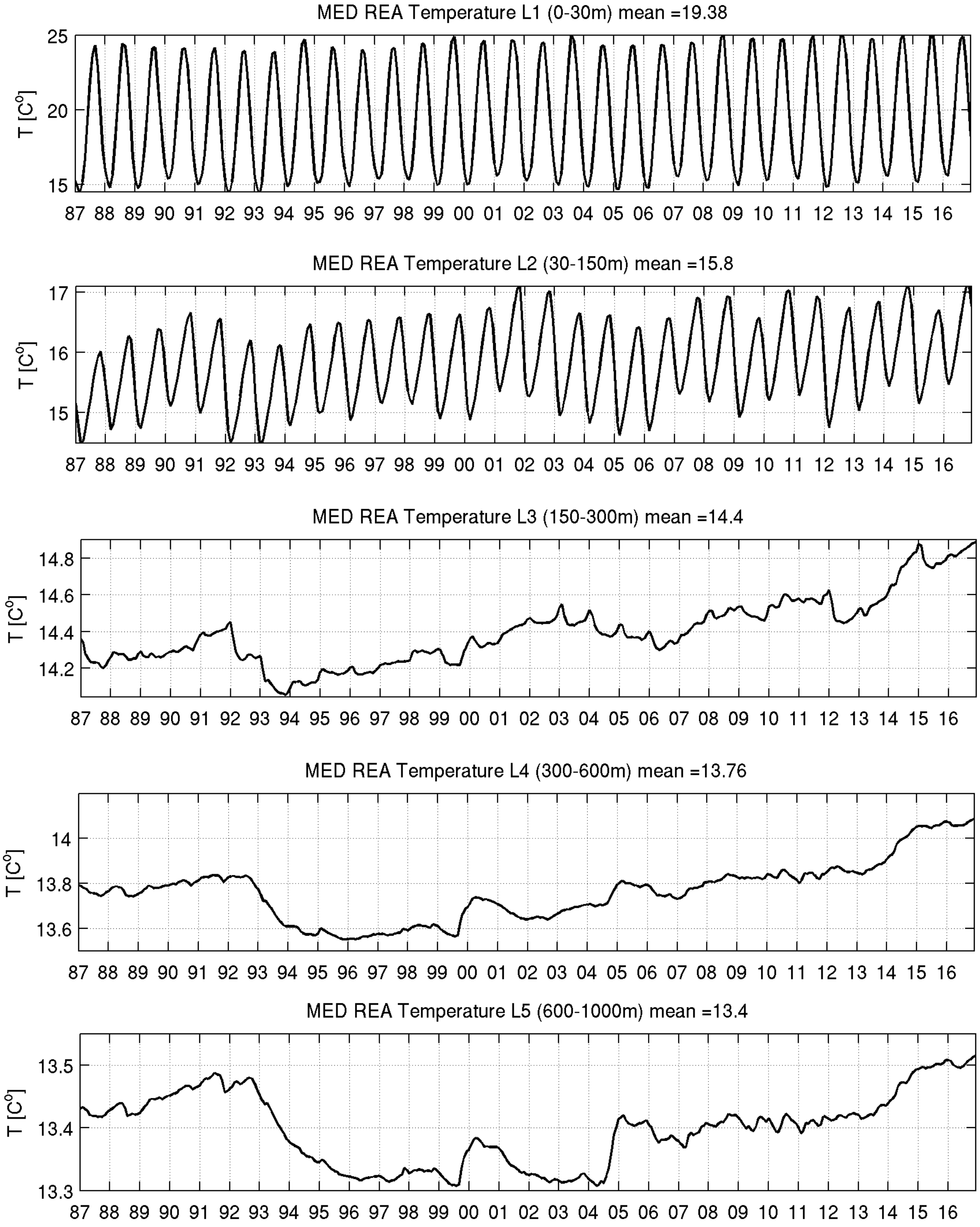


Figure 10 T-CLASS3-BIAS Monthly climatology (upper panel) and monthly basin averaged profiles (bottom panel) comparison between reanalysis product and SDN climatology.

Figure 11 (**T-CLASS3-LAYER**) shows the time series of temperature in different layers over the Mediterranean Sea. The first layer (0-30 m) presents a clear seasonal signal with the highest values during summer time (~25°C) and lowest values during wintertime (~15°C). This layer is highly influenced by the atmospheric forcing and is where the seasonal thermocline evolves. The seasonal signal is also evident in the change of temperature with respect to initial condition (**T-CLASS3-IC-CHANGE**), as shown in Figure 12

The seasonal cycle tends to disappear going to the deeper layers that exhibit smooth variations during the reanalysis period.



MED REA Temperature L1 (0-30m) mean =19.38

MED REA Temperature L2 (30-150m) mean =15.8

MED REA Temperature L3 (150-300m) mean =14.4

MED REA Temperature L4 (300-600m) mean =13.76

MED REA Temperature L5 (600-1000m) mean =13.4

Figure 11 T-CLASS3-LAYERS Domain average temperature monthly mean computed from reanalysis product at different layers.

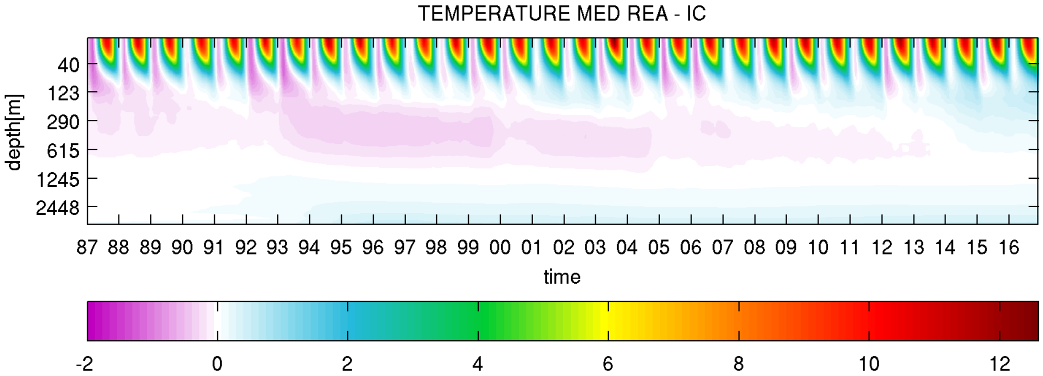


Figure 12 T-CLASS3-IC-CHANGE Domain average temperature change with respect to initial conditions.

Figure 13 **-** Figure 14 (**T-CLASS4-RMS-LAYERS and T-CLASS4-BIAS-LAYERS**) present the RMS and BIAS computed in different layers at observation space-time location.

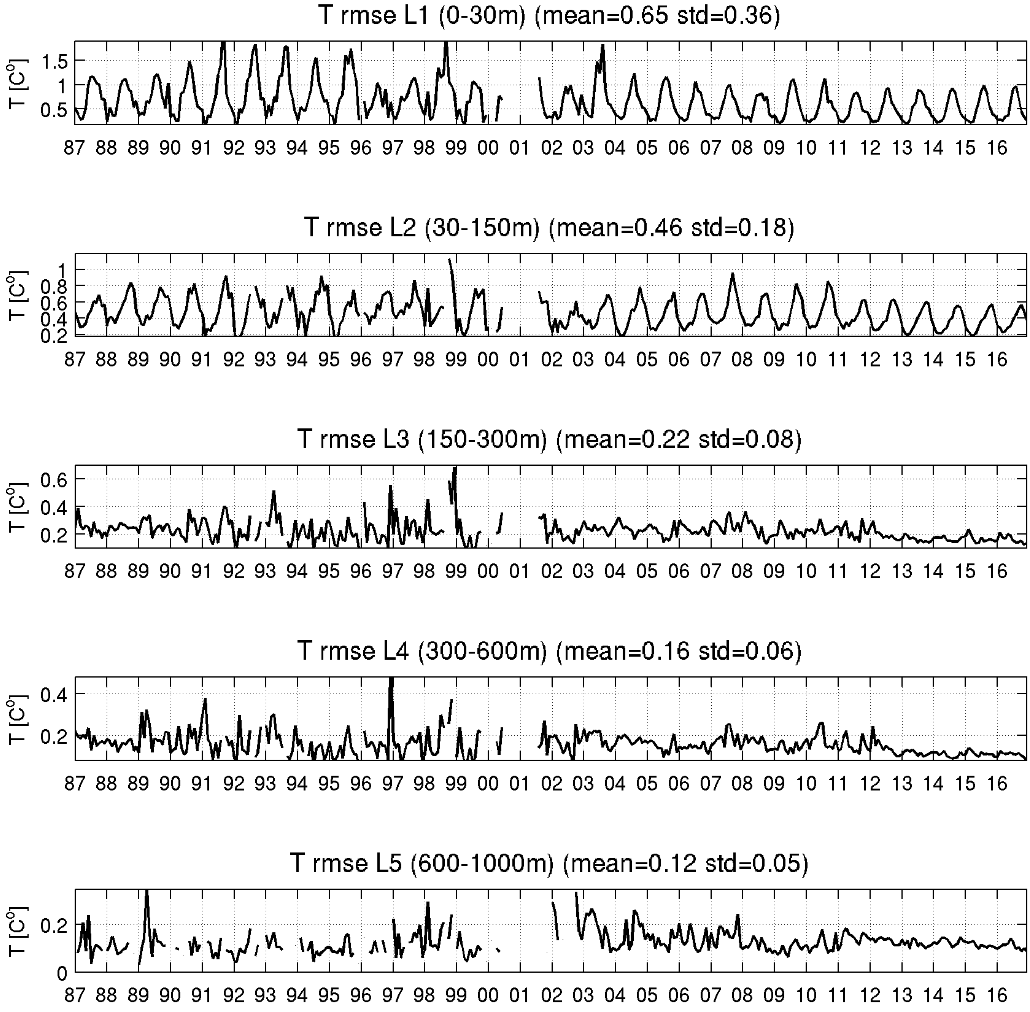


Figure 13 T-CLASS4-RMS-LAYERS RMSD computed from misfits of reanalysis product at different layers.

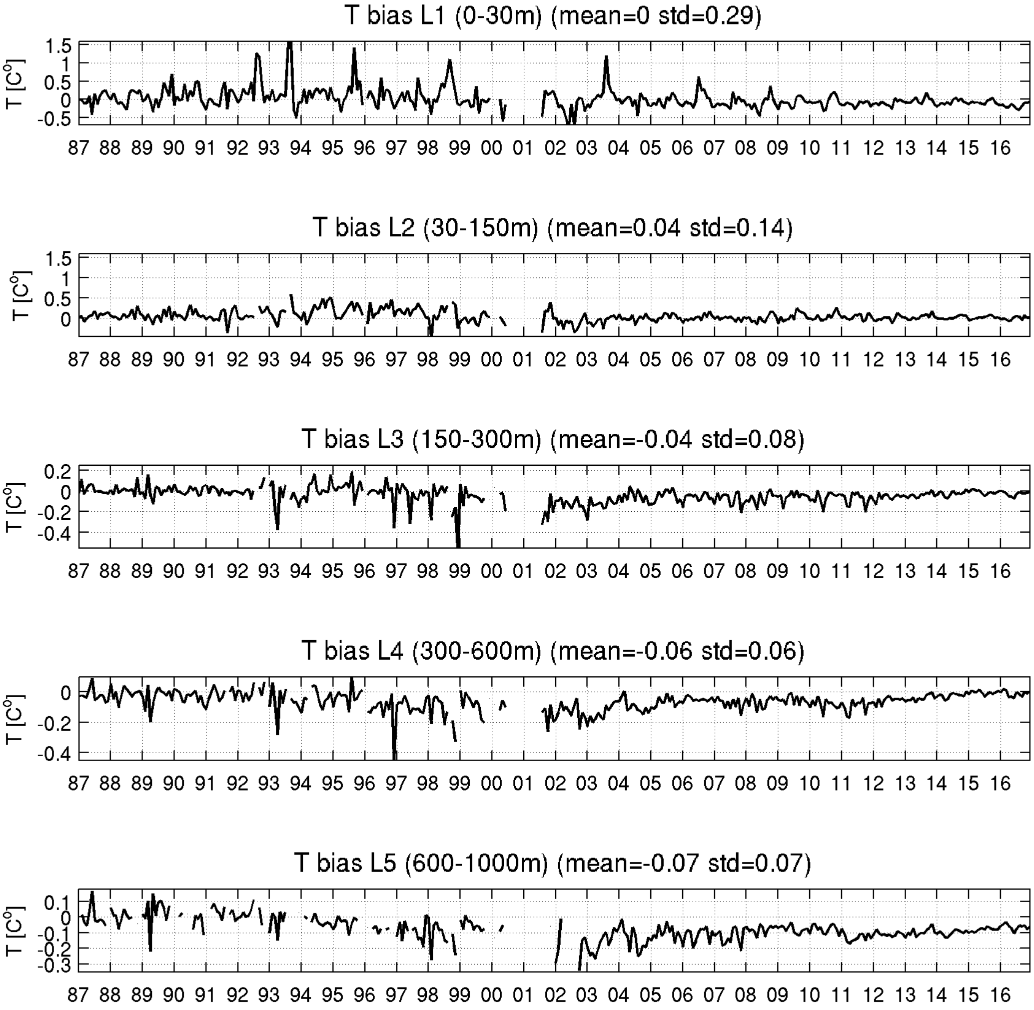


Figure 14 T-CLASS4-BIAS-LAYERS BIAS computed from misfits of reanalysis product at different layers.

Figure 15 (**T-CLASS4-RMS-DEPTH**) displays temperature BIAS (left) and RMSD (middle) profiles averaged up to 100 m over the entire reanalysis period. Skill scores below 1000 m are not shown due to data sparseness. Temperature BIAS exhibits maximum positive values within the first 150 m, where the seasonal thermocline evolves, and RMSD peaks at about 30 m of depth (~0.8°C). The water column averaged BIAS is equal to -0.02 ± 0.004 and RMSD is equal to -0.33 ± 0.02.

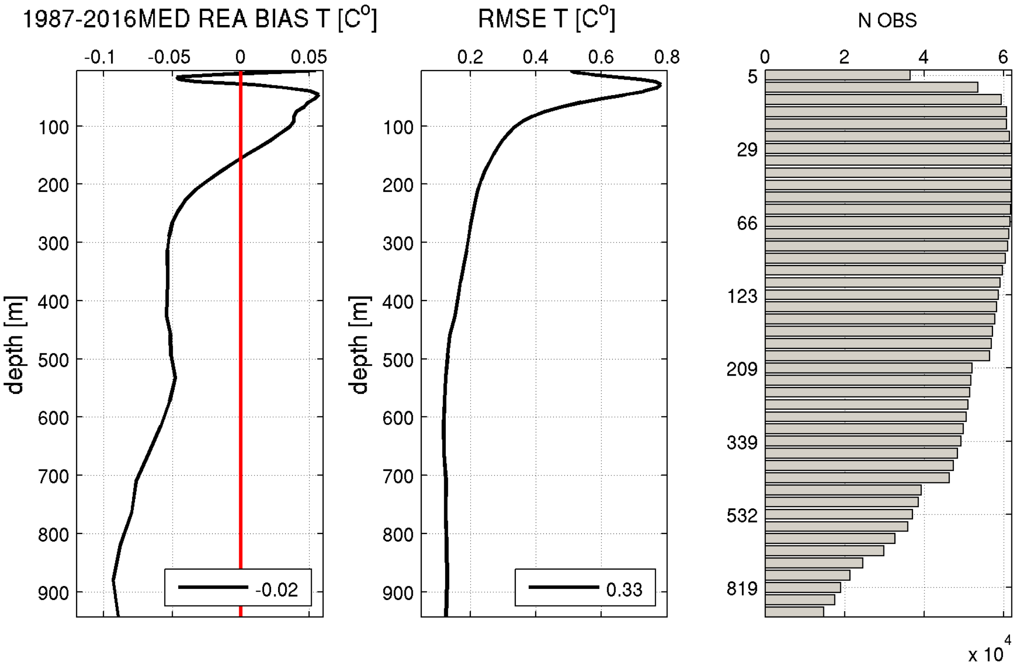


Figure 15 T-CLASS4-RMS-DEPTH and T-CLASS4-BIAS-DEPTH computed from reanalysis misfits.

The total EANs, BIAS and RMS for temperature are included in Table 5.

TEMPERATURE [°C]	BIAS	RMS
0 -30 m	0.0± 0.29	0.65 ± 0.36
30 -150 m	0.04 ± 0.14	0.46 ± 0.18
150 - 300 m	-0.04 ± 0.08	0.22 ± 0.08
300 - 600 m	-0.06 ± 0.06	0.16 ± 0.06
600 -1000 m	-0.07 ± 0.07	0.12 ± 0.05
Total	-0.02 ± 0.0	0.33± 0.02

Table 5 EANs for temperature.

IV.3 Sea Surface Salinity

Table 6 summarizes the metrics and the observations used in the assessment of Sea Surface Salinity.

Name	**Reference dataset**	**Quantity**
SSS-CLASS3-2DMEAN	None	Averaged monthly mean over the Mediterranean Sea
SFW-CLASS3-2DMEAN	SFW from from *Pettenuzzo, D., Large, W.G., & Pinardi, N. (2010); Mariotti et al., 2010.*	Mediterranean Sea averaged monthly fresh water flux

Table 6 Metrics and observations used to assess the Sea Surface Salinity.

Figure 16 (**SSS-CLASS3-2DMEAN**) shows the domain averaged monthly sea surface salinity. The SSS exhibits a weak seasonal cycle within 0.2 psu with minimum values during spring time and maximum values during summer time. The SSS shows a clear jump from summer 2005 when starts to increase.

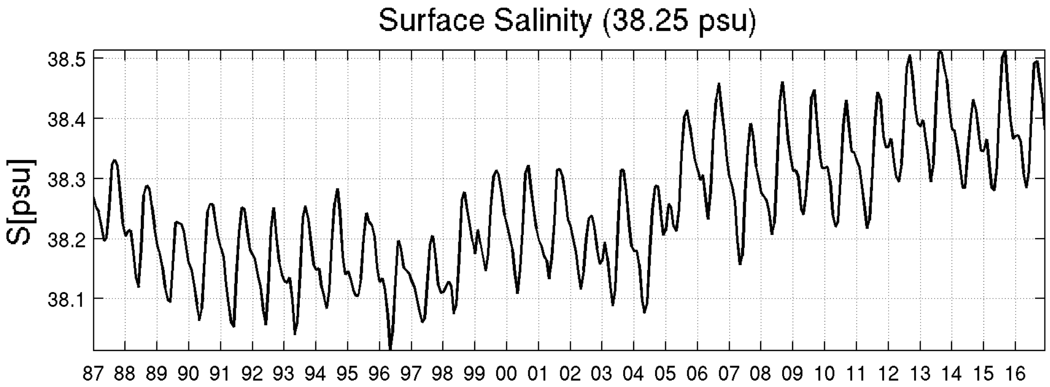


Figure 16 SSS-CLASS3-2DMEAN Averaged monthly mean of SSS

Figure 17 (**SFW-CLASS3-2DMEAN**) shows the net water flux which has an average value of 577 mm/yr. Considering river runoff equal to 185 mm/yr, the resulting evaporation minus precipitation budget is 759 mm/yr th at is in good agreement with the literature (*Mariotti et al.,2010; Pettenuzzo et al., 2010, Jordà et al., 2017 and Pellet et al., 2019*).

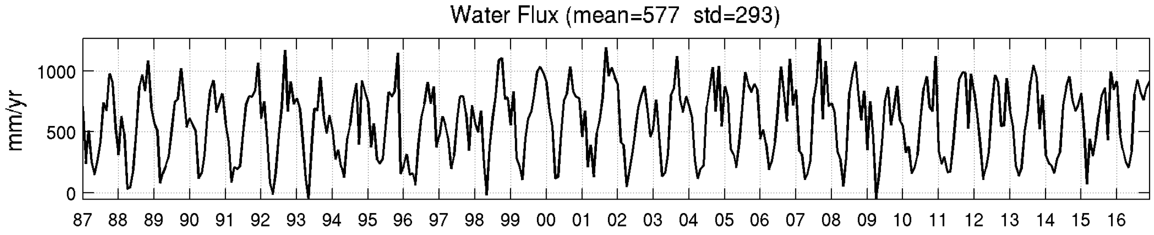


Figure 17 SFW-CLASS3-2DMEAN Averaged monthly fresh water flux.

IV.4 Salinity

Table 7 summarizes the metrics and the observations used in the assessment of Salinity.

Name	Reference dataset	Quantity
S-CLASS1-MEAN-DEPTHS	Targeted monthly mean gridded climatology from SDN	Maps of long-term annual mean from reanalysis product and reference dataset and differences at different depths
S-CLASS3-BIAS	Targeted monthly mean gridded climatology from SDN	Monthly climatology and monthly basin averaged profiles comparison against reference dataset
S-CLASS3-LAYERS	None	Time series of salinity computed from reanalysis product at different layers
S-CLASS3-IC-CHANGE	Targeted monthly mean gridded climatology from SDN	Water column differences between monthly basin averaged reanalysis salinity profiles and the IC
S-CLASS4-RMS-LAYERS	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Time series of RMS computed from misfits in different layers
S-CLASS4-BIAS-LAYERS	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Time series of BIAS computed from misfits in different layers

Table 7 Metrics and observations used to assess the Salinity (continues overleaf).

Name	Reference dataset	Quantity
S-CLASS4-RMS-DEPTH	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Mean RMS profiles
S-CLASS4-BIAS-DEPTH	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030 MEDAR-MEDATLAS MFS Insitu SDN products	Mean BIAS profiles

Table 8 (continued) Metrics and observations used to assess the Salinity.

Figure 18 - Figure 21(**S-CLASS1-MEAN-DEPTHS**) shows the salinity annual mean computed at different depths (15-100-350-1000 m) from SDN climatology, reanalysis and their differences.

At 15 m of depth (Figure 18), major positive differences (~1.5psu) are located in the Northern Aegean Sea at the Dardanelles inflow, where the reanalysis results are too salty with respect to the climatology. Negative differences values are instead located in the Western basin where reanalysis incoming Atlantic water is fresher than SDN climatology and along the Western coast of the Adriatic Sea, where the signal of Po river, as for the temperature, is absent in the SDN climatology.

Negative differences values in the Western basin are present also at 100 m of depth (Figure 19), along Algerian coast.

At 350 m of depth (Figure 20) instead, the major positive differences are located along the southern coasts of the western basin, along the Turkish coast and in the Cretan Sea, indicating that the reanalysis waters are saltier than SDN climatology.

At 1000 m of depth (Figure 21), the major positive differences are located in the Levantine basin and in the Southern Adriatic Sea, while South-Eastern Tyrrhenian Sea appears fresher than SDN climatology.

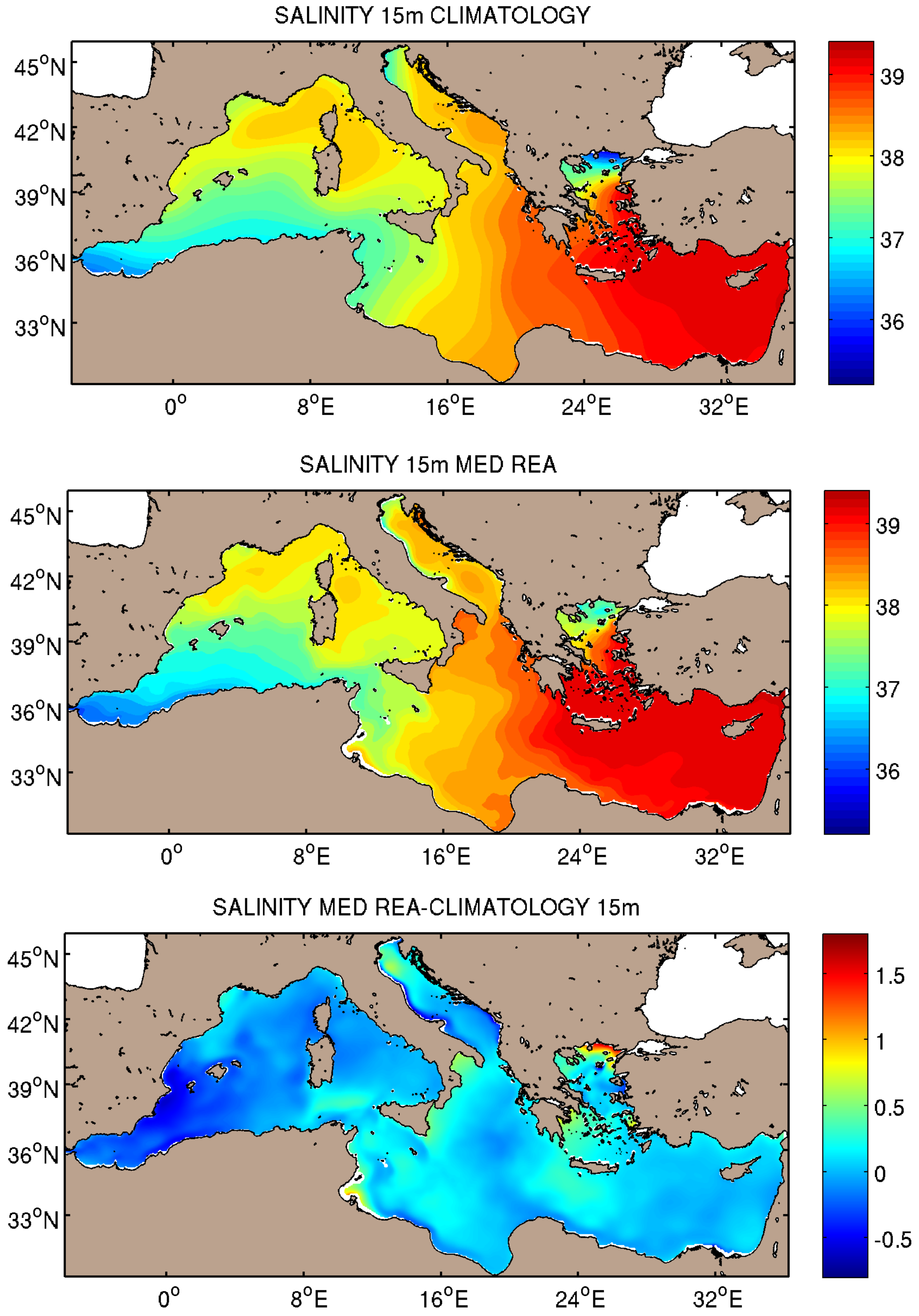


Figure 18 S-CLASS1-MEAN-DEPTHS Annual mean maps of salinity at 15 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

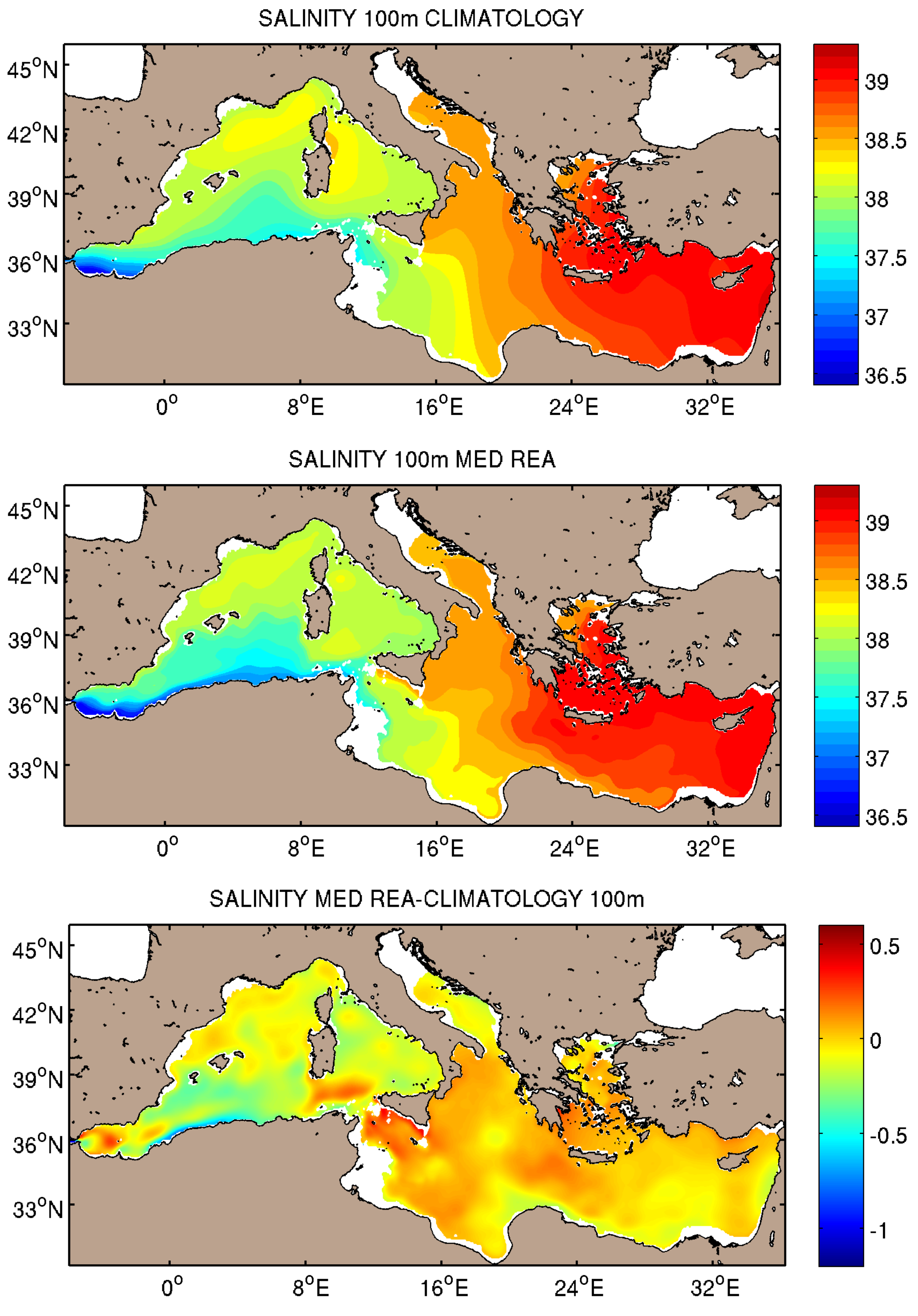


Figure 19 S-CLASS1-MEAN-DEPTHS Annual mean maps of salinity at 100 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

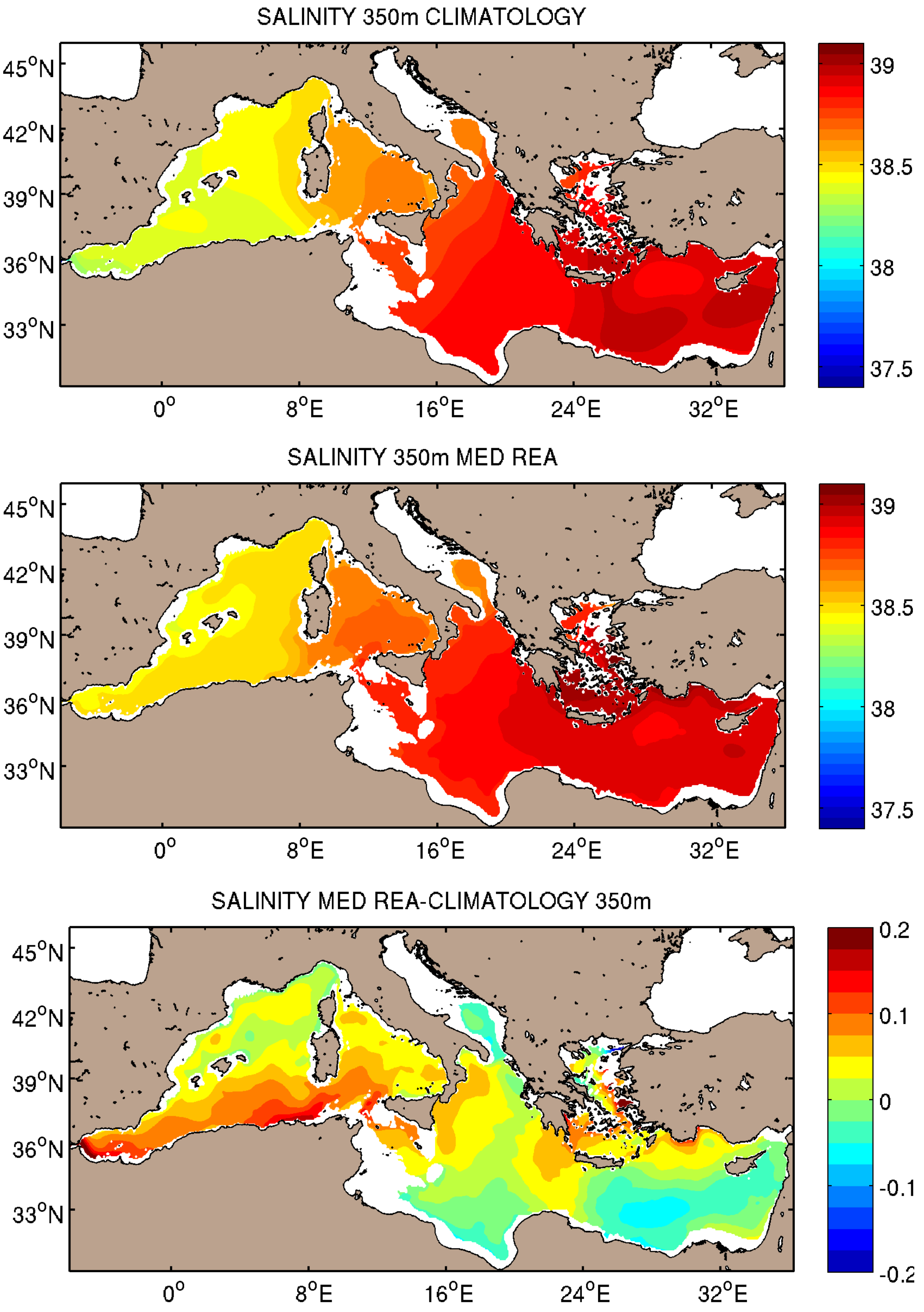


Figure 20 S-CLASS1-MEAN-DEPTHS Annual mean maps of salinity at 350 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

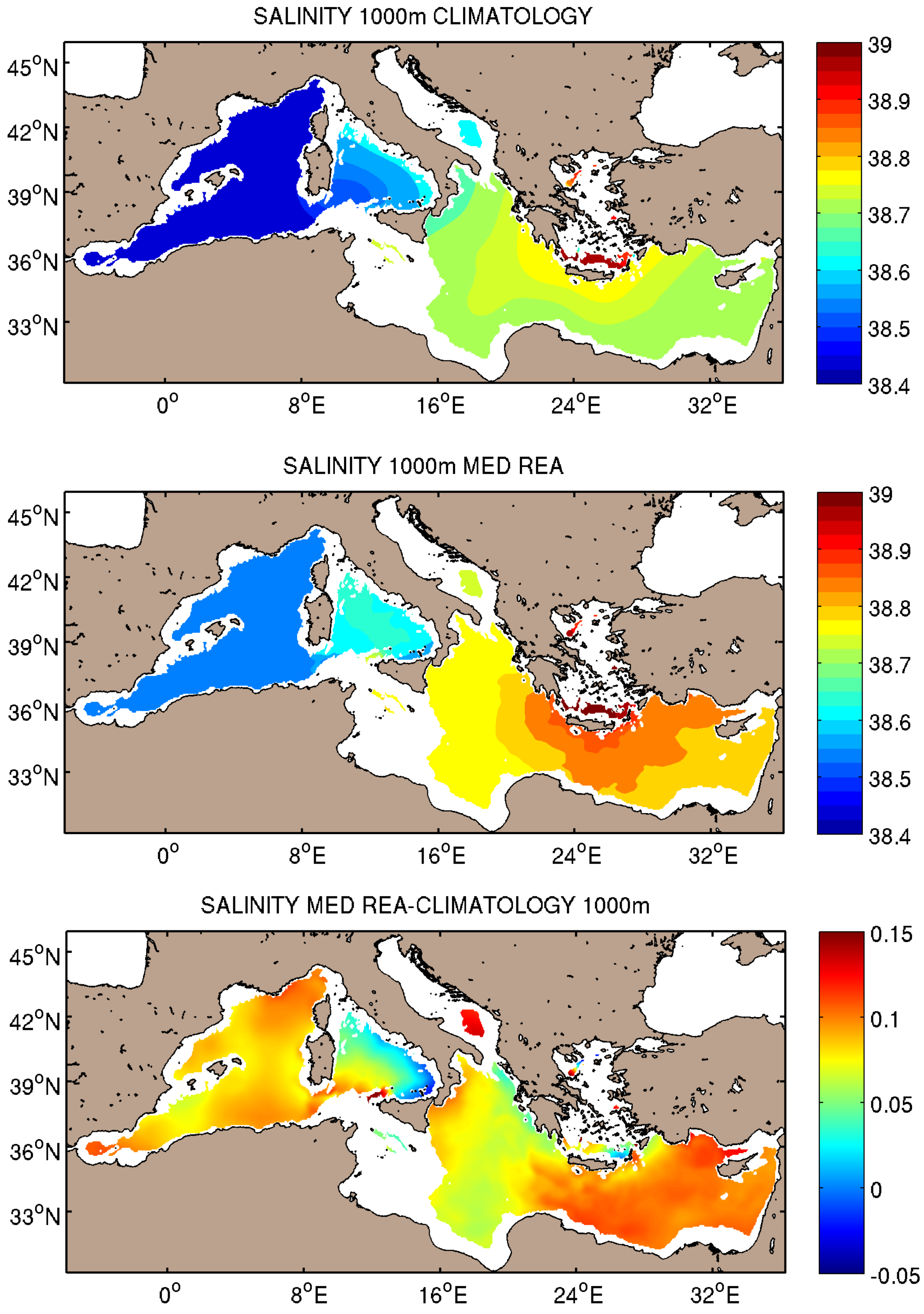


Figure 21 S-CLASS1-MEAN-DEPTHS Annual mean maps of salinity at 1000 m of depth computed from SDN climatology (upper panel), reanalysis product (middle panel) and differences (bottom panel).

Figure 22 (**S-CLASS3-BIAS**) shows the salinity monthly climatology and monthly basin averaged profiles comparison against SDN climatology as a function of depth up to 1000 m.

Within the first 20 m of depth, from May to September is present a positive anomaly indicating that reanalysis product is saltier than SDN climatology. From 20 m to ~130 m of depth, a negative anomaly is present all over the year and the reanalysis product is fresher than SDN of about 0.05 PSU. Down to 130 m to ~1000 m anomalies are positive all over the year and the reanalysis product is always saltier than SDN climatology, reaching maximum value of 0.1psu at 1000 m.

The differences between reanalysis and SDN as monthly basin averaged profiles (Figure 22 – bottom panel) show negative values (0.1-0.2psu) within the first 150 m of depth until 2005, indicating that reanalysis is fresher than climatology. This tendency is reversed starting from 2005 when a positive tendency is established within first 20 m. From 2012 the positive anomalies become deeper than 40 m.

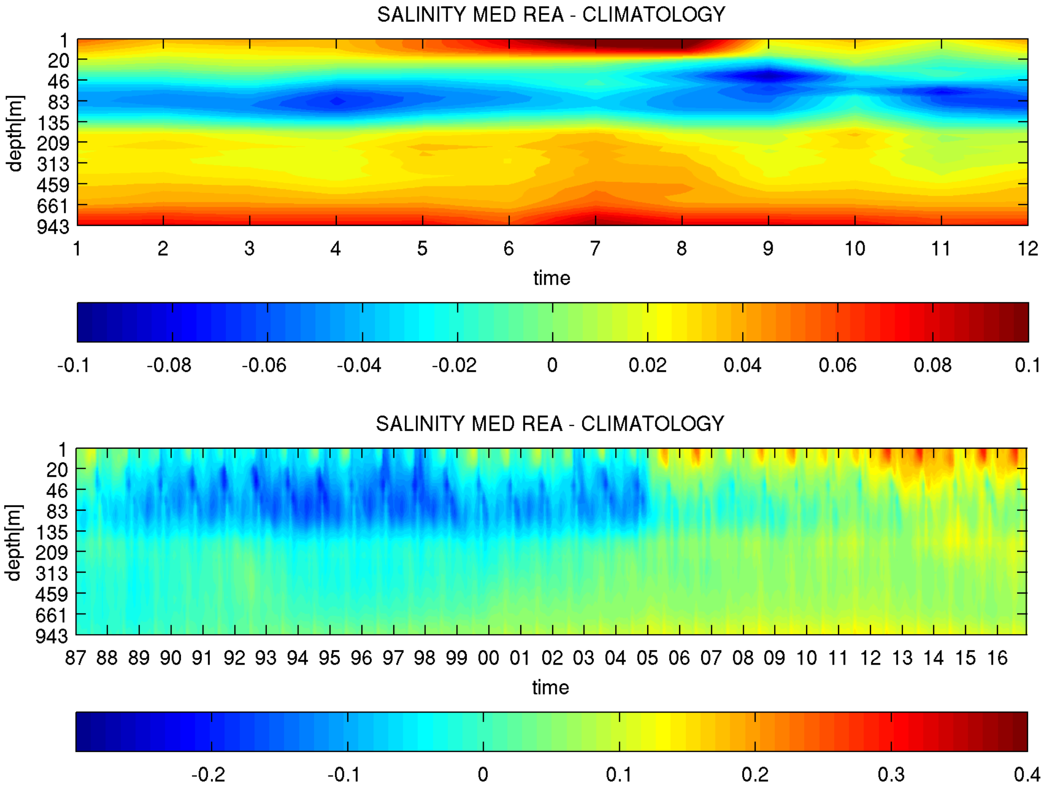


Figure 22 S-CLASS3-BIAS Monthly climatology (up) and monthly basin averaged profiles (bottom) comparison between reanalysis product and SDN climatology.

Figure 23 (**S-CLASS3-LAYERS**) shows the evolution of domain averaged salinity computed as function of time in different layers. As for the temperature, the first layer (0-30 m) shows a clear seasonal signal with minimum values at the end of summertime and an average of 38.26 PSU. Starting from 2005 a jump is obvious in the salinity behaviour above 150 m and starting from 2000 below 150 m. The salinity increase could be explained by ARGO advent (2001) that provides a better representation of water column characteristics. The advantages of the assimilation of ARGO data are evident also in the time series of salinity RMS (Figure 25) where, after 2001, the model is much more constrained by observation from ARGO and RMS errors tend to remain quite constant.

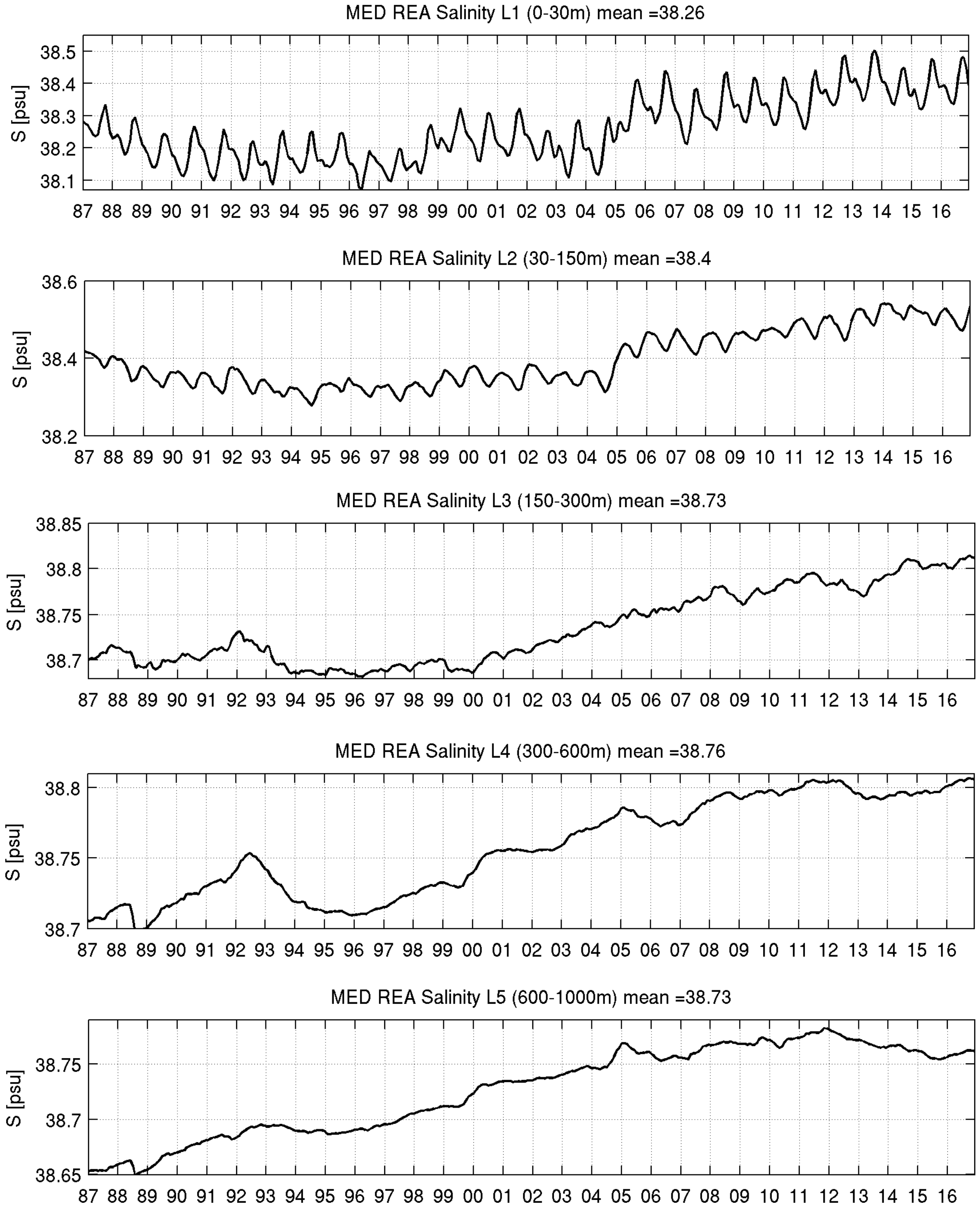


Figure 23 S-CLASS3-LAYERS Domain average salinity monthly mean computed from reanalysis product at different layers.

Evidence of the seasonal signal is also present in the water column differences between monthly basin averaged salinity profiles and the initial condition (**S-CLASS3-IC-CHANGE**)

(Figure 24), where salinity increases within the first 50 m during summertime, while decreases up to 100 m of depth during springtime. Also in this comparison, it is evident an increase of salinity starting from 2005.

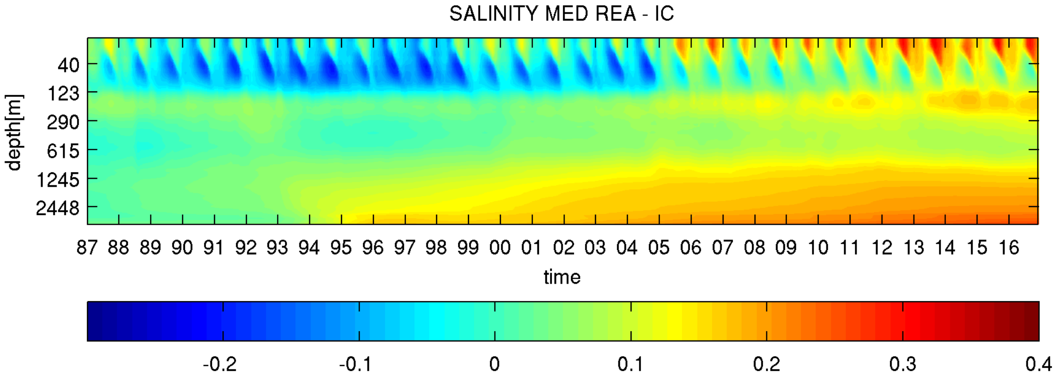


Figure 24 S-CLASS3-IC-CHANGE Domain average salinity change with respect to initial condition.

Figure 25 - Figure 26 (**S-CLASS4-RMS-LAYERS and S-CLASS4-BIAS-LAYERS**) present the RMS and BIAS computed in different layers at observation space-time location.

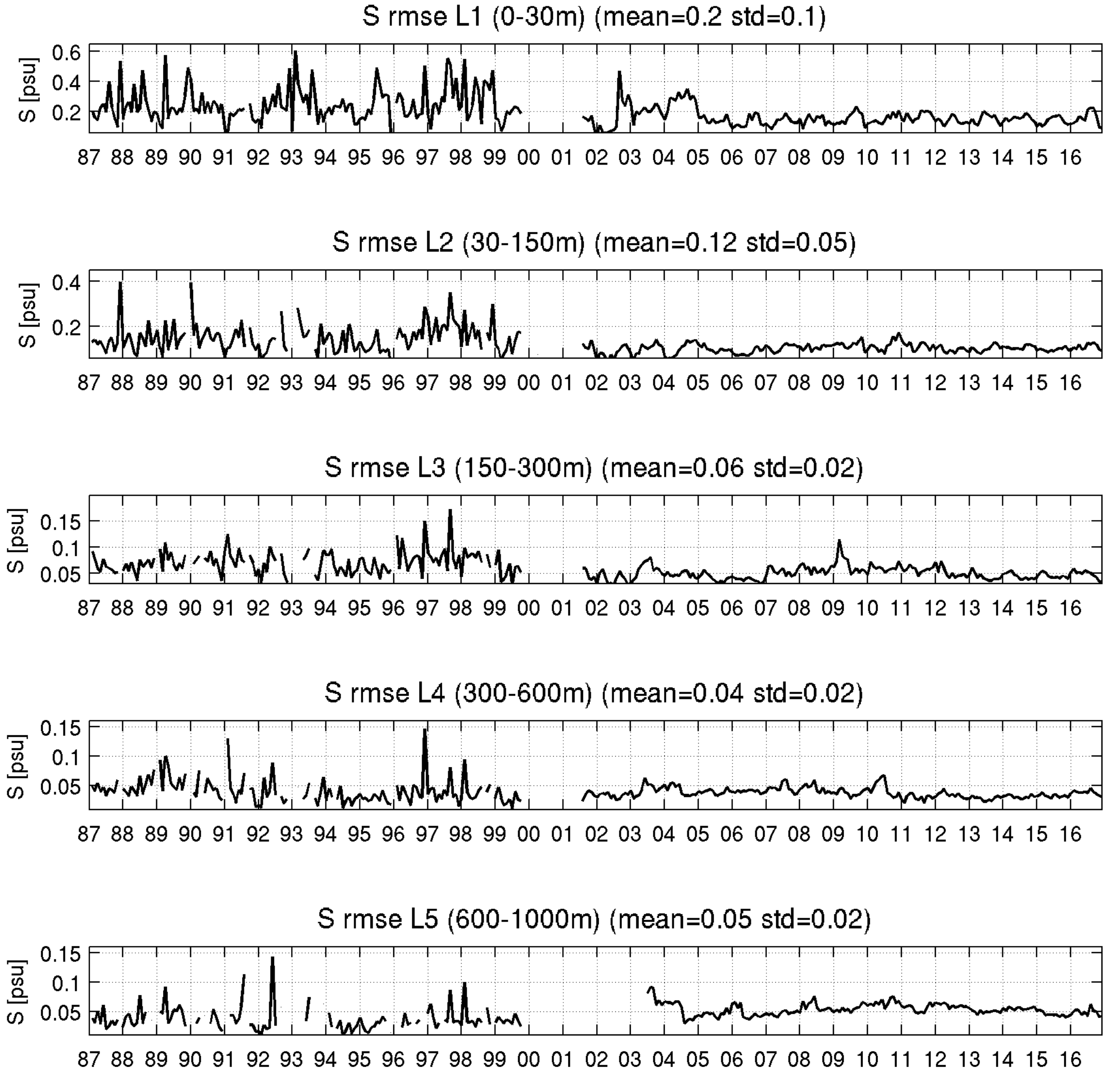


Figure 25 S-CLASS4-RMS-LAYERS computed from misfits of reanalysis product in different layers.

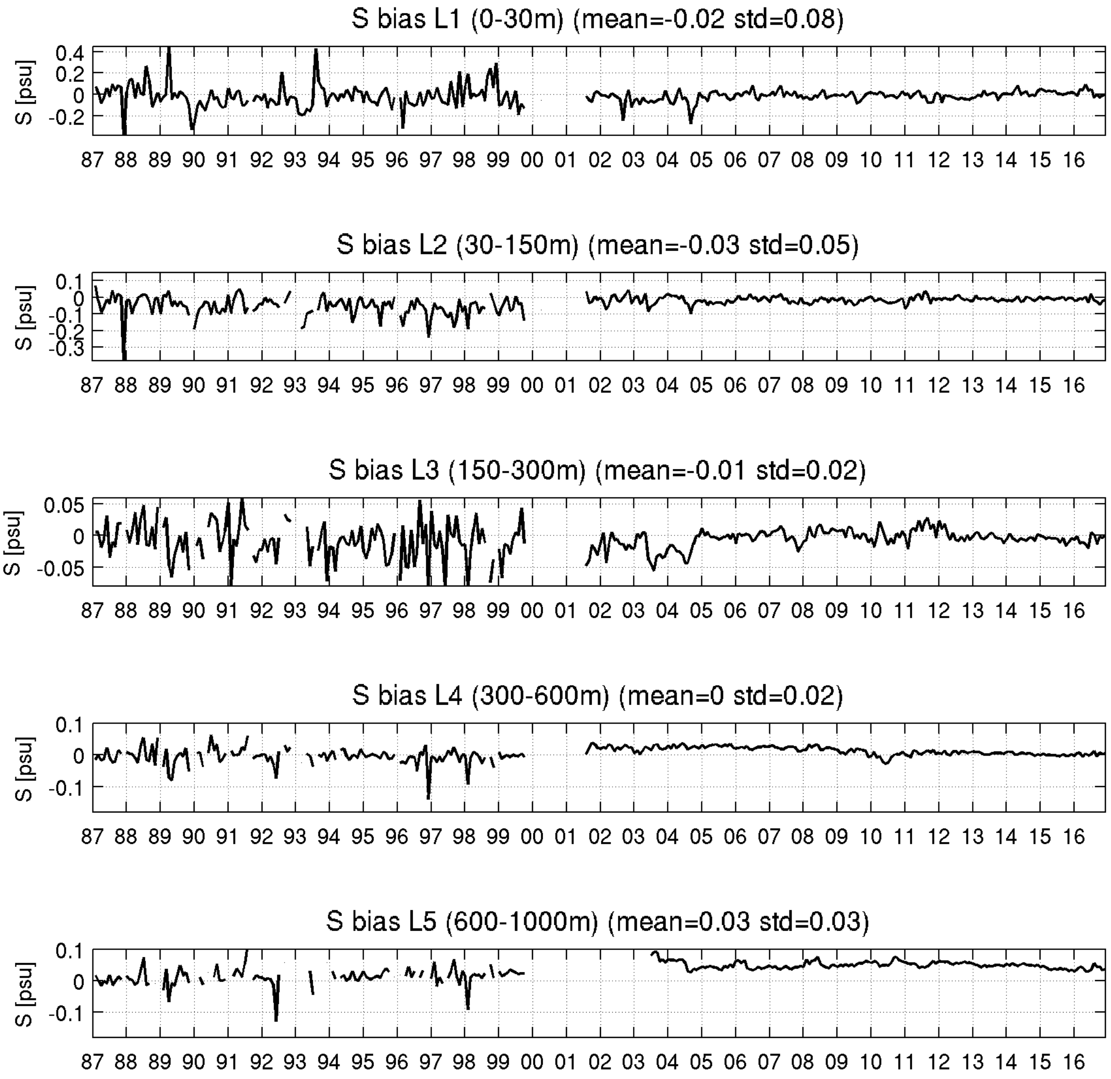


Figure 26 S-CLASS4-BIAS-LAYERS computed from misfits of reanalysis product in different layers.

Figure 27 (**S-CLASS4-RMS-DEPTH** and **S-CLASS4-BIAS-DEPTH**) displays salinity BIAS (left) and RMS (middle) mean profiles computed on misfits. Salinity Bias is negative within the first 400 m and positive below. The RMSD reaches maximum value of 0.3 PSU at the surface where both the atmospheric and land forcings play a fundamental role.

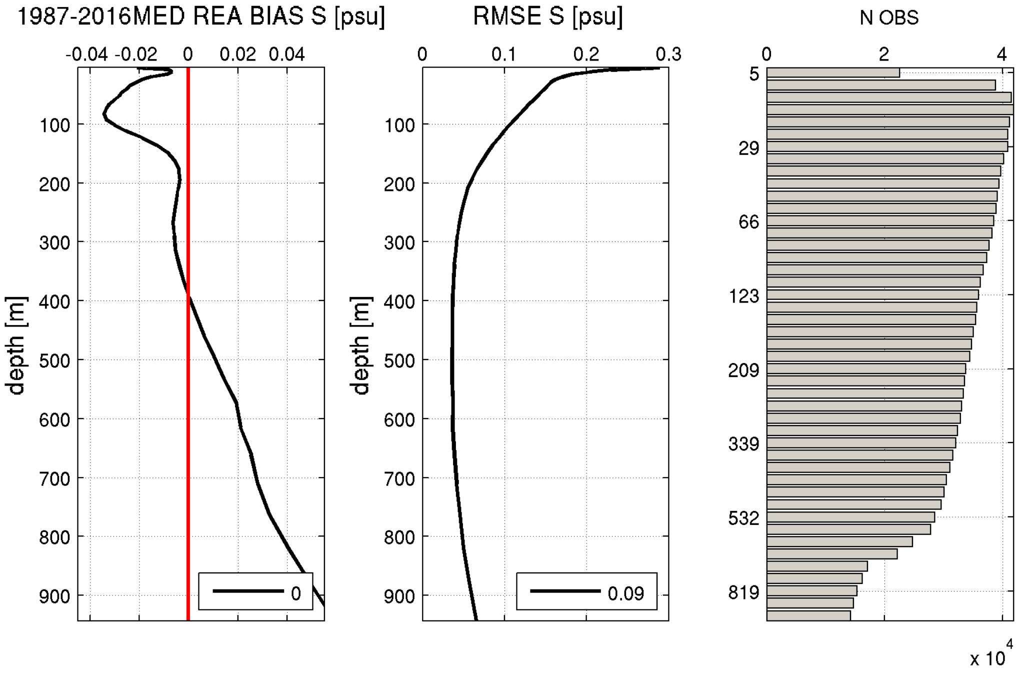


Figure 27 S-CLASS4-RMS-DEPTH and S-CLASS4-BIAS-DEPTH computed from reanalysis misfits.

The total EANs, BIAS and RMS for salinity are included in Table 9.

Salinity [psu]	BIAS	RMS
0 -30 m	0.02 ± 0.08	0.2 ± 0.1
30 -150 m	-0.03 ± 0.05	0.12 ± 0.05
150 - 300 m	-0.01 ± 0.02	0.06 ± 0.02
300 - 600 m	0.0 ± 0.02	0.04 ± 0.02
600 -1000 m	0.03 ± 0.03	0.05 ± 0.02
Total	0.0± 0.003	0.09 ± 0.01

Table 9 EANs for salinity.

IV.5 Currents

Table 10 summarizes the metrics and the observations used in the assessment of currents.

Name	**Reference dataset**	**Quantity**
UV-CLASS1-15M-MEAN	*Pinardi et al. (2015)*	Maps of Mediterranean Sea surface mean currents at 15 m

Table 10 Metrics and observations used to assess the currents.

Figure 28 (**UV-CLASS1-15M-MEAN**) displays maps of surface mean currents at 15 m of depth computed from reanalysis product following Pinardi et al. (2015). The climatological circulation was computed over the period 1987-1996 and 1997-2006 in order to compare the decadal variability of the Mediterranean Sea circulation as in Pinardi et al. (2015). The changes between the two periods in the Western Mediterranean take place in the Alboran Sea and the Tyrrhenian Sea. The Major changes happened in the Eastern Mediterranean circulation where a current reversal took place in the Northern Ionian Sea related to the reversal from anticyclone to cyclonic circulation. During the second period the general circulation in the Levantine basin intensifies.

The mean surface circulation is in agreement with the literature and presents the well-know Mediterranean surface circulation features.

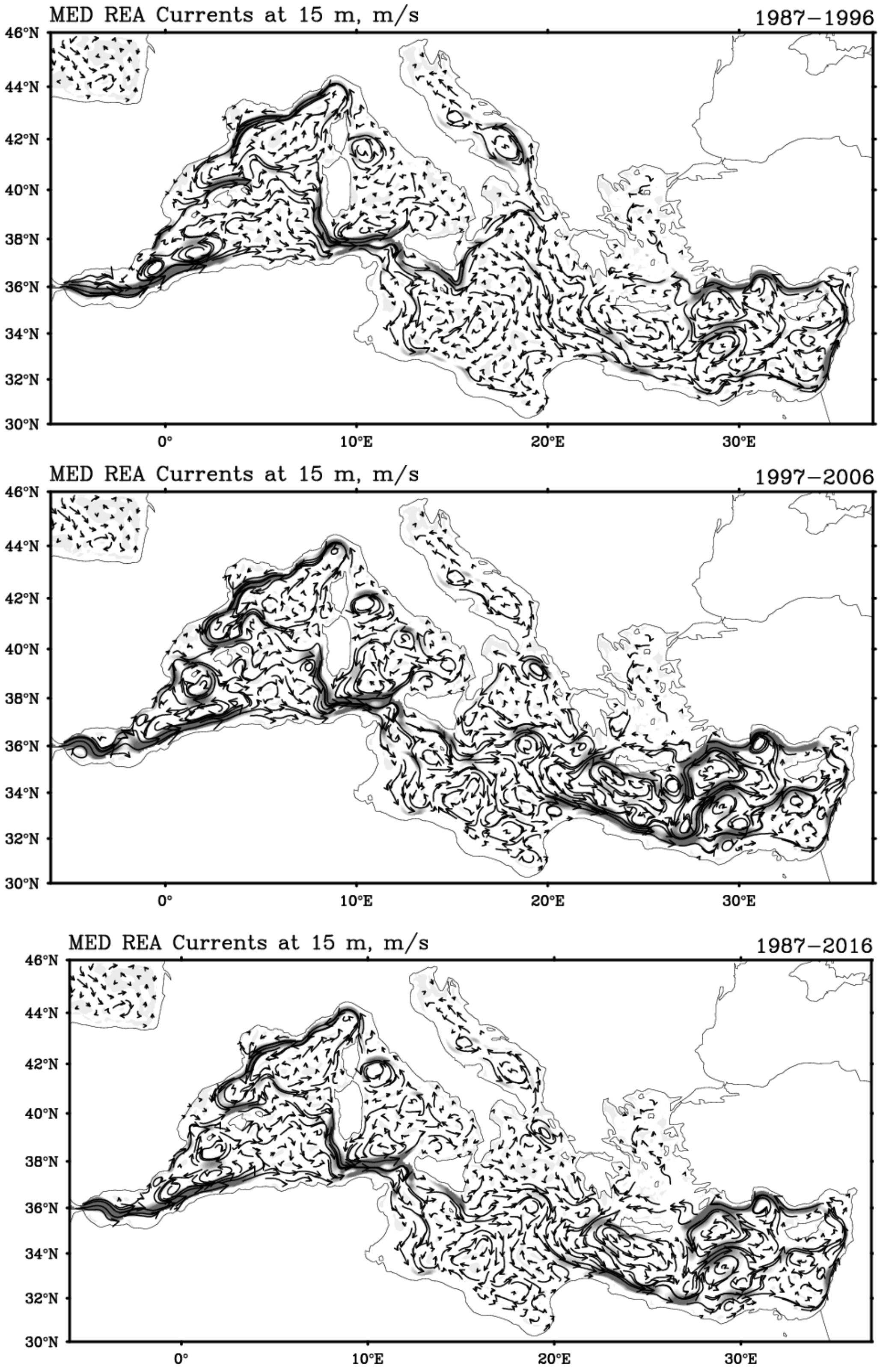


Figure 28 UV-CLASS1-15M-MEAN for different periods.

IV.6 Sea Level

Table 11 summarizes the metrics and the observations used in the assessment of Sea Level.

Name	Reference dataset	Quantity
SL-CLASS4-RMS	SELEVEL_MED_SLA_L3_REP_OBSERVATIONS_008_020	SL RMSD averaged over the whole domain.
SL-CLASS3-2DMEAN	SEALEVEL_MED_SLA_MAP_L4_REP_OBSERVATIONS_008_029	Domain averaged sea level monthly mean time series.

Table 11 Metrics and observations used to assess the Sea Level.

Figure 29 (**SL-CLASS4-RMS**) presents SLA RMS computed along track over the reanalysis period on a daily (top) and monthly (bottom) basis. The RMSD oscillates between 2 and 7 cm on daily basins and between 2.5 and 4.5 cm on monthly basis. When the number of observations increases, RMSD decreases, as it is evident between 2002 and 2006, while when the number of assimilated observations decreases the RMSD increases as it is evident starting from mid 2013.

The total EANs, BIAS and RMS for sea level are included in Table 12.

Figure 30 (**SL-CLASS3-2DMEAN**) presents basin averaged SL monthly mean time series computed respectively from MED REA (blue line) and reference altimetry gridded dataset (green line). The full signal (upper panel) is wider in MED REA than in the altimetry data due to a SL MED REA over-estimation, while, when the monthly climatological signals are removed (bottom panel) from their relative datasets, the signals become comparable, especially in the period 1995-2012.

Parameter	BIAS	RMSD
SLA [cm]	0.08 ± 0.13	3.55 ± 0.59

Table 12 EANs for SLA.

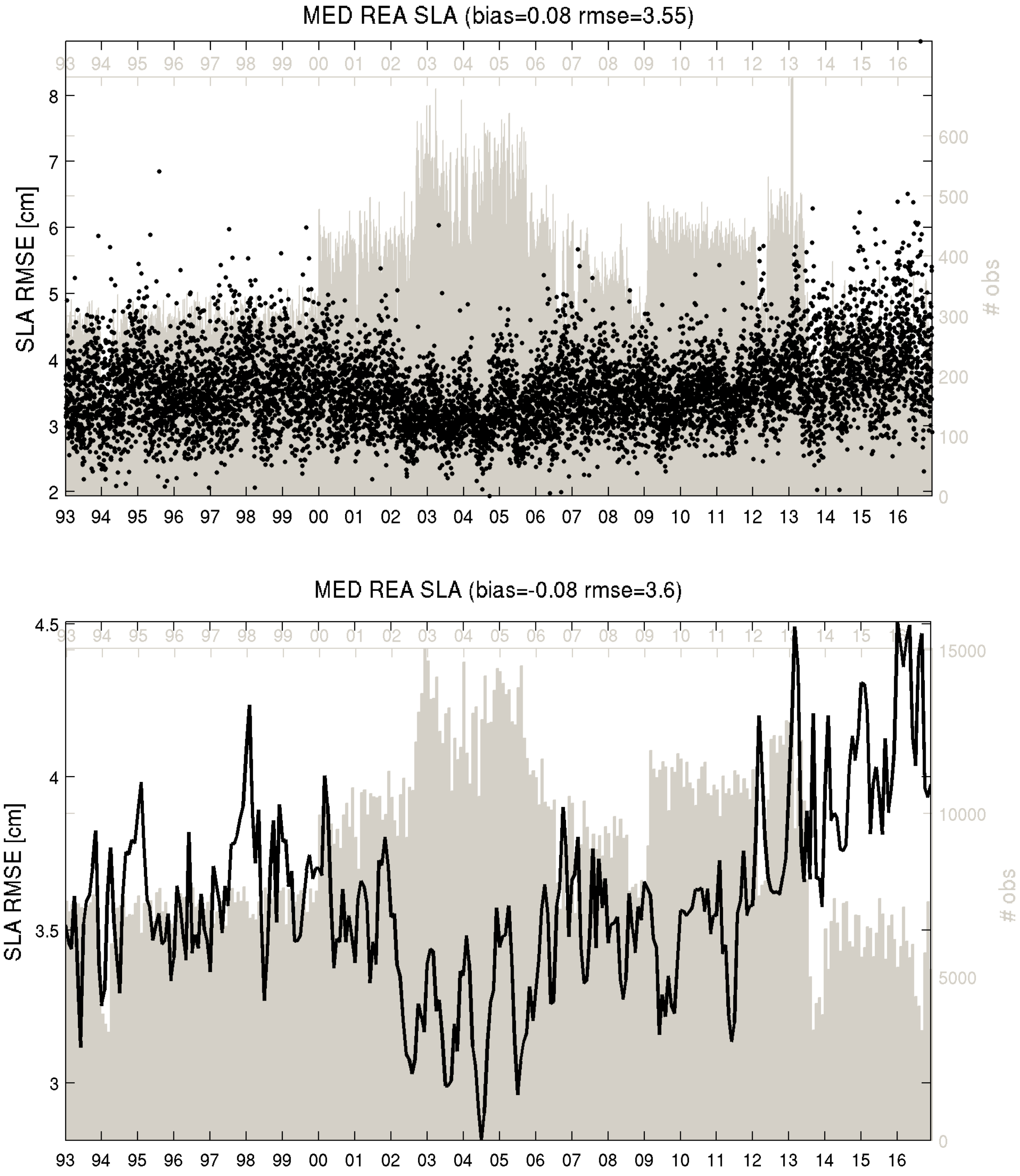


Figure 29 SL-CLASS4-MEAN: SLA RMS computed along track over the reanalysis period on daily (top) and monthly (bottom) basis.

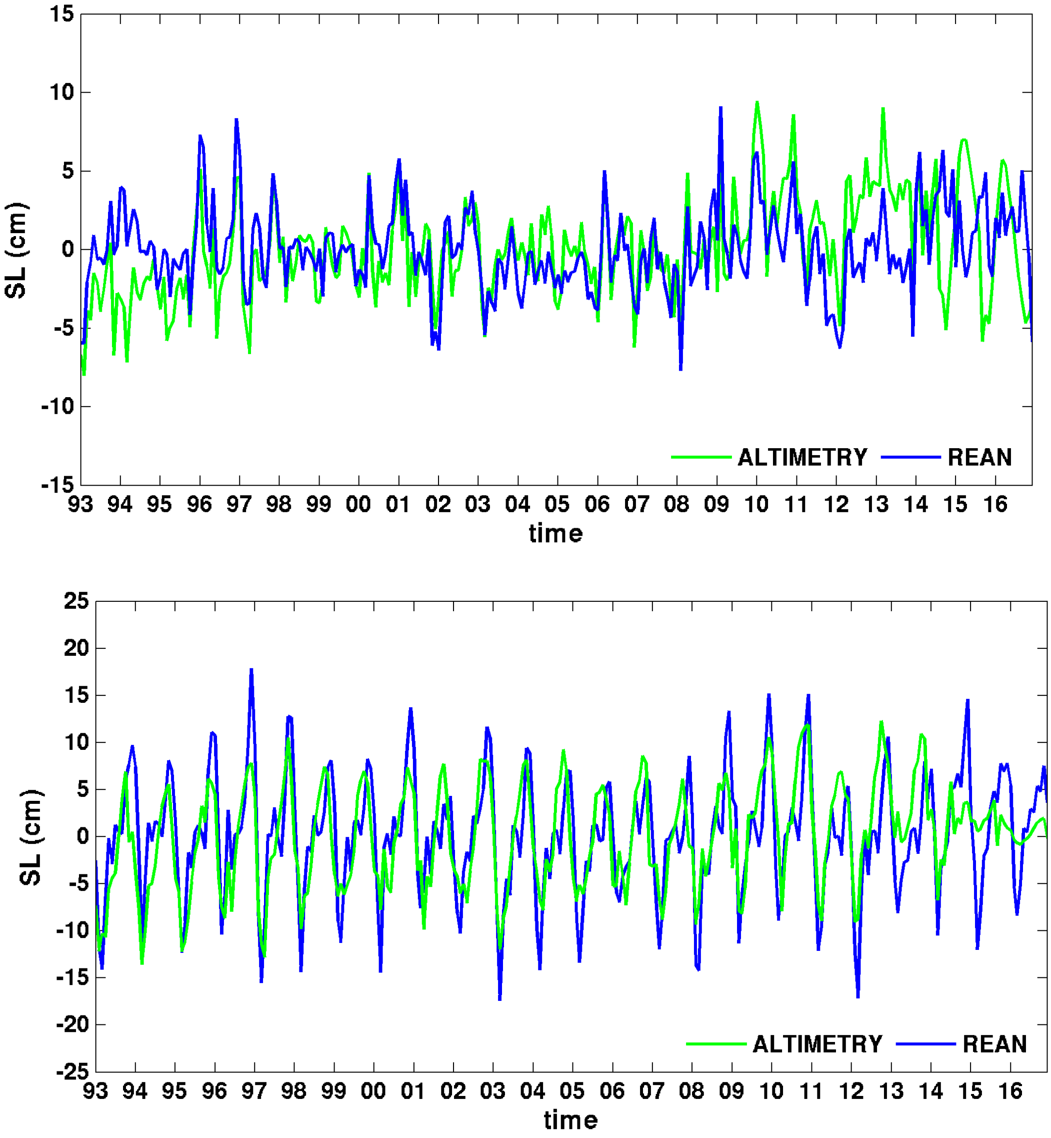


Figure 30 SL-CLASS3-2DMEAN Domain averaged sea level monthly mean time series computed from MED REA (blue line) and altimetry gridded product (green line): full signal (upper panel) and monthly climatological signal removed (bottom panel).

IV.7 Transport

Monthly time series of net volume transport through the Gibraltar Straight is displayed in **Figure 31** top (**UV-CLASS3-VOL_TRANSP**), while **Figure 31** bottom shows its westward and the eastward components. The inflow eastward transport is slightly higher than the westward outflow component determining a long-term net value of 0.04 Sv with a standard deviation of 0.06 Sv; the presented values are coherent yywith the literature (*Soto-Navarro et al., 2010*).

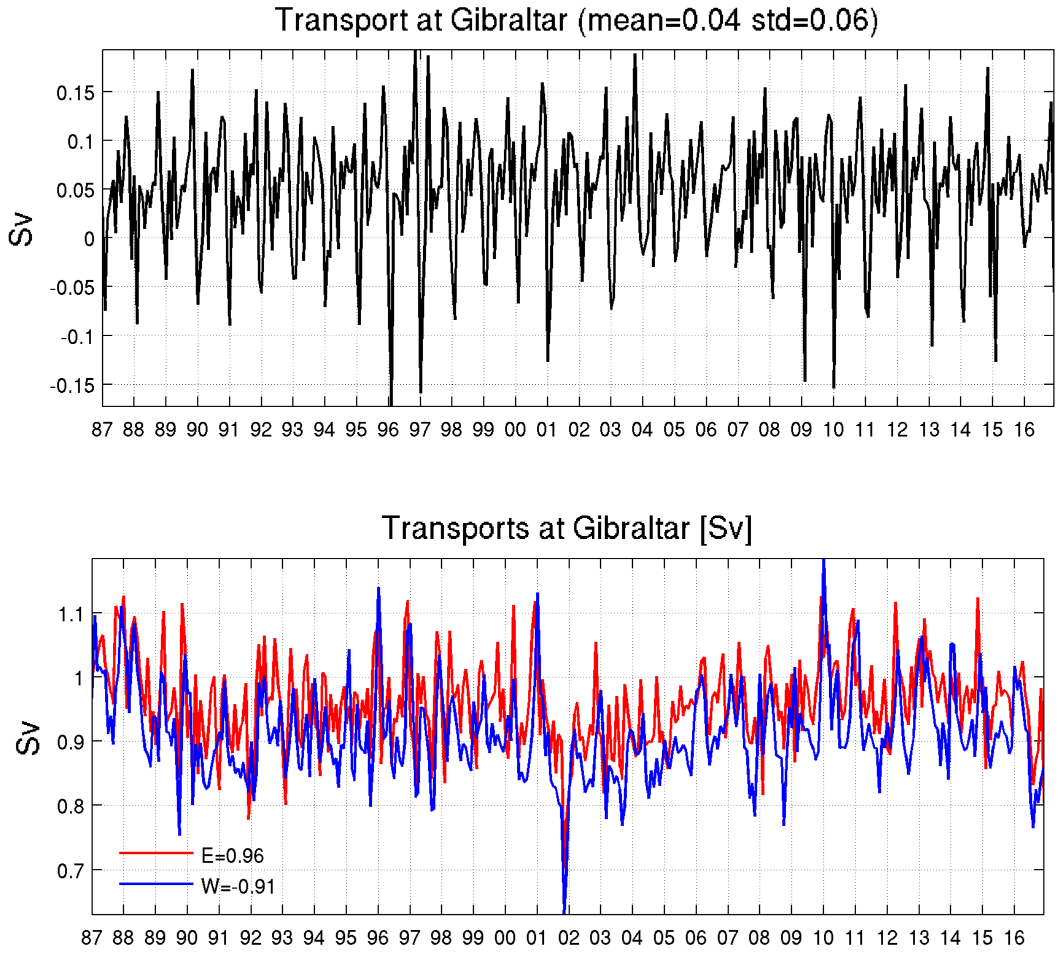


Figure 31 UV-CLASS3-VOL_TRANSP: Gibraltar Net transport (top) East and West ward transport (bottom)

V SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

Date	Change/Event description	System version	other
13/04/2016	Numerical ocean model was changed from Nemo version 3.2 to Nemo version 3.4	MFSe1r1	
10/09/2018	Reanalysis modeling sytem porting on a different cluster. Minor changes between end 2017-beginning 2018.	MFSe1r2	

VI QUALITY CHANGES SINCE PREVIOUS VERSION

April 2018: Extension to year 2017 has been included to the previous reanalysis time series, that covered the time period between 1987 and 2016. A consistency check was performed on the 2017 results in order to assure the continuity in the quality of the reanalysis product that remains substantially unchanged.

September 2019: Extension to year 2018 has been included to the previous reanalysis time series, that covered the time period between 1987 and 2017. A consistency check was performed on the 2018 results in order to assure the continuity in the quality of the reanalysis product that remains substantially unchanged.

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