Project of Strategic Interest NEXTDATA

Deliverable D1.3.5
Report on RR quality indexes and data transmission to archive and General Web Portal

WP Coordinator: Nadia Pinardi
INGV, Bologna

Authors
S. Simoncelli, C. Fratianni, N. Pinardi
INGV, Bologna

Contents

Abstract

The 58 years NextData Reconstruction-Reanalysis (RR) has been produced for the period 1955-2012 and validation of the output is illlustrated. Validation is mainly carried out by a 'consistency' analysis with respect to consolidated climatologies and the evaluation of root mean square and bias Quality Indices based upon the difference between model and assimilated observations. Quality Indices are similar to the previous reanalysis values of Adani et al. (2011), done with much higher resolution atmospheric forcing and a different model. A trend in volume salinity is evident which is now actively being investigated and possibly changed in the future.

Introduction

The general methodology used to validate the Mediterranean Sea RR products consists in an extension of the diagnostics developed for the past Mediterranean Sea reanalysis products (Adani et al., 2011).

The validation considers statistical Quality Indexes (QI) calculated on the basis of misfits:

$$m = [H(x) - y_0] \qquad (1)$$

where y_o is the observation, H is the linearized observational operator, and x is the model solution (background). The QI have been computed considering the observations listed in Tab. 1. Since SST is used in a flux correction term (see Deliverable 3.1.2), SST misfits are not available: in this case the QI are based upon statistics of the difference between monthly mean RR and monthly mean observational SST values.

Observations	**Producer**
SLA	MyOcean reprocessed data set SEALEVEL_MED_SLA_L3_REP_OBSERVATIONS_008_020
ARGO	Coriolis and INSITU TAC dataset INSITU_MED_NRT_OBSERVATIONS_013_035 INSITU_GLO_NRT_OBSERVATIONS_013_030
XBT	MEDATLAS, MFS (Enea), INSITU-TAC dataset
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	Hadley Center monthly mean values

Tab. 1. Observational data sets used to evaluate Quality Indices for the Mediterranean RR.

The background is semi-independent from observations used in (1) since data are continuously assimilated in a daily cycle (see previous Deliverables) but they are scarce enough in space and time that the background can be considered independent from the previous observation assimilated.

Mean profiles of BIAS and RMS of misfits have been computed over the entire domain and the entire time period and for the first 1000 m of the water column since assimilation was carried out only up to that level (see Deliverable D3.1.2).

RR validation methodology uses also climatological reference data sets in order to assess the RR "consistency" (Murphy, 1993). In particular we considered:

- Climatological estimates for heat flux and water flux from PETTENUZZO et AL. (2010);
- MEDATLAS temperature and salinity climatologies from RIXEN et AL. (2005).
  SeaDataNet temperature and salinity climatologies produced from observations with Optimal Interpolation by the INGV group in Bologna.

Validation Results

Sea Surface Temperature

Fig. 1 shows SST RMS and BIAS QI computed from the difference between monthly mean RR and the Hadley SST for the time period 1955-2012. SST RMS and BIAS QI present a seasonal signal with largest values during spring-early summer. RMS QI oscillates around its multi-year average of 0.54°C with minima between ~0.2°C and maxima between ~1 °C. During the summertime the BIAS QI is always positive and ranges usually between 0.5-0.8°C (warm bias) while the wintertime cold bias is generally less than 0.5°C. BIAS QI oscillates around its multi-year value of 0.23°C.

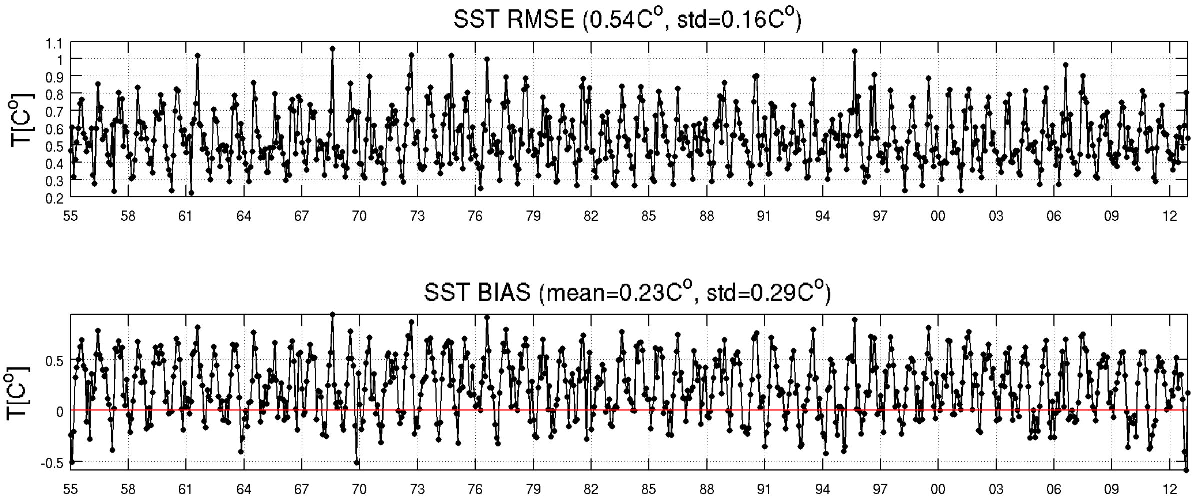


Fig. 1 SST RMSE (top) and BIAS (bottom) computed from monthly mean RR SST and the Hadley Center monthly mean.

SST QI averaged over the whole period are listed in Tab. 2.

Parameter	BIAS	RMS
SST [°C]	0.23±0.29	0.54±0.16

Tab. 2. SST Quality Indices averaged over the entire Mediterranean Sea and the RR time period (1955-2012).

Fig. 2 shows SST RMS and BIAS QI maps computed over the RR time period 1955-2012. SST BIAS and RMS QI show systematic model errors in the upwelling regions and in the southeastern Mediterranean regions where atmospheric forcing uncertainties could produce positive bias, as shown in PETTENUZZO et AL. (2010). An open ocean, large positive BIAS and RMS QI value is found in the south-western Ionian Sea which deserves more investigations. Negative BIAS and large positive RMS QI values appear in all the upwelling areas of the Mediterranean Sea (Eastern Adriatic Sea, southern Sicily, southern Cyprus and Turkeysh coasts), the Northern Adriatic Sea and in the Aegean Sea.

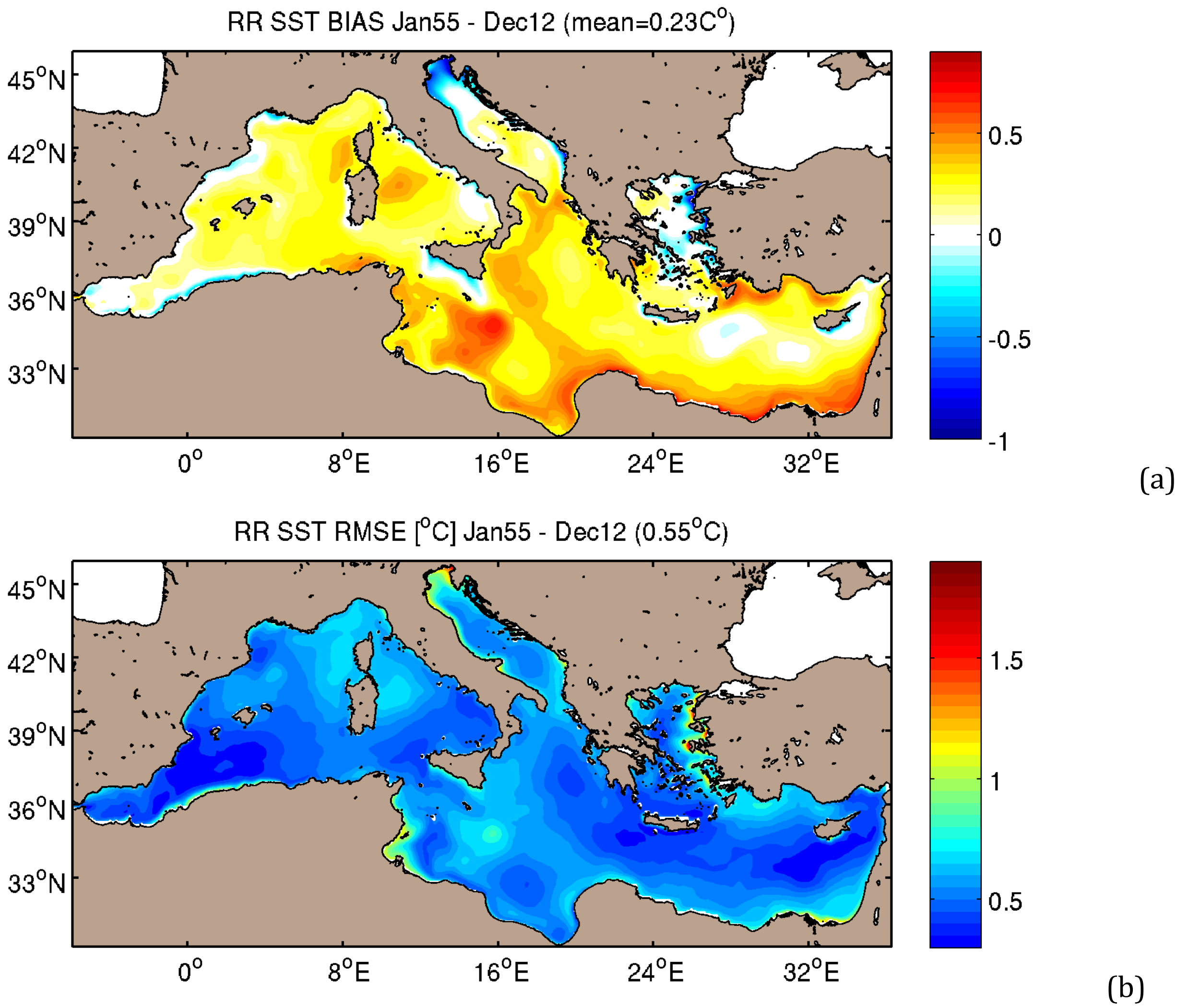
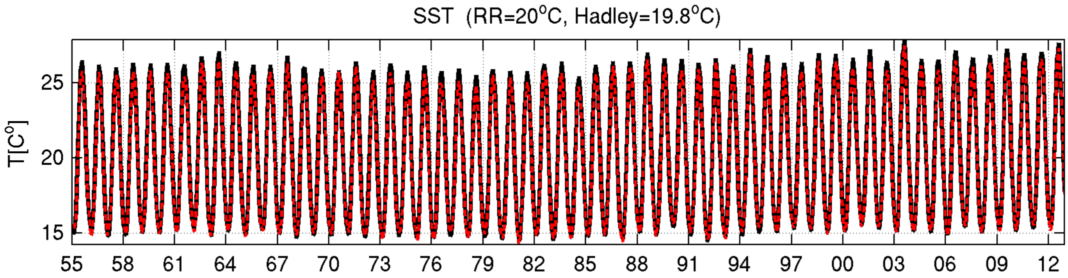


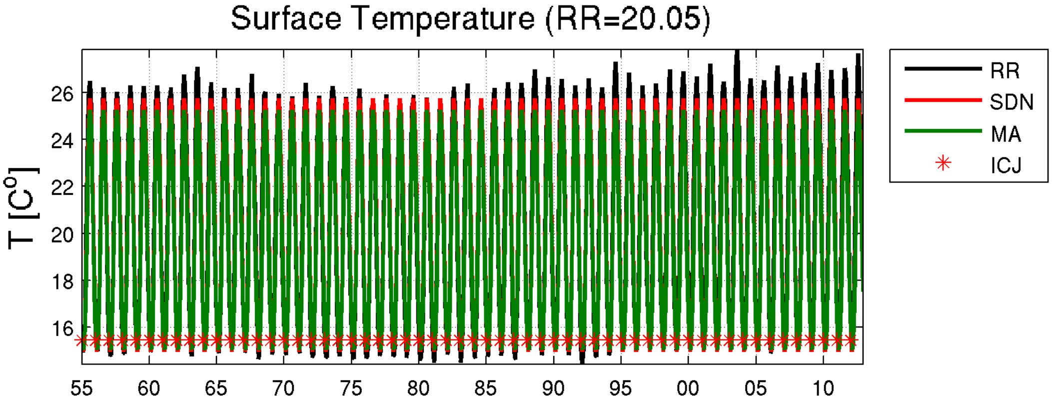
Fig. 2. SST RMSE (a) and BIAS (b) maps computed from RR and the reference Hadley SST on monthly basis over the entire RR time period 1955-2012.

Fig. 3a displays the overlay between the Hadley and RR SST. Basin temperature ranges on average between 14°C in winter and 28°C in summer for both. RR long-term average is 20.1°C while Hadley SST is 19.8°C. The highest temperatures can be noticed during summer 2003 and 2012, which coincide with literature recorded extremes.

Another consistency check is carried out in Fig. 3b comparing the SeaDataNet and Medatlas climatologies to the RR monthly mean SST. RR SST exhibits summer peaks always higher than the reference values due to the warm bias.



(a)



(b)

Fig. 3 (a) Domain averaged monthly SST from RR (black line) and from Hadley Center (red line); (b) RR domain averaged SST overlay on the SeaDataNet (SDN) and the MedAtlas (MA) monthly climatologies. The RR Initial Condition value in January (ICJ) is also illustrated.

Fig. 4 shows the comparison of monthly RR net heat flux with the monthly climatology computed from ERA40 atmospheric reanalysis corrected by PETTENUZZO et AL. (2010). The difference in the amplitude of the summer peaks, with RR larger than ERA40, offsets the multi-year average of few W/m^2 between the two data sets. In fact the RR net heat budget is equal to 0 W/m^2 slightly higher than the negative heat flux value of -4 ± 3 W/m^2 computed by PETTENUZZO et AL. (2010).

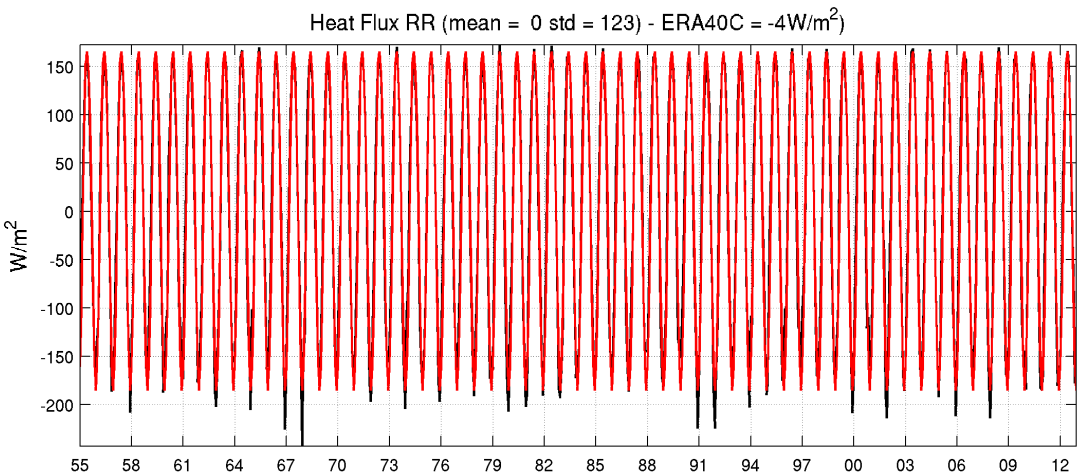


Fig. 4. Domain averaged monthly surface net heat comparison between RR (black line) and ERA40C climatology (red line) computed from PETTENUZZO et AL (2010).

Temperature vertical structure

The vertical thermal structure error is now discussed starting with few consistency checks. Fig. 5 displays RR volume averaged time series compared to our reference climatologies. Volume temperature long term average is 13.7°C and its time evolution presents higher summer maxima than climatological values in the time periods 1960-1965, 1988-1993 while from 1996 to 2012 both maxima and minima values are below the climatological values, recovering at the end of the period. The conclusion is that volume mean temperature is consistent with climatological values but shows large inter-annual and decadal variability.

Fig. 6 shows RR monthly basin averaged profile anomalies with respect to SDN and MedAtlas climatologies for the first 1000 m of water column. Within the surface layer the differences alternate between negative and positive anomalies that are due to the large interannual variability of the summer thermocline. Starting from the late nineties positive anomalies extends from the surface up to 200 m of water column almost all year long, while below 200 m a constant negative anomaly of about 0.5°C dominates. This large surface warming and deep cooling is to be further investigated.

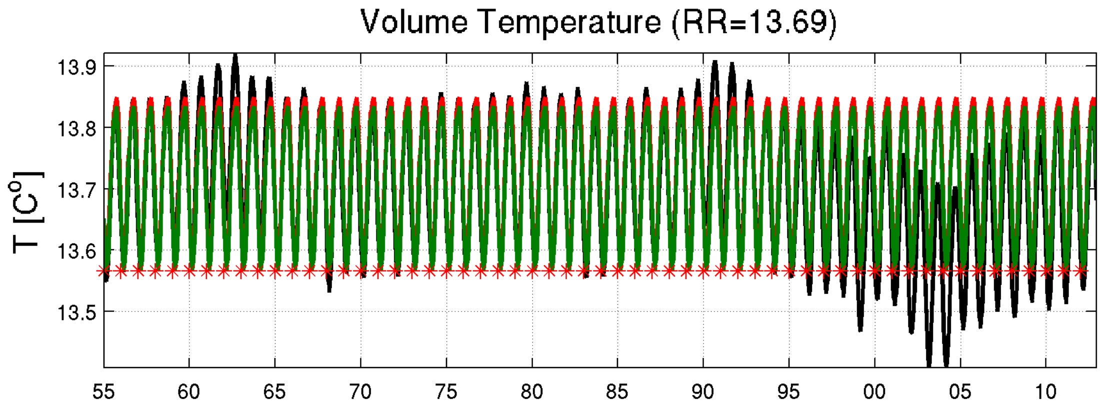
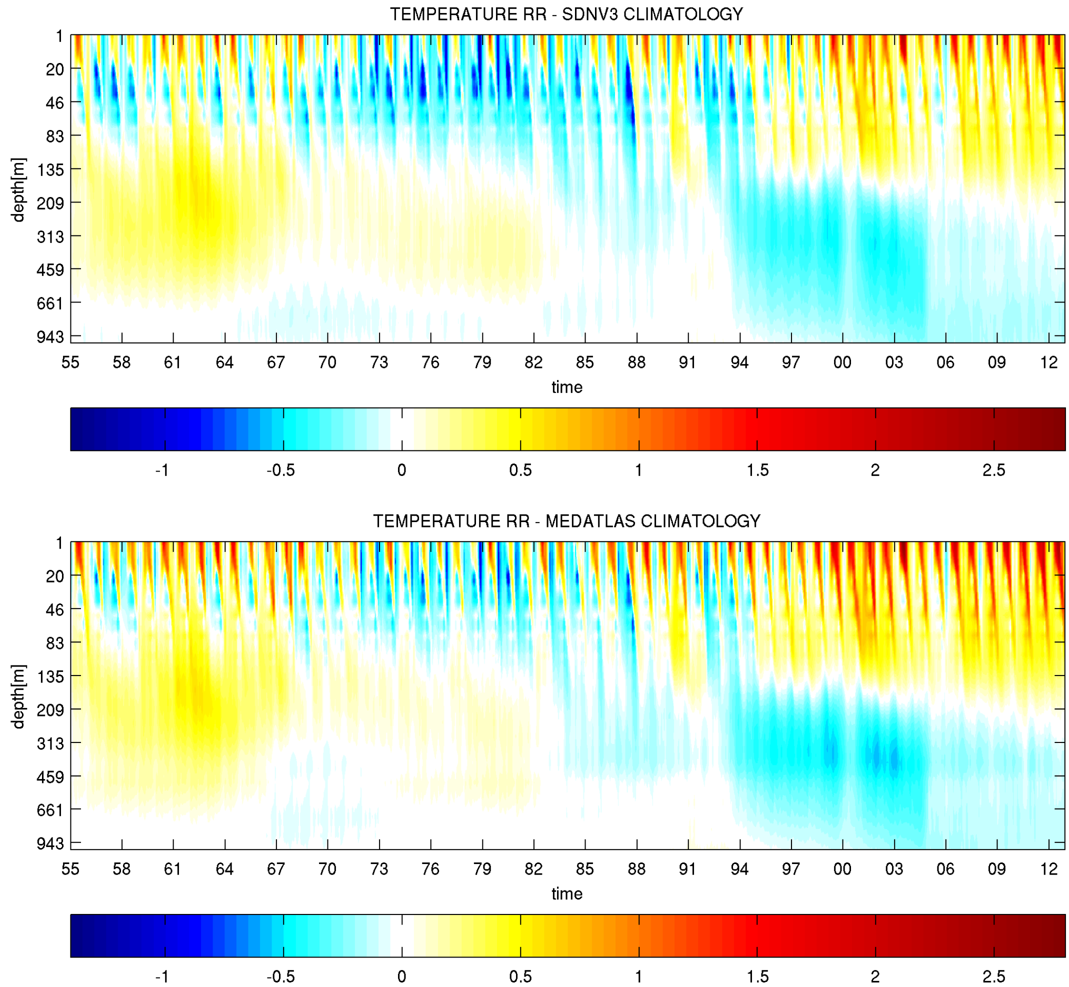


Fig. 5. RR volume average time series (black) compared to SeaDataNet (SDN; red), MEDATLAS (MA; green) climatology and the Initial Condition value in January (ICJ; red stars) used in the RR.



(a)

(b)

Fig. 6. Temperature (a) RR monthly basin averaged profile minus SDN monthly climatology; (b) RR monthly basin averaged profile minus MEDATLAS monthly climatology within the first 1000m of water column and for the 1955-2012 time period.

Fig. 7 shows temperature BIAS and RMS QI profiles averaged over the whole domain and over the entire RR time period. Temperature BIAS exhibits a maximum positive value (~0.2°C) at the surface while below 200m the BIAS is negative (<0.1°C). RMS QI instead peaks at about 30m of depth (>0.9°C) where the upper seasonal thermocline limit is located. Together with the surface warm SST bias, the 1 degree error in the upper seasonal thermocline is the largest and most important error in the temperature RR, as found in the previous reanalyses (Adani et al., 2011). With respect to previous RMS QI values, RR maximum values have increased by 0.2°C probably due to the different accuracy of the atmospheric forcing.

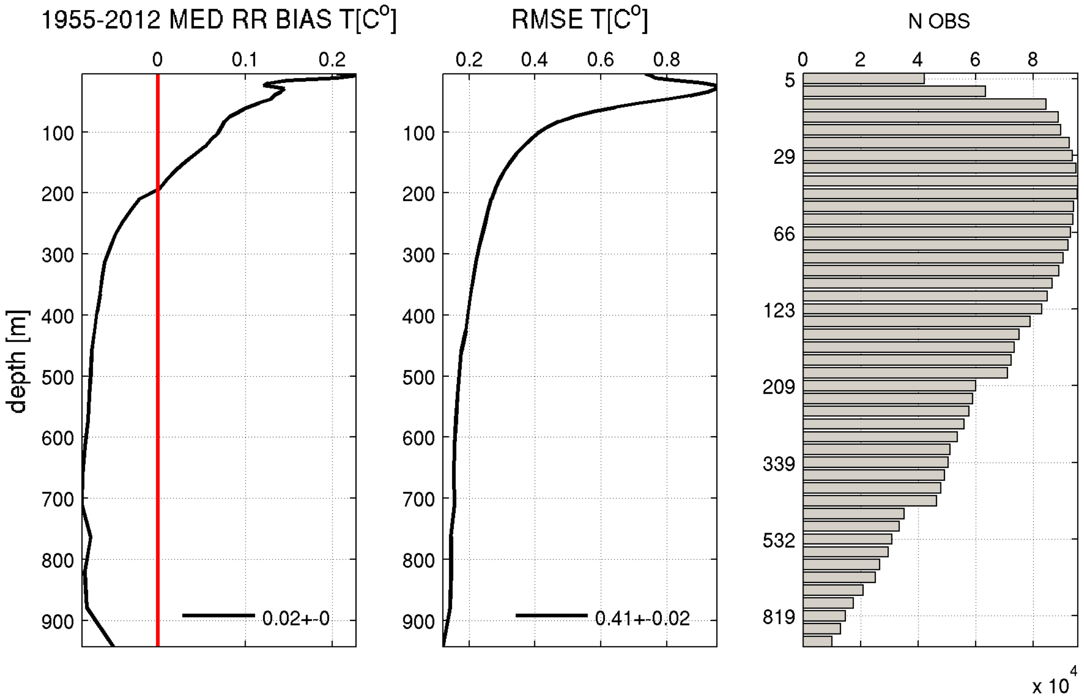


Fig. 7. Temperature BIAS (left) and RMSE (middle) profiles averaged over the whole domain over the entire RR time period. The number of temperature observations per each RR vertical level used to compute the misfit statistics is displayed on the right.

The volume mean QI (up to 1000 m) are listed in Tab. 3.

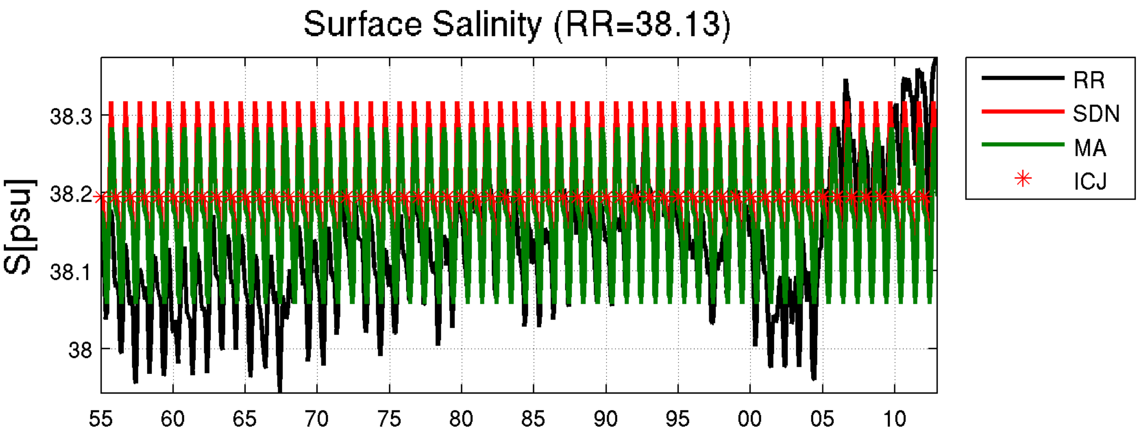
TEMPERATURE [°C]	BIAS	RMSE
Volume mean	-0.02±0.05	0.41±0.02

Tab. 3 Temperature QI computed computed over the whole domain (up to 1000m of depth) over the entire RR time period (1955-2012).

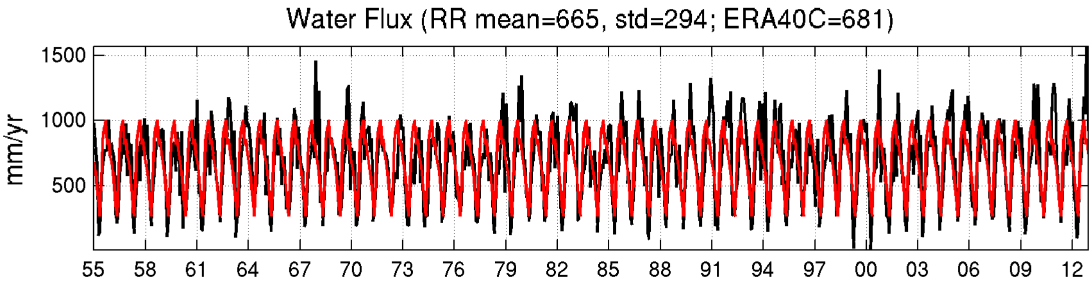
Salinity vertical structure

The error vertical structure for salinity is examined in this section again starting with the consistency analysis.

Fig. 8a presents RR Sea Surface Salinity (SSS) evolution with respect to reference climatological values (SDN, MedAtlas). SSS has a long-term average of 38.13 PSU and oscillates below the climatological values up to 2005 where it increases above climatological values. Fig. 8b displays net Mediterranean Sea water flux temporal evolution (evaporation minus precipitations) compared to ERA40 monthly climatology from PETTENUZZO et AL. (2010). RR long term budget is 665 mm/yr while for ERA40 the budget is 681mm/yr. The reason for the increase of surface salinity is not then due to water budget changes and this issue is being investigated at the moment.



(a)



(b)

Fig. 8 a) Domain averaged monthly SSS compared to SDN, MA climatologies and to the RR initial condition (ICJ); b) surface net fresh water flux (black line) as a function of time compared to the ERA40C climatology computed from PETTENUZZO et AL (2010).

Fig. 9 presents the RR volume average salinity time evolution which shows a large positive trend of about 0.18 PSU in the 58 years of integration. This trend is difficult to interpret: volume mean salinity conservation is not ensured because of the lateral open boundary condition in the Atlantic Ocean, but other problems are being investigated such as the specific linear free surface used in the model (Roullet and Madec, 2000). This trend was also present in the previous reanalyses and now it has decreased from 0.07 PSU/decade (Adani et al., 2011) to 0.03 PSU/decade which is however still relevant.

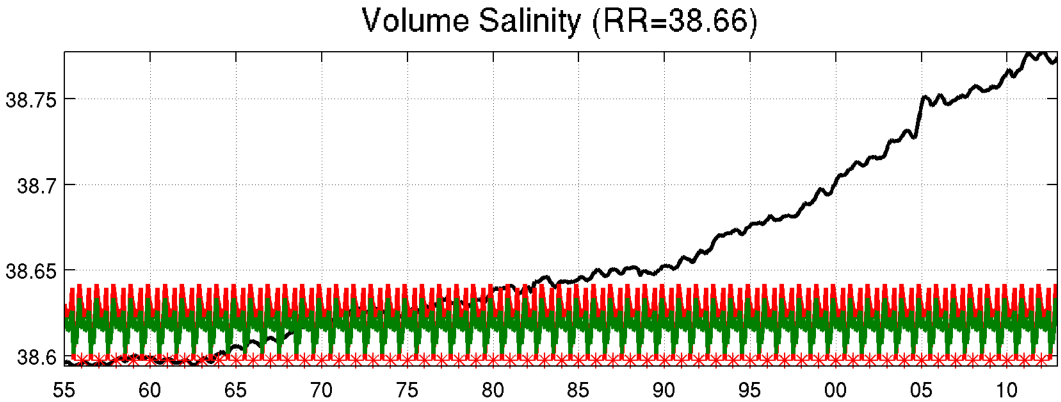


Fig. 9. RR volume salinity time series compared to SDN (red curve), MA (green curve) climatologies and Initial Condition value for January (ICJ, red stars).

Fig. 10 shows the Hovmoller plots of the anomalies between monthly RR basin-averaged salinity profile and SDN (a) and MedAtlas climatologies (b) over the reanalysis time period.

RR is fresher than the climatologies within the first 200 m from 1955 to 2005 (~-0.2 PSU) while it is saltier below (~0.05 PSU). Positive anomalies appear sistematically in the whole water column after 1988 and 2005 giving rise to the positive trend of Fig.9.

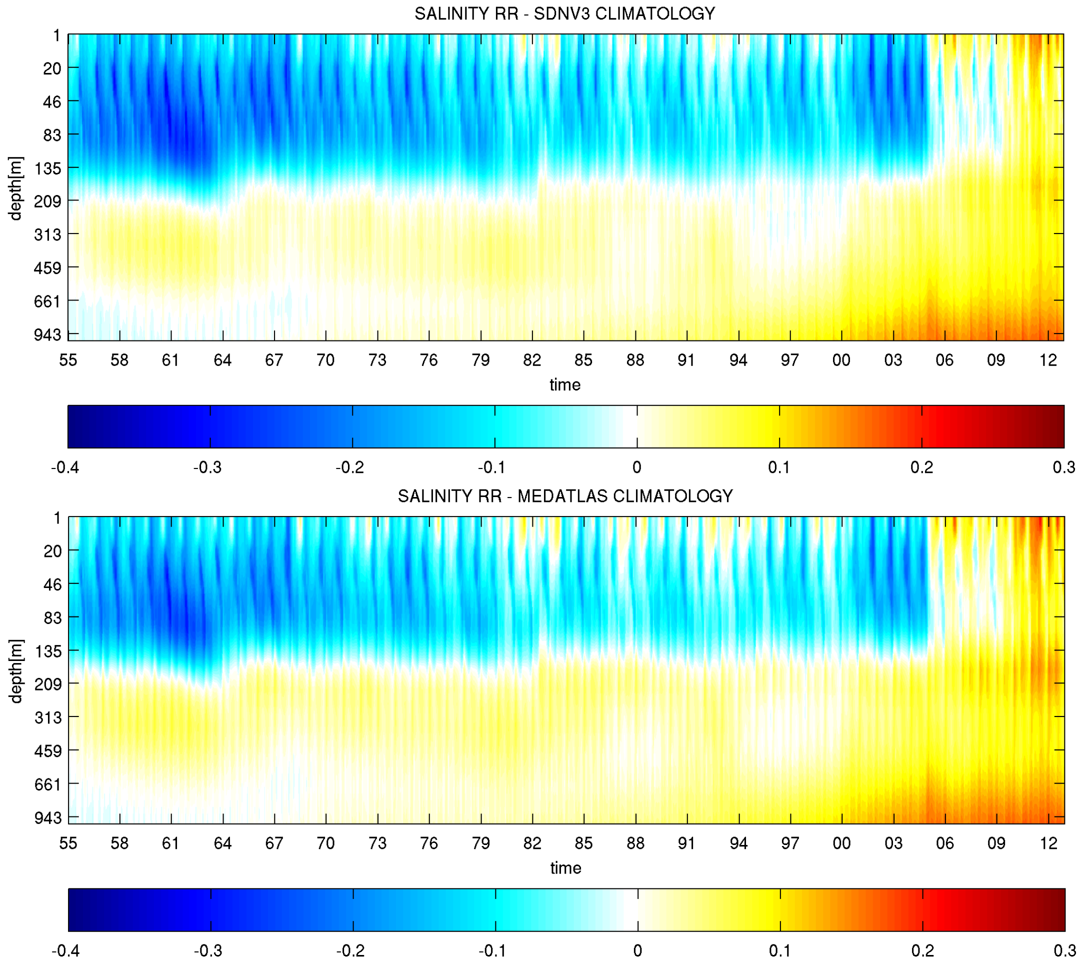


Fig. 10. Salinity difference between: (top panel) RR monthly basin averaged profile and monthly SDN climatology (bottom panel) RR monthly basin averaged profile and MA monthly climatology within the first 1000m of water column.

Fig. 11 displays salinity BIAS (left) and RMSE (middle) QI profiles averaged over the whole domain over the entire RR time period. Salinity bias is negative in the first 200 m of water column and positive below. The maximum RMSE value is at the surface (>0.3psu) and decreases below 0.1 psu below 200 m of depth.

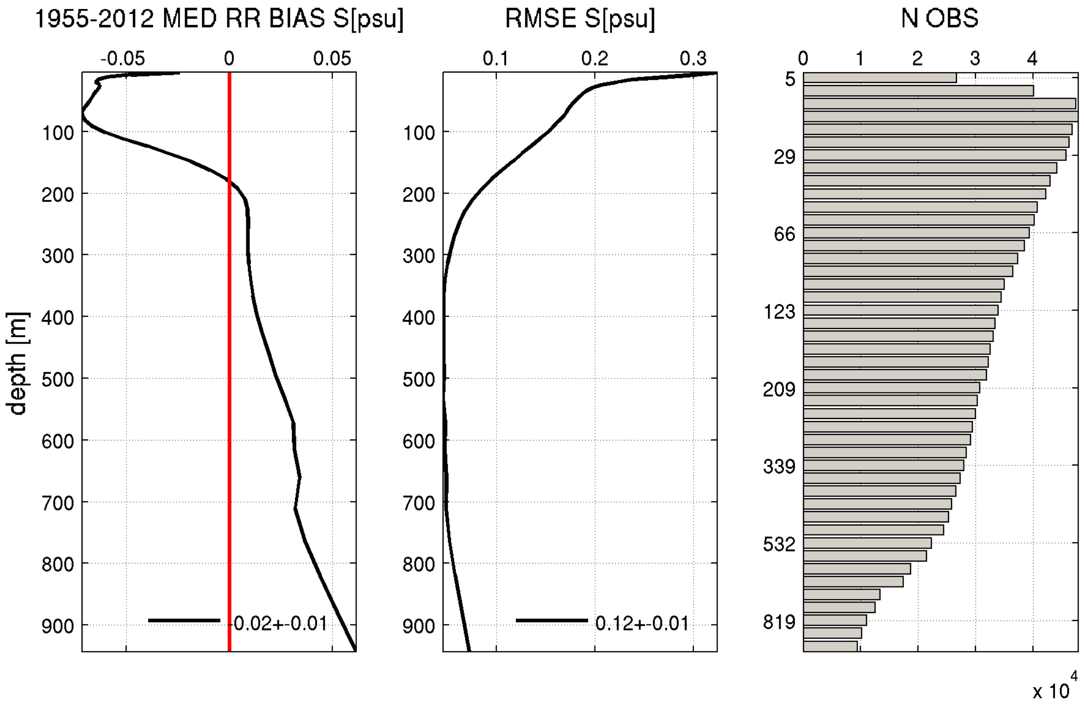


Fig. 11 Salinity BIAS (left) and RMSE (middle) profiles averaged over the whole domain over the entire RR time period. The number of salinity observations per each RR vertical level used to compute the misfit statistics is displayed on the right.

Tab. 4 overviews the volume average BIAS and RMSE QI for salinity.

SALINITY [psu]	BIAS	RMSE
Volume mean	-0.02±0.01	0.12±0.01

Tab. 4 Salinity BIAS and RMSE were computed over the whole domain (up to 1000m of depth) over the entire RR time period (1955-2012).

Sea surface height

Fig. 12 presents Sea Level Anomaly (SLA) RMS QI computed along satellite tracks over the altimeter time period (1993-2012) on a monthly basis. SLA RMS QI oscillates from about 3 cm (2004) to 4.4 cm minimum and maximum values. When the number of observations increases SLA RMS QI decreases, as between 2002 and 2006. Average RMS QI is 3.7 cm while the BIAS QI is equal to 0.11 cm.

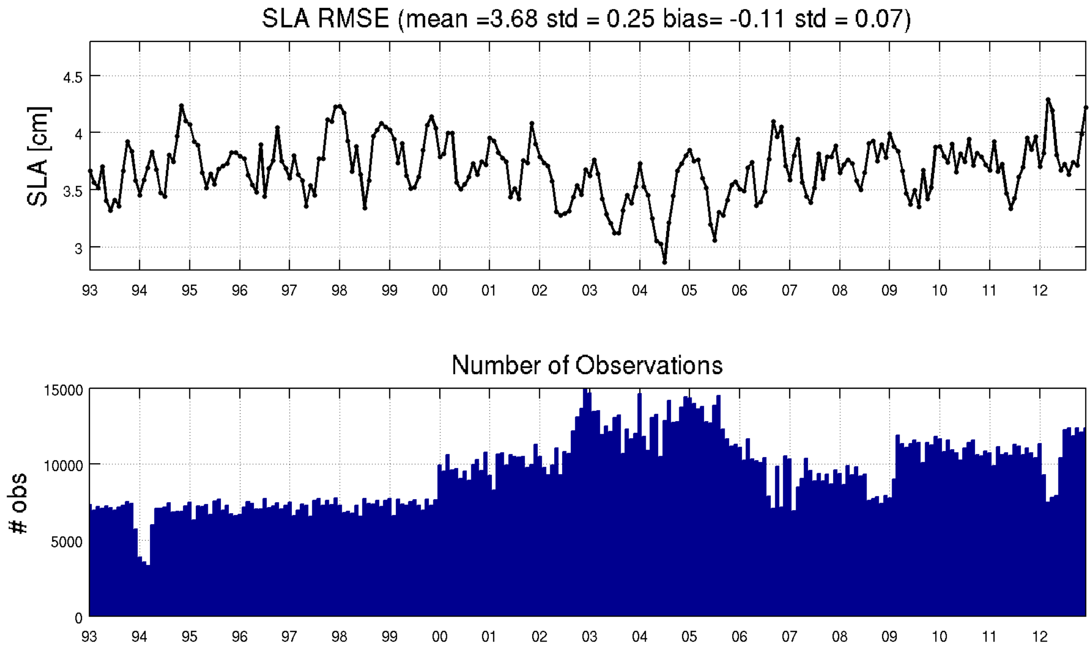


Fig. 12 Sea level RMSE averaged over the whole domain as a function of time (top) monthly RMSE (b) bars indicate the number of observations.

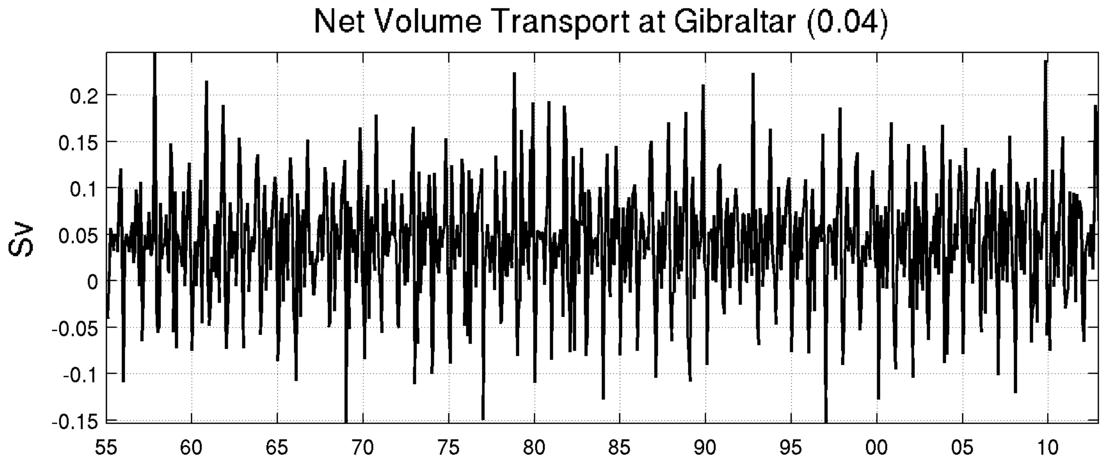
Tab. 5 summarizes RR SLA BIAS and RMSE QI computed over the time period 1993-2012.

Parameter	**BIAS**	**RMSE**
SLA [cm]	0.11±0.07	3.68±0.25

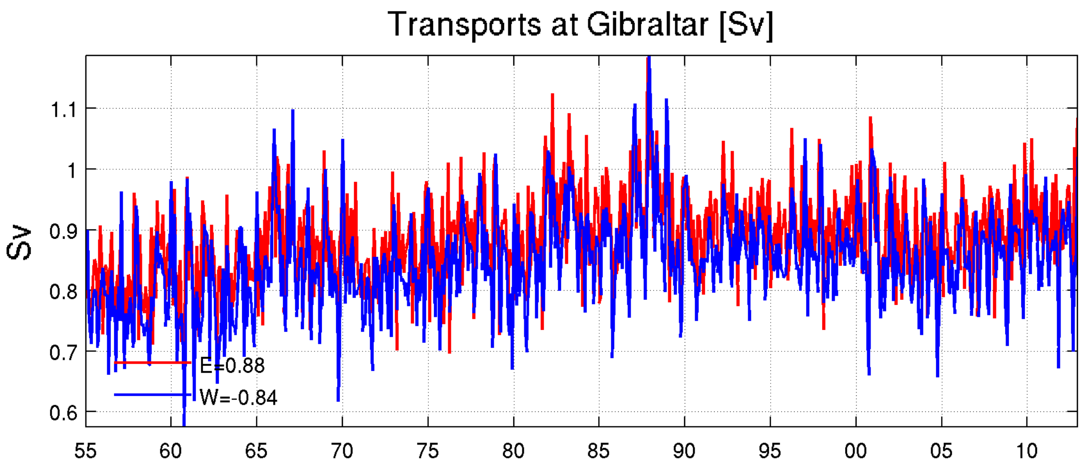
Tab. 5. RR SLA mean BIAS and RMSE computed on the Mediterranean Basin over the time period 1993-2012 on a monthly basis.

Gibraltar transport

In this section we discuss a consistency analysis of the Gibraltar transport. The monthly time series of net volume transport through the Gibraltar Straight is displayed in Figure 13a while Figure 13b shows its westward and the eastward components. The eastward inflow (0.88Sv) is slightly higher than the westward (0.84Sv) outflow component determining a long-term net value of 0.04 Sv. These values are coherent with the literature (Menemellis et al., 2007).



(a)



(b)

Figure 13 Monthly volume transport through Gibraltar Straight: (a) net transport; (b) eastward and westward transport.

Circulation structure

Fig. 14 displays maps of surface mean currents at 15 m depth computed from RR over two different time periods, following PINARDI et AL. (2015). The climatological circulation has been computed for two different time periods (a) 1987-1996; (b) 1997-2006.

The largest change between the two decades happened in the Eastern Mediterranean, where in the Northern Ionian Sea a current reversal took place related to a southern shift of the Atlantic-Ionian Stream (AIS) position. During the second decade the circulation in the Levantine Basin increases. Thus the RR is consistent with the previous analysis of the circulation from the ADANI et AL. (2011) reanalysis.

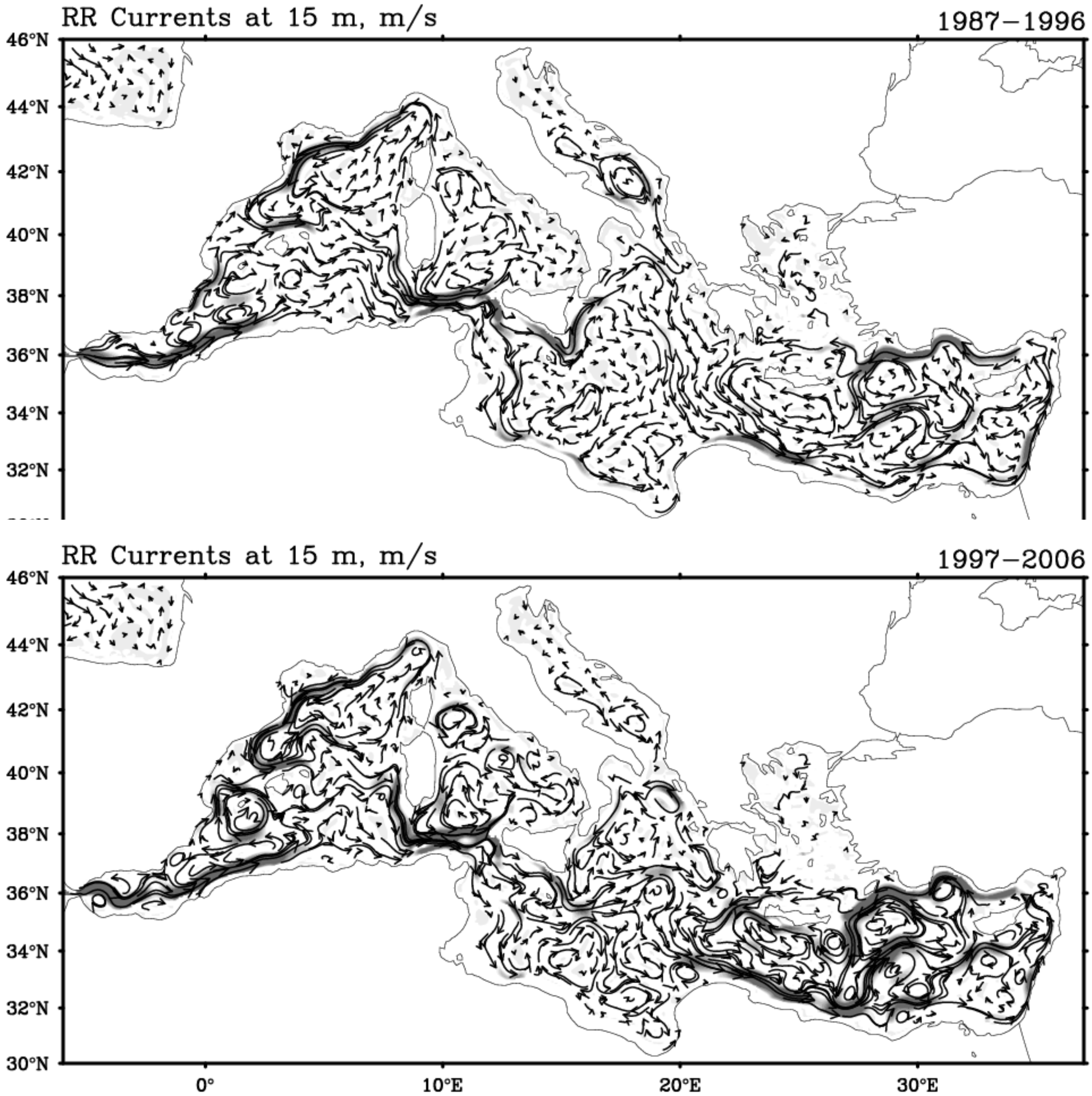


Fig. 14. Currents climatology at 15m depth computed over three different time periods: (a) 1987-1996 period; (b) 1997-2006 period. Gray areas indicate velocity amplitudes greater than 0.15 m/s.

Summary

The quality of the RR system has been assessed for the entire 1955 to 2012 period. The analysis concentrated on 'consistency' checks with different climatologies and on Quality Indices (QI) computed from misfits in terms of RMS and BIAS.

The QI values for each of the four variables assessed are listed in Tab. 6 and can be summarized as follows:

- **Sea Surface Temperature (SST):** RMS of the difference between monthly mean values of Hadley Center and RR SST is 0.54°C. The SST RMS error is characterized by a high seasonal cycle with maximum values occurring during spring and summer and RR presents a positive BIAS (RR warmer than Hadley SST).

- **Temperature:** RMS QI along the water column is on average 0.4°C with RMS maximum values around 0.9°C at approximately 30 m, the base of the mixed layer and the start of the seasonal thermocline.
- **Salinity:** RMS QI along the water column are on average 0.12 PSU with maximum RMS QI at the surface of about 0.3 PSU. BIAS QI is on average negative in the first 200 m of water column and positive below. The volume mean salinity shows a drift of about 0.03 PSU/decade toward higher salinity values, an effect that is under investigation at the moment.
- **Sea Level Anomaly (SLA):** misfit RMS is 3.68 cm, almost double of the estimates of satellite along-track altimetry errors.

Variable	**BIAS**	**RMS**
SST [°C]	0.23±0.29	0.54±0.16
Volume T [°C]	-0.02±0.05	0.41±0.02
Volume S [PSU]	-0.02±0.01	0.12±0.01
SLA [cm]	0.11±0.07	3.68±0.25

Tab. 6. Summary of RR QI in terms of BIAS and RMS for different variables averaged over the entire basin and RR time period.

Bibliography

ADANI M., DOBRICIC S. PINARDI N., (2011): Quality Assessment of a 1985–2007 Mediterranean Sea Reanalysis. *J. Atmos. Oceanic Technol.*, 28, 569–589. doi: http://dx.doi.org/10.1175/2010JTECHO798.1

MURPHY A.H., (1993): What is a good forecast? An essay on the nature of goodness in weather forecasting, Weather Forecasting, 8, 281– 293.

PETTENUZZO D., LARGE W. G., & PINARDI N., (2010): On the corrections of ERA ‐ 40 surface flux products consistent with the Mediterranean heat and water budgets and the connection between basin surface total heat flux and NAO. *Journal of Geophysical Research: Oceans* (1978–2012), 115 (C6).

PINARDI N., et AL., (2013): Mediterranean Sea large-scale low-frequency ocean variability and water mass formation rates from 1987 to 2007: A retrospective analysis. *Prog. Oceanogr*. doi: http://dx.doi.org/10.1016/j.pocean.2013.11.003

RIXEN M., BECKERS J.M. and MAILLARD C., (2005): A hydrographic and bio-chemical climatology of the Mediterranean and the Black Sea: a technical note on the use of coastal data. *Bollettino di Geofisica Teorica ed Applicata* 46.4 319-327.

ROULLET G. and MADEC G., (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.