Project of Strategic Interest NEXTDATA

Deliverable D1.3.4
Report on the Mediterranean Sea RR and data transmission to the archive and the general portal.

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Summary

Introduction

During the second year of the NextData Project, WP1.3 activity focused on completing the feasibility study of a Mediterranean RR to cover a time period of 60 years from 1953 to 2012. This involved validating the atmospheric forcing and implementing a localization technique in the *OceanVar* (Dobricic and Pinardi, 2008) data assimilation scheme, as described in D1.3.3. RR quality assessment procedures were also developed following the general error evaluation framework of Adani et al (2011) and the circulation structure analysis illustrated in Pinardi et al. (2013).
INGV reanalysis products made available to, and produced for the NextData Portal are:

- MedReanV2 (1985-2007) Adani et al*,* 2011 produced within the framework of the CIRCE Project (http://www.circeproject.eu/);
- MedReanV4bis 1985-2012 produced for NextData (Simoncelli et al. in preparation);
- Part of the NextData RR 1953-2012, for the first twenty year period 1953-1973.

Tab. 1 summarizes the main differences between the three INGV reanalysis products (updated Table 1 of D1.3.2).
MedReanV4bis was a preparatory product to RR and it was delivered to the NextData Portal as monthly average fields. In addition, MedReanV4bis led to the development of a quality assessment procedure that could be immediately applied to the NextData RR fields.
The next section briefly describes the MedReanV4bis system and presents the main validation results, which will be soon published (Simoncelli et al., 2014, in preparation). We will then discuss the initial RR results for 1953-1972.

	MedReanV2 (1985-2007) Adani et al. 2011 Pinardi et al. 2013	**MedReanV4bis (1985-2012)**	**NextDataRR (1953-2012)**
OPERATIONAL SYSTEM	Sys3a2(OPA8.1) Tonani et al. 2008	Sys4c1 (OPA9.0) Oddo et al. 2009	Sys4c1 (OPA9.0) Oddo et al. 2009
LBC (Atlantic Box)	closed	open	open
Initial Condition	Med Atlas climatology (obs 1900-1999) Maillard et al. 2005	SDNV2aa climatology (obs until1987)	SDNV2aa climatology (obs until1987)
ATM Forcing	ERA-15 1.125° (1985-1992) ECMWF analysis 0.5° (1993-2007)	ERA-Interim 0.75°	**AMIP** 1.125°
Total Cloud Cover	NCEP–NCAR	ERA-Interim 0.75°	**AMIP** 1.125°

	(1985–92) ECMWF analyses 0.5° (1993-2007)		
Precipitations	NCEP–NCAR (monthly climatology)	ERA-Interim 0.75°	**CMAP** (monthly climatology)
SST	SST reconstruction (1985-2007) Marullo et al. 2007	SST reconstruction (1985-2007) Marullo et al.2007 My Ocean data (2008-2010)	**HadISST1**
Partial Cells	NO	YES	YES
True Stress	NO	YES	YES
Data Assimilation	OceanVar (Dobricic&Pinardi 2008)	OceanVar (Dobricic&Pinardi *2008*)	OceanVar + **LOCALIZATION**

Tab. 1 INGV reanalysis system development. Summary of the main characteristics of MedReanV2 (Adani et al., 2011, Pinardi et al., 2013*)*, MedReanV4bis and Mediterranean RR in production within the framework of the NextData project.

MedReanV4bis 1985-2012

The model component of MedReanV4bis is an updated version of Oddo et al. (2009) OPA9.0 code, implemented in the Mediterranean Sea with the same domain of Tonani et al. (2008) but with open lateral boundary conditions in the Atlantic. The data assimilation component is a variational data assimilation scheme (*OceanVar,* Dobricic and Pinardi*,* 2008) for temperature and salinity vertical profiles and satellite Sea Level Anomaly (SLA) along track data. The horizontal grid resolution is 1/16˚ (ca. 6-7 km) and there are 72 unevenly spaced vertical levels.
The OPA9.0 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 global model (Drevillon et al., 2008). The model uses an implicit free surface scheme and vertical partial cells to fit the shape of the bottom depth.
The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae (Pettenuzzo et al., 2010) specifically developed for the Mediterranean Sea, using the 6-h, 0.75° horizontal-resolution ERA-Interim reanalysis fields (Dee et al. 2011) from the European Centre for Medium-Range Weather Forecasts (ECMWF). The atmospheric variables used are: air temperature at 2 m, dew point temperature at 2 m, mean sea level pressure, total cloud cover, and 10 m wind u and v components. Satellite SST estimates, objectively gridded

by Marullo et al. (2007), are used to interactively correct the computed heat fluxes with a relaxation constant of 60 W m^{-2} K^{-1}.
Water balance is computed as evaporation minus precipitation and runoff. The evaporation is derived from the latent heat flux. Precipitations are taken from ERA-Interim reanalysis (6-h, 0.75° horizontal-resolution). 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).
The data assimilation system is the *OceanVar* scheme developed by Dobricic and Pinardi (2008). The background error covariance matrix is estimated from the standard deviation of temperature, salinity and sea surface height fields from along model simulation. Background error correlation matrices vary seasonally in 13 regions of the Mediterranean Sea, which have different physical characteristics (Dobricic et al., 2006). The mean dynamic topography, used to compute SLA from the model output, was taken from Dobricic et al. (2005).

The assimilated data include:

- SLA from 1992 to 2012;
- in situ temperature and salinity profiles;
- SST.

The SLA dataset is composed of different altimeter satellite along-track SLA (Topex / Poseidon, ERS-1 and -2, Envisat, Jason-1, Jason-2) computed with respect to a seven-year mean (1993-1999). All the missions are inter-calibrated with respect to a reference mission, which is currently Jason-2. The processing time series available from MyOcean2 Portal (www.myocean.eu) corresponds to up-to-date datasets with up to four satellites at a given time, which means a non-homogenous series but better quality sampling. The time coverage depends on the duration of the missions and starts in 1992.
The in situ temperature and salinity profiles belong to several instrumental data types: CTDs, XBTs, MBTs, bottles, and ARGO floats. In situ data sets were collected from European Marine databases and were archived in a specific format to be assimilated, as detailed in D1.3.1.
The SST dataset, which was used to interactively correct the computed heat flux at air-sea interface, is a time concatenation of SST products characterized by horizontal maps already optimally interpolated:

- SST reprocessed data (1985-July 2008) at 1/16° of the recent AVHRR Path finder SST (Marullo et al., 2008).
- SST Reconstruction DT data at 1/16° from 2008 to August 2010 (Marullo et al. 2007).
- SST_MED_SST_L4_HR: Level 4 (L4) products covering the Mediterranean correspond 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).

MedReanV4bis was initialized by a temperature and salinity monthly climatology (named SDN_V2aa) calculated using 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) occurring after that date. Mediterranean observations were merged with the World Ocean Atlas climatology (WOA05) in the Atlantic Box. The climatology was computed with DIVA software (Data-Interpolating Variational Analysis, which allows observations to be interpolated spatially onto a regular grid in an optimal way
(http://modb.oce.ulg.ac.be/mediawiki/index.php/DIVA).

MedReanV4bis was initialized on January 1st, 1985 and ended on December 31st, 2012. The first two years of integration are not provided to the NextData Portal since they are considered as model spin up fields.
MedReaV4bis has been quality controlled using all the assimilated observations and looking at volume and level integrated quantities. Below is a summary of the validation analysis on a monthly basis, which is the data frequency of MedReanV4bis data released through the NextData web portal. BIAS and RMSE (root mean square error) were computed for SST, SLA and in situ temperature and salinities using the misfit definition:

$$m = y_o - H(x)$$

Where y_o is the observation, H is the linearized observational operator, and x is the model background simulation field, prior the insertion of observations. Close observations in both space and time may create a weak dependence between the background and the observations but for the climatological data from 1985 to 1999 this is a minor problem since data are somewhat isolated, being collected during specific cruise surveys. From 1999 the SOOP and then ARGO data started to collect data more frequently and regularly, so dependence is increased.
In the following we will comment on the quality of MedReanV4bis temperature, salinity, sea level fields and describe the consistency of the circulation and Gibraltar Strait transport with respect to the known values and structures.

MedReanV4bis temperature quality

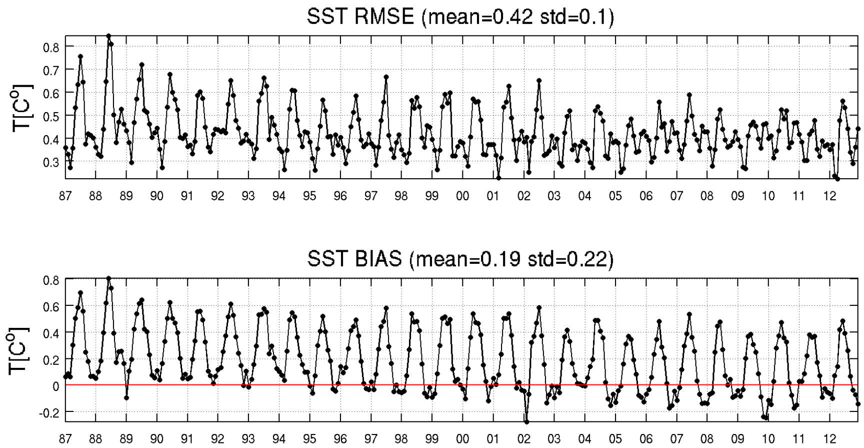


Fig. 1 shows RMSE and BIAS monthly time series for SST. Note that RMSE is characterized by a seasonal cycle with the lowest values during the winter months and the highest values during the summer months. RMSE progressively decreases over the years and multi-year average RMSE is 0.42±0.1°C. SST BIAS is always positive with about zero winter values until the late 1990s, afterwards summer BIAS maxima go down and winter minima become slightly negative. Multi-year mean BIAS value is 0.19±0.22°C.

Figure 2 shows the SST RMSE and BIAS map computed over the whole MedReanV4bis time period 1987-2012. The largest RMSE are located along the western Adriatic coast, the Turkish and Tunisian coasts. Cold BIAS is mainly present along the Turkish Aegean coast and south of Crete while the warm BIAS attains highest values in the northern Ionian Sea (Gulf of Taranto), south of Rhode Island, around Cyprus, south west Crete, and along the Libyan coast. SST skill score spatial patterns are mainly related to the accuracy of atmospheric forcing and the numerical model approximations that are critical along the coasts and in areas where the topography plays a fundamental role.

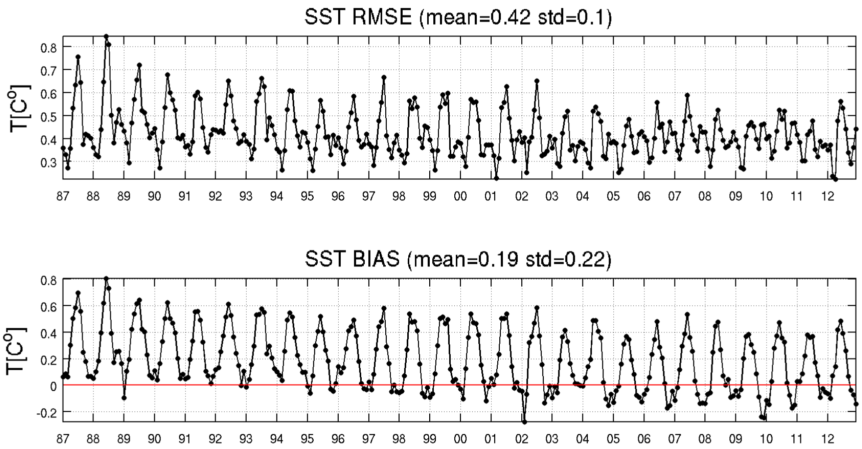


Fig. 1. SST RMSE (top) and BIAS (bottom) computed from MedReanV4bis and the satellite reference SST on a monthly basis.

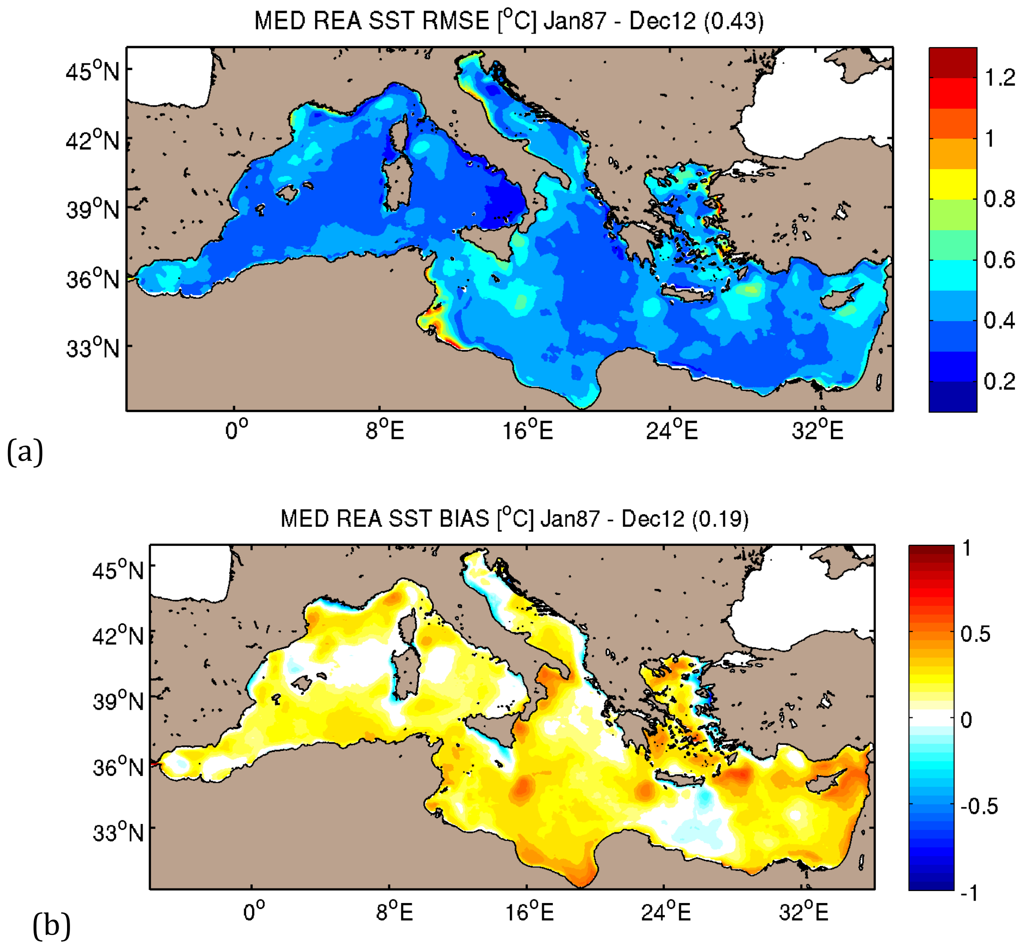
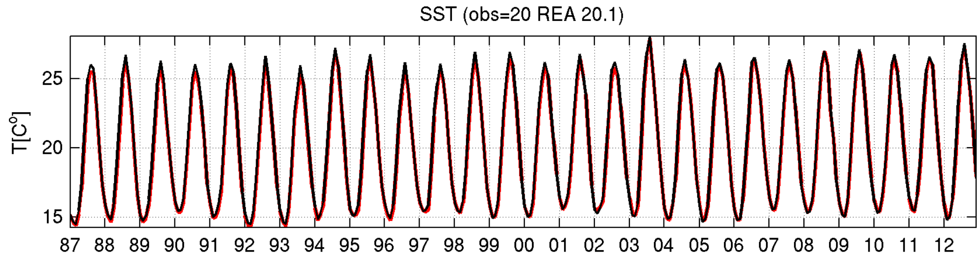
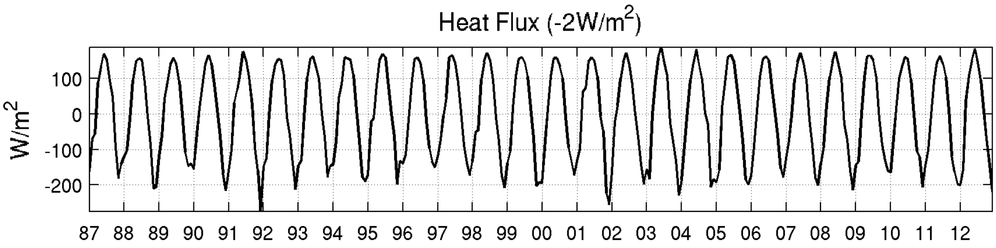


Fig. 2. SST RMSE (a) and BIAS (b) maps computed for the entire MedReanV4bis time period, 1987-2012.

Figure 3 displays the time series of the domain averaged monthly SST: the basin averaged SST ranges between 14.3-14.5°C during winter and 28-28.1°C for observations and model MedReanV4bis values. The net heat budget, emerging from the multi-year mean of the model fluxes, is equal to -2 W m^{-2} in agreement with the literature values (-6±3 W m^{-2}) for the Mediterranean Sea (Pettenuzzo et al., 2010).



(a)



(b)

Fig. 3(a) Domain averaged monthly SST from MedReanV4bis (black line) and from satellite observations (red line). (b) MedReanV4bis domain averaged surface net heat flux as a function of time.

Figure 4 shows temperature BIAS (left) and RMSE (middle) profiles averaged over the whole domain (up to 1000 m) over the entire MedReanV4bis time period. Temperature BIAS exhibits maximum positive values within the first 150 m, where the seasonal thermocline evolves, while below 150 m the BIAS is negative. RMSE peaks at about 30 m of depth (0.8°C). The water column averaged BIAS is equal to -0.02±0.05°C and RMSE is 0.35±0.02°C. The right panel shows the data distribution per each model level. Skill scores below 1000 m are not shown due to data sparseness.

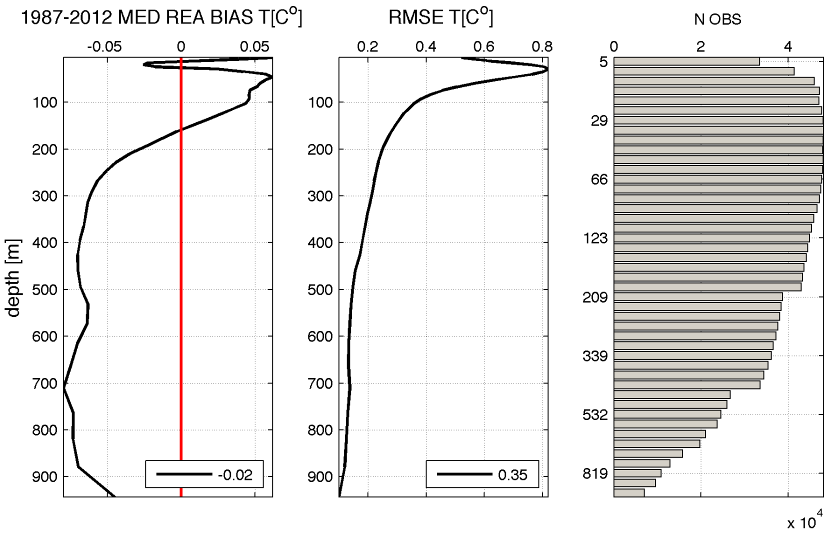
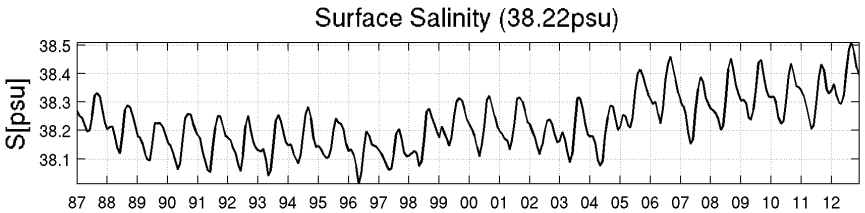


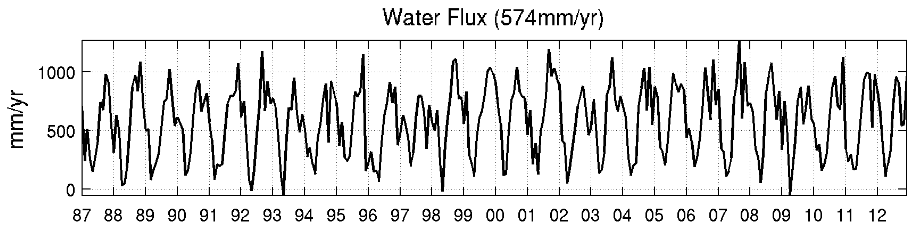
Fig. 4. Temperature BIAS (left) and RMSE (middle) profiles averaged over the whole domain and the entire MedReanV4bis time period. The number of temperature observations per each MED REA vertical level used to compute the misfit statistics is displayed on the right.

MedReanV4bis salinity quality

Domain averaged monthly Sea Surface Salinity (SSS) is shown in Figure 5a and exhibits a low seasonal cycle with amplitude of the order of 0.2 psu with minimum salinity values during spring months and maximum values at the end of the summer. The averaged salinity over the MedReanV4bis time period is 38.22 psu. Decadal and inter-annual variability is evident but time scales are longer than the available time series and they will not be commented for the MedReanV4bis time series, only the RR will resolve some of these long term signals. Figure 5b shows the net water flux that shows a multi-year average value of 574 mm yr^{-1} containing 185 mm yr^{-1} of river runoff. The resulting evaporation minus precipitation budget results to be 759 mm yr^{-1}, in good agreement with the literature (Mariotti et al., 2010; Pettenuzzo et al., 2010).



(a)



(b)

Fig. 5. a) Domain averaged monthly SSS; b) surface net fresh water flux as a function of time. Long-term mean value of the net surface fresh water flux is displayed in the title of (b).

Figure 6 displays the MedReanV4bis salinity misfit BIAS (left) and RMSE (middle) profiles averaged over the entire 1987-2012 time period. Salinity BIAS is negative in the first 200 m of the water column and positive below. The maximum RMSE value is at the surface (0.3 psu), where the atmospheric forcing and the river runoff play a fundamental role. The multi-year average BIAS is equal to -0.01±0.05 psu and the multi-year RMSE is 0.10±0.02 psu.

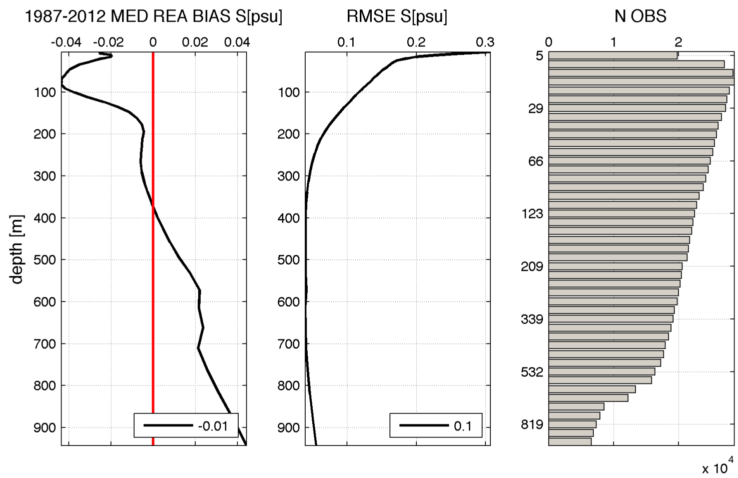


Fig. 6. Salinity misfits BIAS (left) and RMSE (middle) profiles averaged over the whole domain over MedReanV4bis time period. The number of salinity observations per each vertical level used to compute the misfit statistics is displayed on the right.

MedReanV4bis sea level quality

Figure 7 shows SLA misfit statistics computed along track over the MedReanV4bis time period on a monthly basis. SLA monthly RMSE oscillates from about 3 to 4.3 cm. When the number of observations increases the RMSE decreases, as highlighted between 2002 and 2006. The multi-year mean RMSE is 3.5 cm.

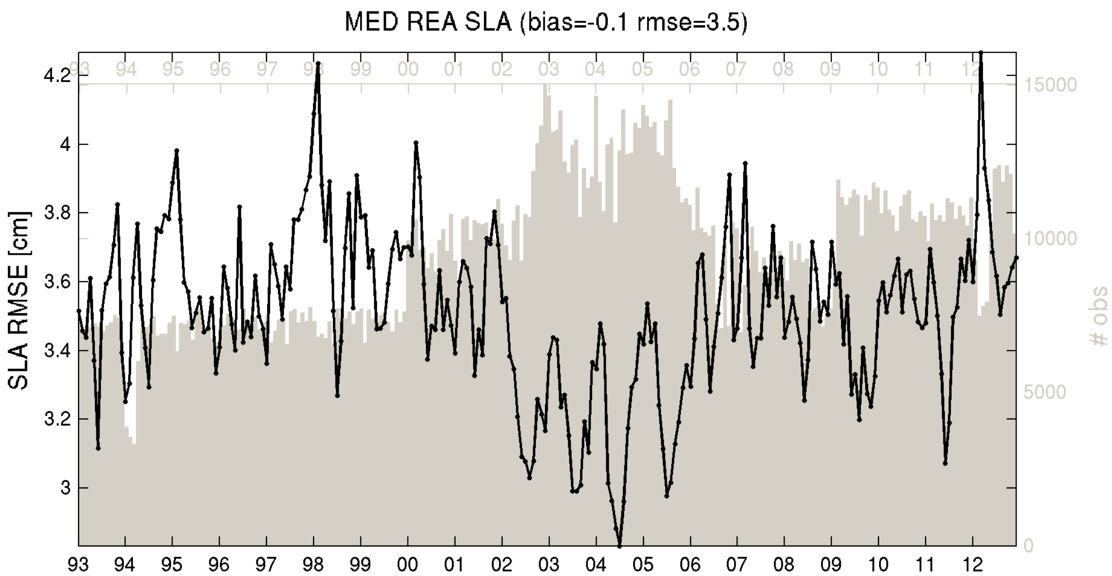
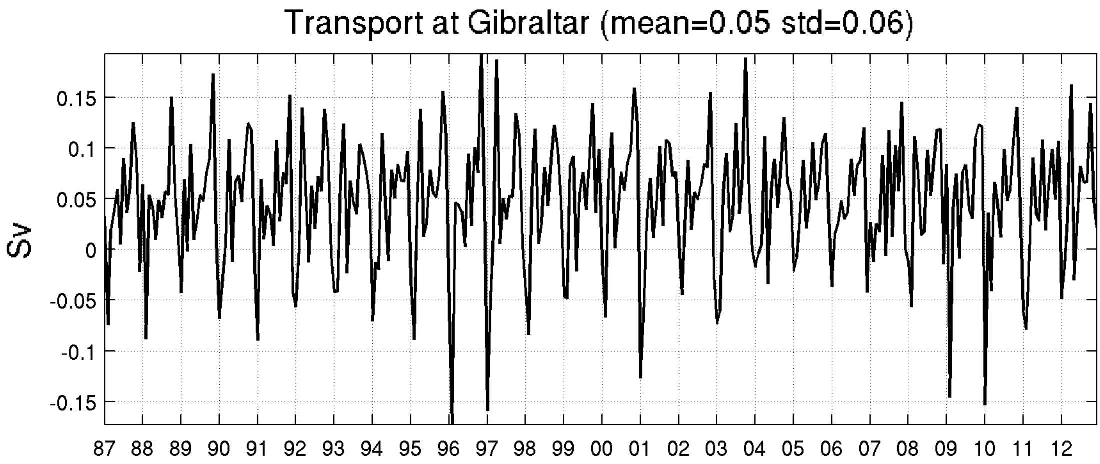


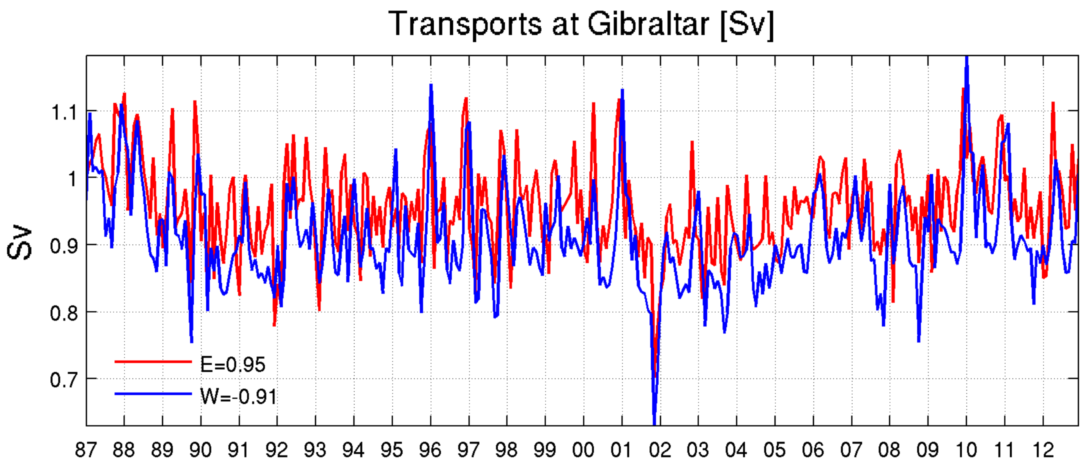
Fig. 7. SLA RMSE averaged over the whole domain as a function of time. Black lines are the monthly RMSE, while gray bars indicate the number of observations per month.

MedReanV4bis transport at Gibraltar

Figure 8a shows the monthly time series of net volume transport through the Gibraltar Strait and Figure 8b its westward and eastward components. The eastward transport is slightly higher than the westward outflow component giving rise to a long-term net volume transport of 0.05 Sv with a standard deviation of 0.06 Sv, values in agreement with the literature (Oddo et al., 2009 and Menemenlis et al., 2007).



(a)

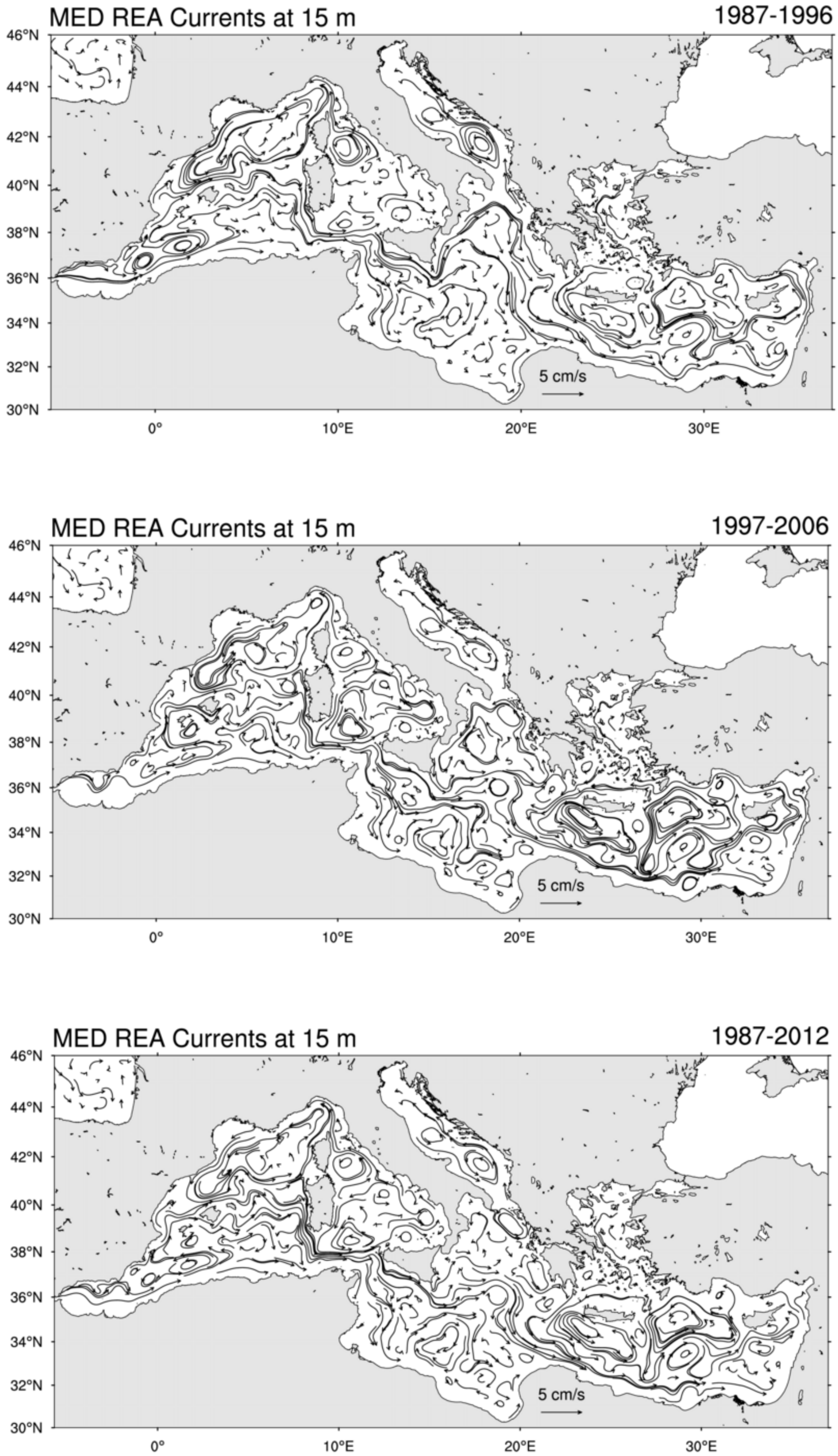


(b)

Fig. 8. MedReanV4bis monthly volume transport through the Strait of Gibraltar: (a) net transport; (b) eastward and westward transport. Long-term mean value and STD from monthly means are indicated in the pictures.

MedReanV4bis circulation structure

Figure 9 shows maps of surface mean currents at 15 m depth computed from MedReanV4bis over three different time periods, following Pinardi et al. (2013). The climatological circulation was computed over three time periods (a) 1987-1996, (b) 1997-2006 and (c) 1987-2012. The changes in periods (a) and (b) in the western Mediterranean take place in the Alboran Sea, in the Tyrrhenian Sea. The largest changes happened in the eastern Mediterranean circulation where a current reversal took place in the northern Ionian Sea related to the Northern Ionian reversal phenomenon *(*Pinardi et al., 2013*).* The mean surface circulation is in agreement with the literature and presents the well-known Mediterranean surface circulation features.



(a)

(b)

(c)

Fig. 9. MedReanV4bis current climatology at 15 m depth computed over three different time periods: (a) 1987-1996; (b) 1997-2006; (c) 1987-2012.

NextData RR 1953-1973

While the feasibility study for MedReanV4bis was underway, the *OceanVar* assimilation scheme was updated with the localization procedure to be used for the NextData RR. The RR covers the period 1953-1973 and we consider the first two years as a model spin-up. The quality control process was partly automatized in order to quickly detect possible anomalies in the RR production. Due to the sparseness of observations before the 1970s (see D1.3.1), we considered also the comparison with climatological temperature and salinity data sets:

- SeaDataNetV3 climatology computed with data from 1900 to 2009.
- MEDATLAS climatology computed with data from 1900 to 1999 *(*Maillard et al., 2005*).*

For the surface heat and water fluxes, we intercompared with the fluxes computed by Pettenuzzo et al. (2011) for the ERA-40 period, so-called ERA-40C data set thereafter.

NextData RR temperature quality

Figure 10 shows the RMSE and BIAS monthly time series. RMSE does not present a clear seasonal cycle and does not decrease over the years, unlike MedReanV4bis. RMSE oscillates around its multi-year average of 0.59°C with minima of about 0.3°C and maxima reaching 1.1°C. SST BIAS is mainly positive with some negative values reaching -0.5°C. BIAS does not have a seasonal cycle and oscillates around its multi-year value of 0.24°C.

Figure 11 shows the SST RMSE and BIAS maps computed over the RR time period 1953-1972. SST BIAS and RMSE shows the same structures of the equivalent fields for MedReanV4bis but with higher values, showing systematic model errors in the upwelling regions (Turkish coasts) and in the south eastern Mediterranean regions where atmospheric forcing uncertainties could produce warm bias, as shown in Pettenuzzo et al. (2010).

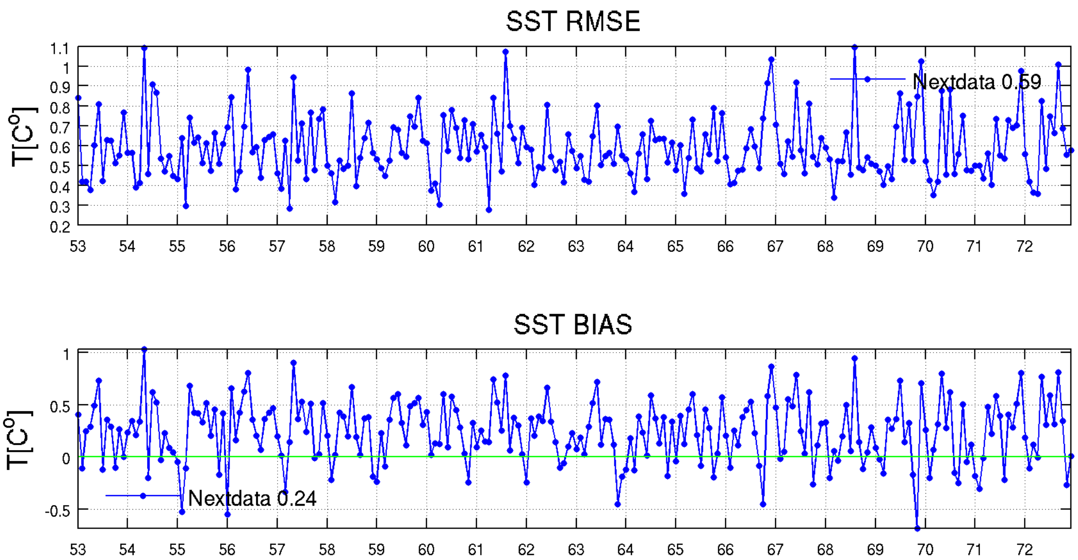
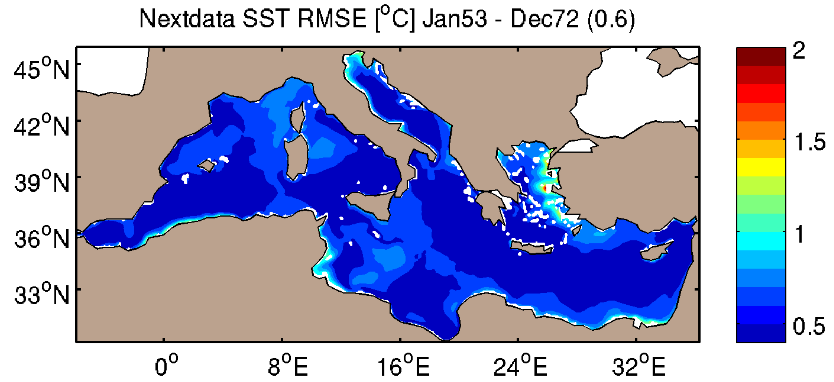
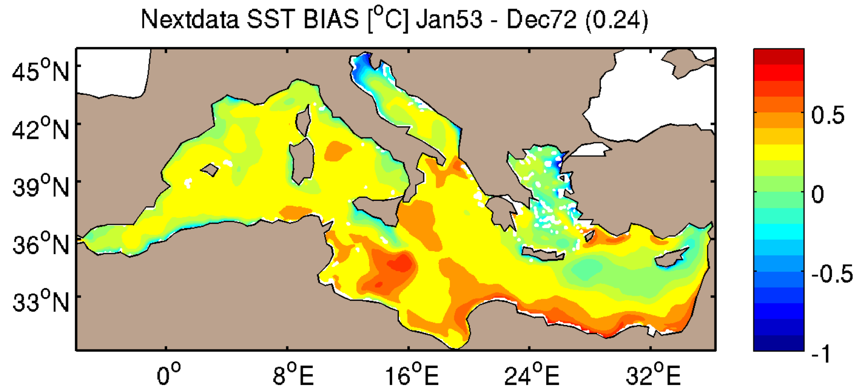


Fig. 10. SST RMSE (top) and BIAS (bottom) computed from NextData RR on a monthly basis on 1953-1973.



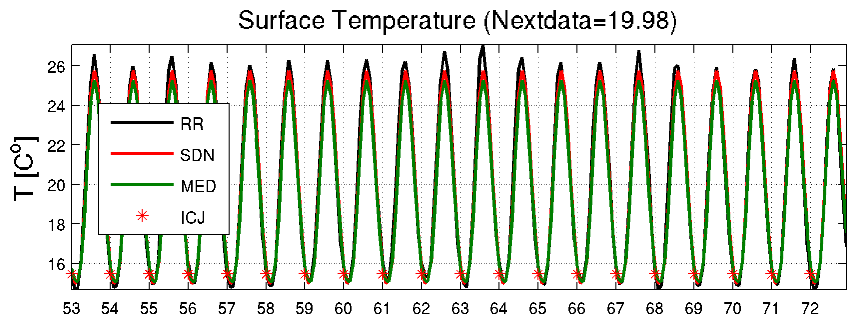
(a)



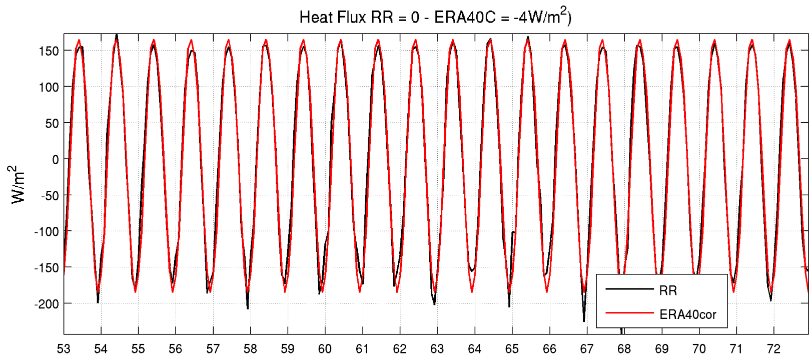
(b)

Fig. 11. SST multi-year RMSE (a) and BIAS (b) maps computed for the NextData RR products for the time period 1953-1972.

Figure 12 shows the time series of domain averaged monthly SST. Basin temperature ranges on average between 15°C in the winter and 28°C in the summer. The NextData RR long-term average is 20°C, 0.1°C lower than MedReanV4bis. The red line represents SDN_V3 climatology and the green line corresponds to MEDATLAS climatology. Both are colder than the NextData RR in the summer, while in the winter, they match the RR values better. Maximum surface temperatures occurred in summer 1963 and 1967.



(a)



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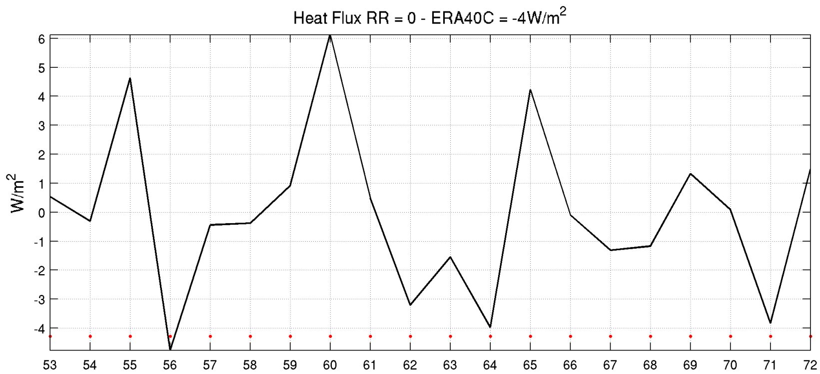


(c)

Fig. 12. (a) Domain averaged monthly SST: NextData RR (black line); SeaDataNetV3 climatology (red line); MedAtlas Climatology (green line); red asterisks indicate the initial conditions from January SDNV2aa climatology. (b) Monthly domain averaged surface net heat flux as a function of time: (black line) RR; (red line) ERA-40C corrected (Pettenuzzo et al., 2011). (c) Annual mean, domain averaged surface net heat flux: (black line) RR; (red dots) ERA-40C average computed over the 1958-2001 time period.

Figure 12b shows that monthly mean net heat flux ranges from -200 to 150 W m^{-2}. The multi-year net heat budget is equal to 0 W m^{-2} which is probably due to decadal variability, to be checked in the next months. Figure 12c shows annual mean net heat flux values that oscillate around zero with a maxima of 6 W/m^2 and minima of -5 W/m^2.
Figure 13 shows multi-year temperature BIAS (left) and RMSE (middle) profiles averaged over the whole domain (up to 1000 m) over the available NextData RR time period. Temperature BIAS is always positive and exhibits maximum positive values (about 0.6°C) within the first 50 m. The multi-year average BIAS is positive and equal to 0.14°C and RMSE is 0.47°C. Both are larger than the MedReanV4bis values and structure is different, probably due to the scarcely resolved observations in vertical which are coming from bottle measurements at this time.

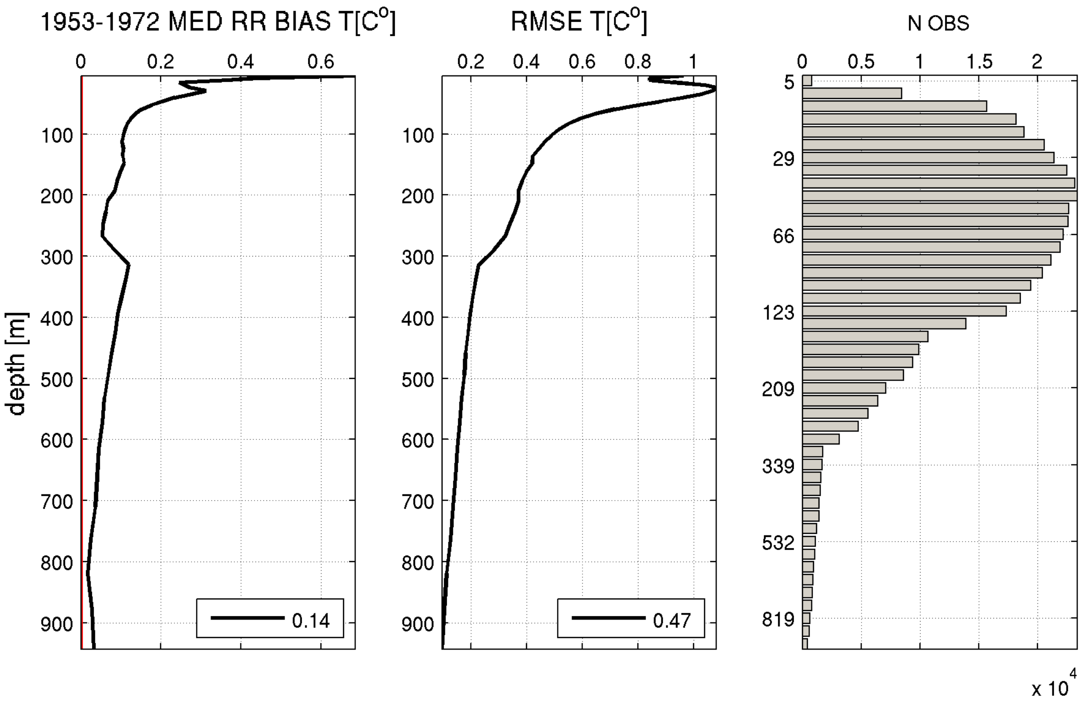
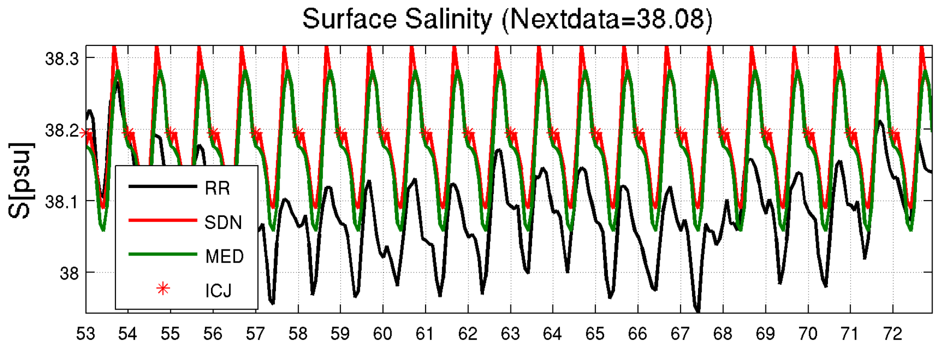


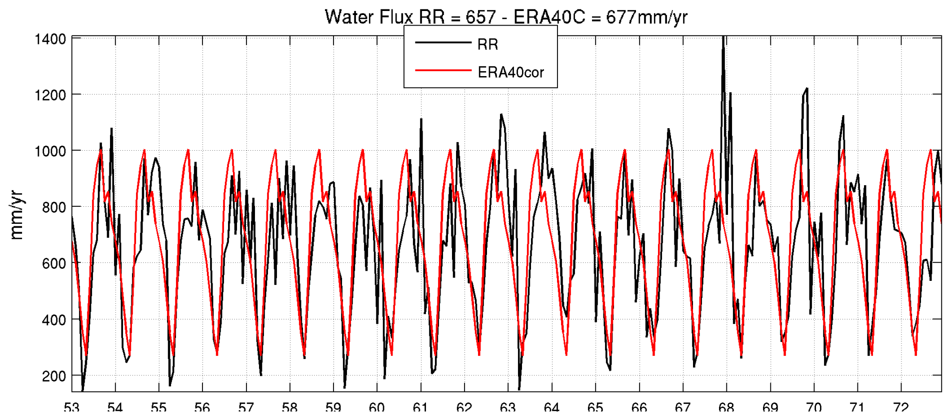
Fig.13. Temperature BIAS (left) and RMSE (middle) profiles averaged over the Mediterranean Sea and for the available NextData RR period 1953-1972. The number of temperature observations for each NextData RR vertical level used to compute the misfit statistics is reported in the right panel.

NextData RR salinity quality

Domain averaged RR monthly SSS is shown in Figure 14a and it exhibits, as expected, a small amplitude seasonal cycle, less than 0.2psu, with minimum salinity values during the spring months and maximum values at the end of the summer. The averaged salinity over the reanalysis time period is 38.08 psu, 0.14 psu lower than MedReanV4bis. Some inter-annual variability is apparent with the lowest surface salinity in 1957 and 1967 and the highest in summer 1971.



(a)



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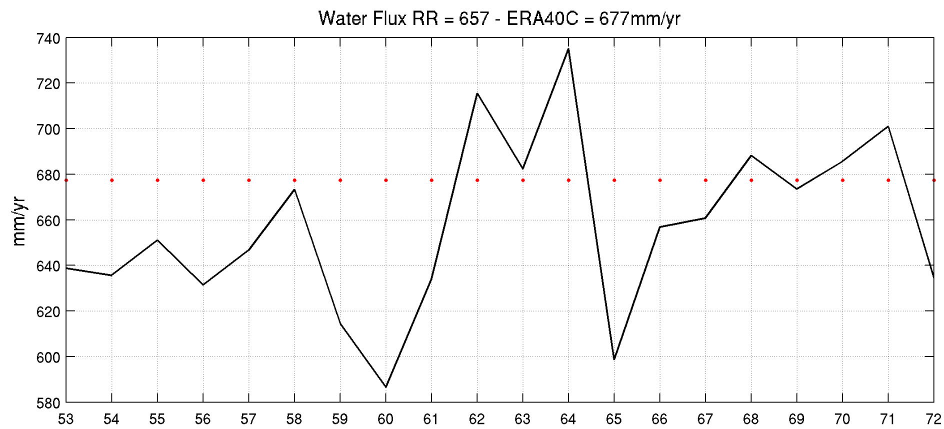


(c

Fig. 14. (a) Domain averaged monthly SSS: RR (black line); Sea Data NetV3 climatology (red line); Med Atlas Climatology (green line); red asterisks indicate the initial conditions from January SDNV2aa climatology. (b) Monthly surface net fresh water flux as a function of time from 1953-1972: (black line) RR; (red line) ERA-40C climatology (Pettenuzzo et al., 2011). (c) Annual domain averaged surface net water flux: (black line) NextData RR; (red dots) ERA40C average computed for 1958-2001.

Figure 14b shows the monthly mean NextData RR surface net fresh water flux as a function of time, compared to ERA-40C. The water budget for the Mediterranean Sea is 657 mm/yr, very close to the ERA-40C budget which is 677 mm/yr (Pettenuzzo et al., 2010).
Figure 15 displays the multi-year salinity RR misfit BIAS (left) and RMSE (middle) profiles averaged over the Mediterranean Sea. Salinity Bias is negative in the first 200 m (minimum

value of about -0.13 psu) of water column and positive below (less than 0.05 psu) and it has the same structure of MedReanV4bis. The total BIAS is equal to -0.03 psu and the total RMSE is 0.16 psu, slightly higher than MedReanV4bis (0.10±0.02psu).

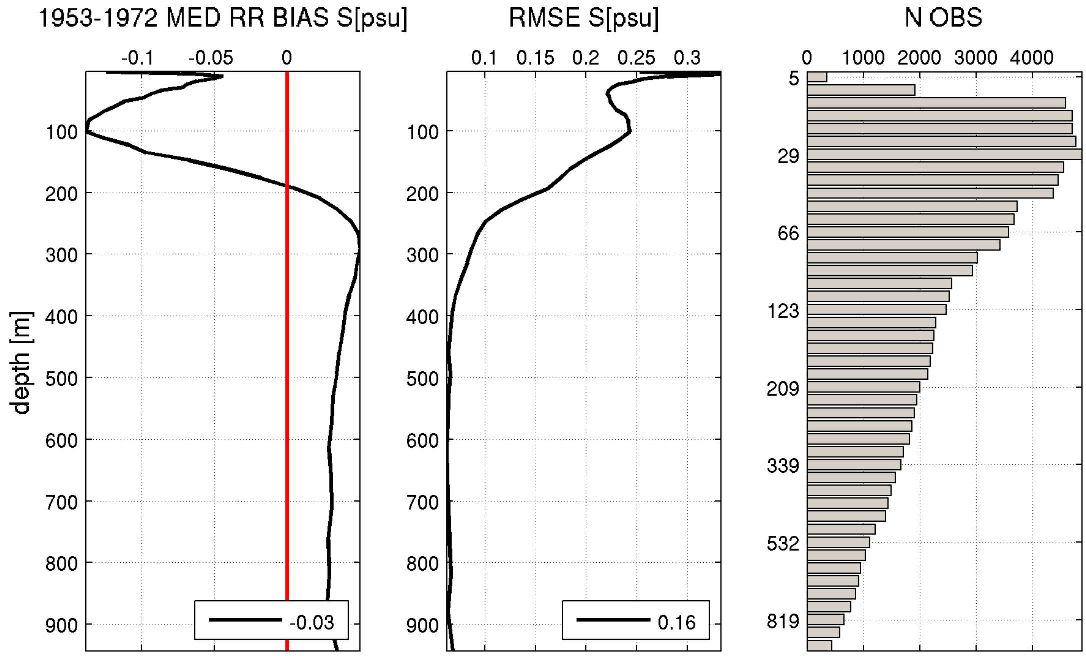


Fig. 15. Salinity misfits BIAS (left) and RMSE (middle) profiles averaged over the whole domain over RR time period 1953-1972. The number of salinity observations for each vertical level used to compute the misfit statistics is displayed on the right.

NextData RR transport at Gibraltar

The monthly time series of net volume transport through the Strait of Gibraltar is shown in Figure 16a, while Figure 16b shows its westward and eastward components. The inflow eastward transport is higher than the westward outflow component thus giving rise to a long-term net value of 0.04 Sv, which is slightly lower than the MedReanV4bis value (0.05 Sv). Eastward and westward components are also weaker than the MedReanV4bis. However, the presented values are in agreement with the literature (Oddo et al., 2009; Menemenlis et al., 2007).

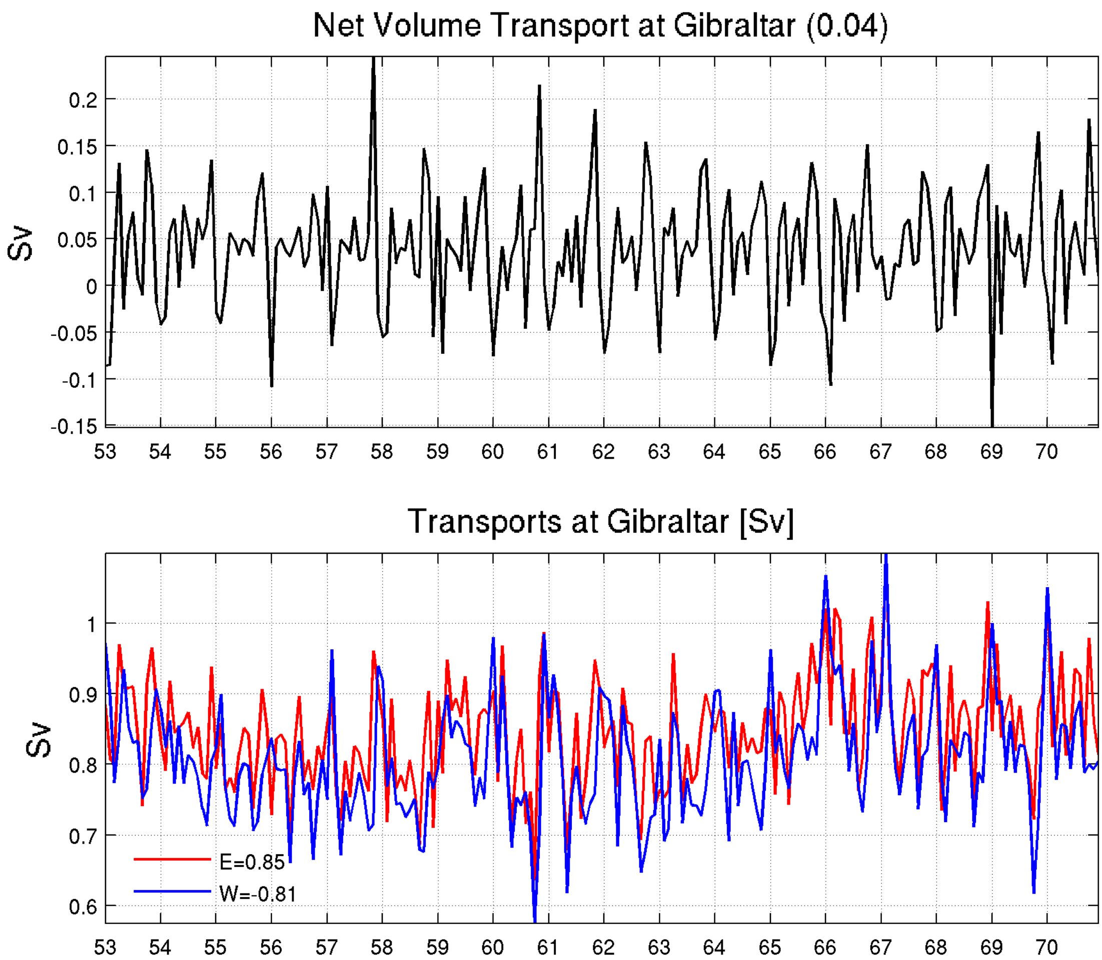
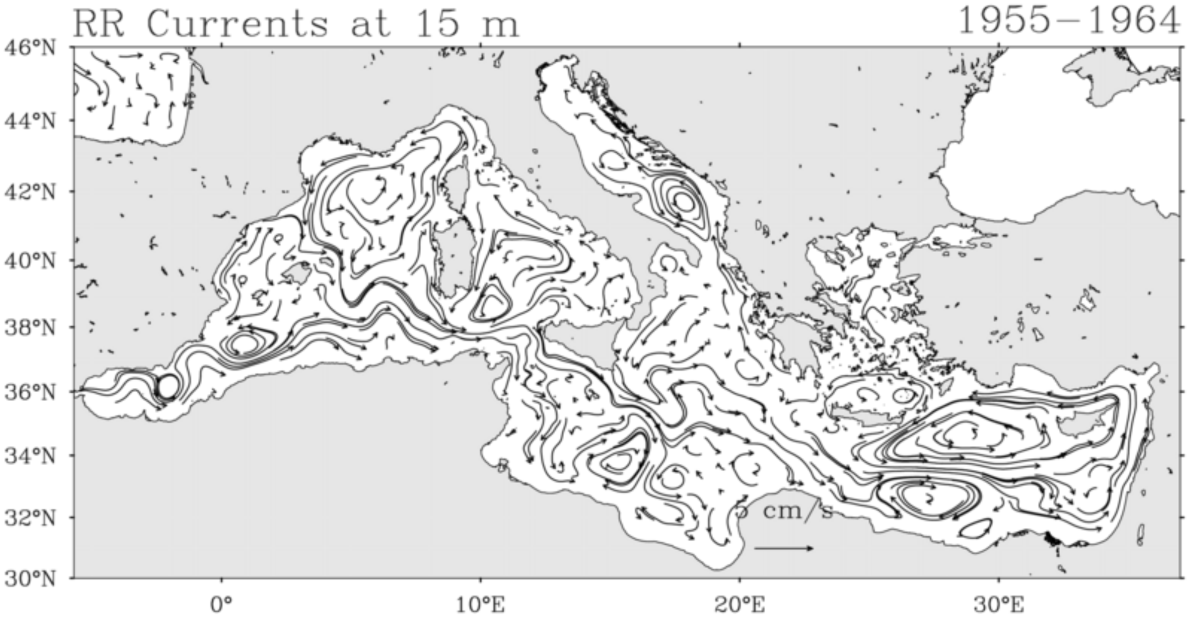


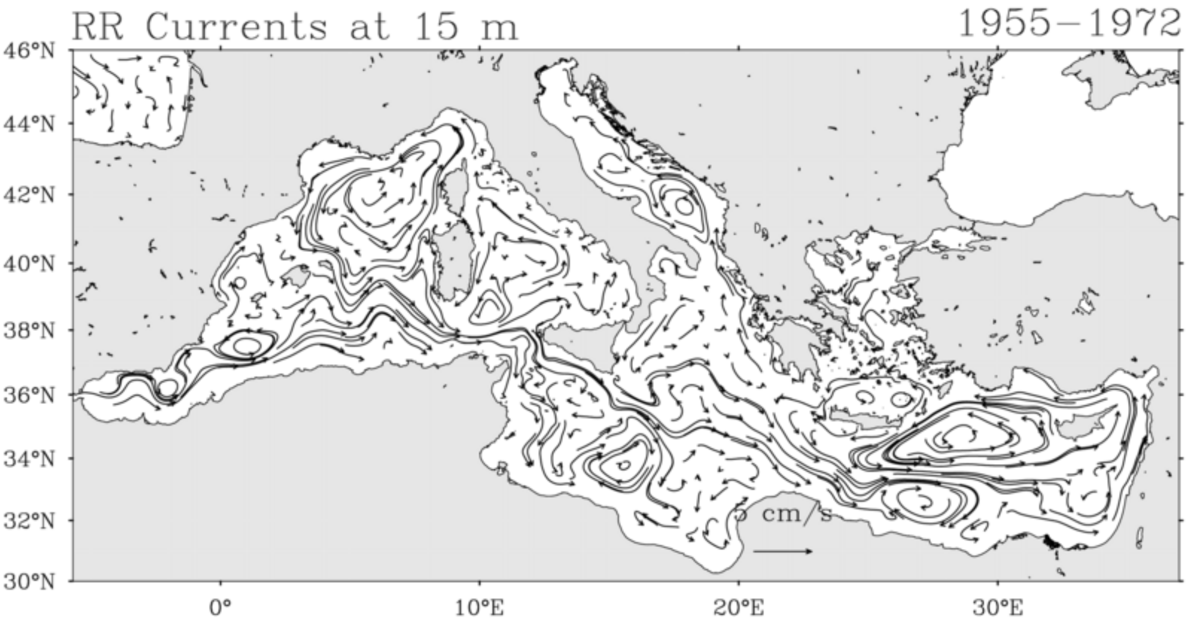
Fig. 16. NextData RR monthly volume transport through the Gibraltar Strait: (a) net transport; (b) eastward (red) and westward transport (blue).

NextData RR circulation structure

Figure 17 shows NextData RR maps of surface mean currents at 15 m depth computed over two different periods: (a) 1955-1964; (b) 1955-1972. The first map (a) is designed to highlight the decadal variability of the circulation in the Mediterranean Sea as described by Pinardi et al., 2013, while the second map (b) shows the mean circulation over the available NextData RR 1955-1972 period. The main difference with respect to Pinardi et al. (2013) and MedReanV4bis is the large scale structure of some of the sub-basin scale gyres, probably connected to the low resolution of the atmospheric forcing (AMIP=12hrs/1.125°, ERA-Interim=6hrs/0.75°). However the mean surface circulation is in agreement with the literature and presents the well-known Mediterranean surface circulation features.



(a)



(b)

Fig. 17. Currents climatology at a depth of 15m: (a) computed over 1955-1964; (b) computed over 1955-1972.

Data transmission to the archive and the general portal

The two products:

1. MedReanV4bis 1987-2012;
2. NextData RR 1953-1970

were made available through an INGV dedicated server using the THREDDS protocol (http://medsearr.bo.ingv.it/thredds). All database technical specifications are detailed in D2.2.

Summary and conclusions

WP1.3 activity was in line with the work planned. A MedReanV4bis feasibility reanalysis for the 1987-2012 time period was produced introducing major improvements with respect to the existing reanalysis products (Adani et al., 2011). The data set was released through the NextData Infrastructure. The NextData RR was started and the first 20 years were produced and released. The 60-years NextData RR data set will be released with a few months delay in 2014 (presumably end of April 2014) on the web portal.

An automated diagnostic procedure was developed and implemented in order to check the quality of all reanalysis products and compare their results. This analysis showed the comparable quality of the initial NextData RR with the well established reanalysis products.

Next year we will work on two publications: one is currently being drafted for MedReanV4bis, and the other will be started as soon as the Mediterranean RR will be finished. In the meantime, we will further develop the automated validation procedure and implement new quality indices as well as consistency checks for the circulation structures. We will also start a climate trend analysis which is very much in demand by the climate scientific community.

References

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

CHERCHI, A. and NAVARRA A., 2007: Sensitivity of the Asian summer monsoon to the horizontal resolution: differences between AMIP-type and coupled model experiments. *Climate Dynamics*, 28, 2, 273-290, doi: 10.1007/s00382-006-0183-z

DEE, D. P., S. M. UPPALA, A. J. SIMMONS, P. BERRISFORD, P. POLI, S. KOBAYASHI, U. ANDRAE et AL. The ERA Interim reanalysis: Configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Society* 137, no. 656 (2011): 553-597.

DOBRICIC, SRDJAN: New mean dynamic topography of the Mediterranean calculated from assimilation system diagnostics. *Geophysical Research Letters* 32.11 (2005).

DOBRICIC, S., et AL.: Mediterranean Forecasting System: an improved assimilation scheme for sea-level anomaly and its validation. *Quarterly Journal of the Royal Meteorological Society* 131.613 (2005): 3627-3642.

DOBRICIC S., PINARDI N., 2008: An oceanographic three-dimensional variational data assimilation scheme. *Ocean Modelling*, Volume 22, Issues 3–4, Pages 89-105, ISSN 1463-5003, 10.1016/j.ocemod.2008.01.004.

GATES, WL, 1992. AMIP: the atmosphere model intercomparison project. *Bulletin of American Meteorological Society* 73, 1962–1970.

KILLWORTH, P. D.: Time interpolation of forcing fields in ocean models. J. *Phys. Oceanogr.*, 26, 136–143, 1996.

MAILLARD, C., and COAUTHORS, 2005: MEDAR/MEDATLAS 1998-2001: A Mediterranean and Black Sea oceanographic data base and network. *Boll. Geofis. Teor. Appl.*, 46, 329–344.

MADEC, G., P. DELECLUSE, M. IMBARD, and C. LEVY, 1998: OPA 8.1 ocean general circulation model reference manual. Institut Pierre-Simon Laplace, *Note du Pole de Modelisazion*, No. 11, 91 pp.

MARIOTTI, A.: Recent changes in the Mediterranean Water cycle: a Pathway toward long-term regional hydroclimatic change? *Journal of Climate* 23.6 (2010): 1513-1525.

MARULLO, S., et AL.: Observing the Mediterranean Sea from space: 21 years of Pathfinder-AVHRR sea surface temperatures (1985 to 2005): re-analysis and validation. *Ocean Science* 3.2 (2007): 299-310.

MENEMENLIS, D., FUKUMORI, I., and LEE, T.: Atlantic to Mediterranean sea level difference driven by winds near Gibraltar Strait. *J. Phys. Oceanogr.*, 37, 359–376, 2007.

ODDO, P., ADANI M., PINARDI N., FRATIANNI C.,TONANI M., and PETTENUZZO D., 2009: A nested Atlantic- Mediterranean Sea general circulation model for operational forecasting. *Ocean Sci.,* 5, 461–473.

PETTENUZZO, D., W. G. LARGE, and N. PINARDI: 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 (2010).

N. PINARDI, M. ZAVATARELLI, M. ADANI, G. COPPINI, C. FRATIANNI, P. ODDO, S. SIMONCELLI, M. TONANI, V. LYUBARTSEV, S. DOBRICIC, A. BONADUCE: Mediterranean Sea large-scale low-frequency ocean variability and water mass formation rates from 1987 to 2007: A retrospective analysis. *Progress in Oceanography*. Available online 5 December 2013, ISSN 0079-6611, doi: *http://dx.doi.org/10.1016/j.pocean.2013.11.003.*

RAYNER, N. A.; PARKER, D. E.; HORTON, E. B.; FOLLAND, C. K.; ALEXANDER, L. V.; ROWELL, D. P.; KENT, E. C.; KAPLAN, A. (2003): Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.* Vol. 108, No. D14, 4407 10.1029/2002JD002670.

A.R. ROBINSON, M. GOLNARAGHI, W.G. LESLIE, A. ARTEGIANI, A. HECHT, E. LAZZONI, A. MICHELATO, E. SANSONE, A. THEOCHARIS, Ü. ÜNLÜATA: The eastern Mediterranean general circulation: features, structure and variability. *Dynamics of Atmospheres and Oceans*, Volume 15, Issues 3–5, April 1991, Pages 215-240, ISSN 0377-0265, 10.1016/0377-0265(91)90021-7.

TONANI,M., PINARDI,N., DOBRICIC,S., PUJOL,I., and FRATIANNI,C., 2008: A high-resolution free-surface model of the Mediterranean Sea. *Ocean Sci.,* 4, 1-14, doi:10.5194/os-4-1-2008.

UPPALA, S.M., KÅLLBERG, P.W., SIMMONS, A.J., ANDRAE, U., DA COSTA BECHTOLD, V., FIORINO, M., GIBSON, J.K., HASELER, J., HERNANDEZ, A., KELLY, G.A., LI, X., ONOGI, K., SAARINEN, S., SOKKA, N., ALLAN, R.P., ANDERSSON, E., ARPE, K., BALMASEDA, M.A., BELJAARS, A.C.M., VAN DE BERG, L., BIDLOT, J., BORMANN, N., CAIRES, S., CHEVALLIER, F., DETHOF, A., DRAGOSAVAC, M., FISHER, M., FUENTES, M., HAGEMANN, S., HÓLM, E., HOSKINS, B.J., ISAKSEN, L., JANSSEN, P.A.E.M., JENNE, R., MCNALLY, A.P., MAHFOUF, J.-F., MORCRETTE, J.-J., RAYNER, N.A., SAUNDERS, R.W., SIMON, P., STERL, A., TRENBERTH, K.E., UNTCH, A., VASILJEVIC, D., VITERBO, P., and WOOLLEN, J. 2005: The ERA-40 re-analysis. *Quart. J. R. Meteorol*. Soc., 131, 2961-3012.doi:10.1256/qj.04.176.15

XIE, P., and P.A. ARKIN, 1997: Global precipitation: a 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bull. Amer. Meteor. Soc.,* 78, 2539 - 2558.