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High-resolution simulations of Mediterranean Sea physical oceanography under current and scenario climate conditions: model description, assessment and scenario analysis

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SUMMARY This report presents the application of a regional ocean circulation model to simulate current conditions and mid-term projections of climate variability in the Mediterranean Sea. On the basis of IPCC-AR5 climate projections and previous projects findings, a detailed analysis of the available external forcing data was carried out to define the most up-to-date scenarios for the investigation period (2000-2050). A synthesis of the results obtained with the regional model for current and future climate is provided, by focusing on the state of the seawater temperature and salinity for specific marine regions of the Mediterranean Sea.

Keywords: Mediterranean, climate scenario, general circulation model, RCP8.5

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THE OCEAN CIRCULATION MODEL

The ocean general circulation model (OGCM) is based on the NEMO modelling system (Madec, 2008; see also http://www.nemo-ocean.eu, version 3.4). The NEMO model configuration and physical set-up for the Mediterranean Sea, herein referred as MFS16, is derived from the Mediterranean Ocean Forecasting System (Oddo et al., 2009).

The MFS16 domain covers the whole Mediterranean Sea and extends to the Atlantic Ocean (Fig. 1) with a horizontal grid resolution of 1/16 of degree, corresponding to nearly 6.5 km. There are 72 levels in the vertical scale, with uneven grid spacing ranging from 3 m at the surface to 600 m in the bottom layers of the Atlantic.

The model computes the air-sea fluxes of water, momentum and heat using specific bulk formulae tuned for the Mediterranean Sea (see details in Oddo et al., 2009).

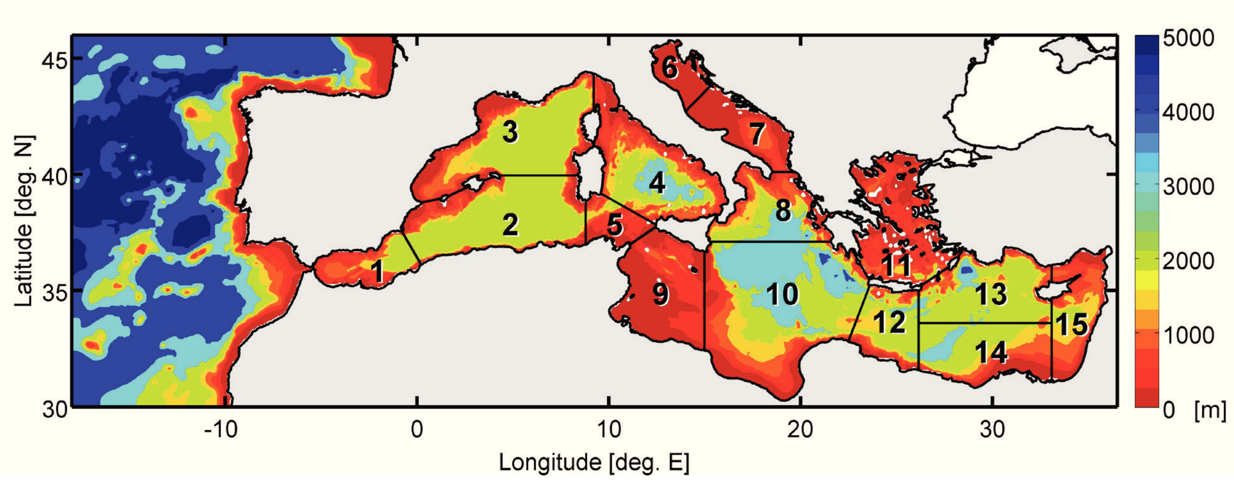

Figure 1. Bathymetry of the Mediterranean Sea used in the MFS16 configuration of the NEMO ocean modelling system. Numbers indicate the selected marine regions: 1 Alboran Sea; 2 North Balearic Sea; 3 South Balearic Sea; 4 Tyrrhenian Sea; 5 Sicily Strait; 6 Northern Adriatic Sea; 7 Southern Adriatic Sea; 8 Ionian Sea; 9 Sicily Channel; 10 Central Mediterranean Sea; 11 Aegean Sea; 12 Cretan Channel; 13 North Levantine Basin; 14 South Levantine Basin; 15 Eastern Levantine Basin. Additional regions are defined as: 16 Adriatic sea (6-7); 17 Western Mediterranean Sea (1-5); 18 Eastern Mediterranean Sea (8-15); 19 Mediterranean Sea (1-15).

REGIONAL CLIMATE MODELLING

The regional circulation model is driven by three external forcing functions, namely (i) the atmospheric fields, (ii) riverine freshwater discharges, and (iii) the currents and sea state at the open Atlantic boundaries. In addition, the initial state of the system has to be defined by providing adequate three-dimensional fields for temperature and salinity.

A major issue here is represented by the identification of a composite set of data that would allow to describe the different forcing and to produce a coherent simulation of the current climate and its future variability.

On the one hand, the large availability of reanalysis products for both the ocean and the atmosphere would provide a reliable input to the model, as they combine direct observations with modelling tools by means of data assimilation techniques (Adani et al., 2010; Dee et al., 2011). Nonetheless, these datasets can only describe the current climate conditions because they are run in hindcast mode. On the other hand, the large effort of international projects (e.g., CMIP, CORDEX, CIRCE) promoted the development of coupled atmospheric and oceanic general circulation models (AOGCM) that either have sufficiently small spatial resolution to resolve regional processes or which are specifically designed as regional climate models. These models allow to investigate the evolution of the climate system under different scenarios of green-house gas emissions and their regional effects on key state variables (e.g., the temperature). A known limitation of the global AOGCMs is the occurrence of strong biases when focusing on specific regional domains (see Cattiaux et al., 2013).

The combination of reanalysis products with AOGCMs fields represents a profitable solution for the setup of a coherent and reliable set of external forcing to drive regional models (White and Toumi, 2013; Watanabe et al., 2013). In fact, it is possible to use reanalyses data to correct the biases of the global AOGCMs for the current climate regional simulation. For future scenario applications, the bias is commonly assumed not to change (see Berg et al., 2012) and the same correction for present climate is applied.

CLIMATE SCENARIOS AND FORCING DATA

The data used for the construction of the MFS16 atmospheric forcing fields were obtained from the high-resolution coupled circulation model CMCC-CM (Scoccimarro et al., 2011). In particular, the future climate variability of the CMCC-CM simulation was based on the RCP8.5 scenario, which represents the worst-case scenario with a change in the global radiative forcing of 8.5 W/m^2 by the end of this century (see details in Moss et al., 2010).

The error analysis of the CMCC-CM atmospheric data for the current climate was performed against the ERA-Interim reanalyses fields (Dee et al., 2011). Fig. 2 shows the difference between the CMCC-CM and ERA-Interim monthly climatologies over the Mediterranean basin for the following atmospheric variables: relative humidity (RH), sea level pressure (SLP), air (TAIR) and dew point (TDWP) temperatures at 2 m height, and wind speed at 10 m (WSPD). The climatological values were computed for the period 1979-2010. The air temperature data simulated with the CMCC-CM are remarkably underestimated throughout the year, with a maximum bias of -3.5°C in July. Similarly, the dew point temperature of the air presents a maximum difference of -3.7°C in August. The other variables have instead a relatively uniform bias, with the exception of the SLP that is characterized by larger errors in the spring period. Nevertheless, the magnitude of the SLP bias is very small when compared with the mean values of the sea level atmospheric pressure over the domain, which is of about 1015 hPa.

The present activity is focused on the two temperature variables, as they are the main atmospheric drivers in the study of climate variability scenarios. A bias correction for the air and dew point temperatures of the CMCC-CM was performed with a stepwise procedure:

1. The ERA-Interim fields were remapped over the grid of the CMCC-CM;
2. The mean monthly biases of the air temperature were computed using the corresponding means of the CMCC-CM dataset over the period 1979-2010 (Fig. 3);
3. The resulting biases were added to the original fields produced by the climate model (see, e.g., Berg et al., 2012);

4. As the differences in the relative humidity were not relevant (see Fig. 2), the original RH field was used in combination with the corrected one for the air temperature to calculate a corrected dew point temperature by means of the Magnus formula (Lawrence, 2005).

Both current and future scenario atmospheric fields were corrected using a linear scaling approach (see, e.g., Teutschbein and Seibert 2012), since the bias is assumed to be a systematic error of the CMCC-CM simulations.

The open boundary fields in the Atlantic Sea were obtained from the ocean model of the CMCC-CM without performing any bias analysis. The open boundaries of the model are far from the Gibraltar Strait and the effects of the imposed lateral conditions on the inner domain of the Mediterranean Sea are generally reduced.

The riverine freshwater discharges and the fluxes at the Dardanelles Strait were obtained from the hydrological component of the AOGCM used within the CIRCE project (Gualdi et al., 2013). The CIRCE simulations were based on the A1b scenario, which represents a “Business as Usual” management of GHG emissions. The reliability of this dataset was assessed through the comparison with other datasets for the current climate period (Fig. 4). The annual evolution of the total river runoff for the Mediterranean Sea estimated within the CIRCE simulation compared satisfactorily with the estimates previously obtained in the SESAME project (Ludwig et al., 2010).

The initial conditions of the Mediterranean Sea were obtained from the gridded temperature and salinity data produced by the SeaDataNet infrastructure (http://www.seadatanet.org/).

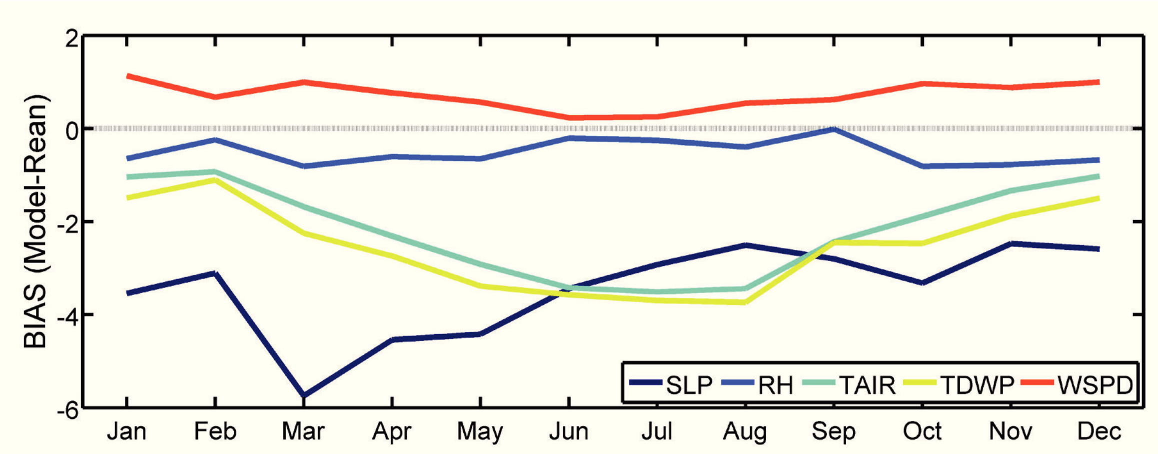

Figure 2. Time series of the difference between the CMCC-CM and ERA-Interim monthly climatologies over the Mediterranean basin for the period 1979-2010. Variables in the plot: SLP - sea level pressure (hPa); RH – relative humidity (%); TAIR – Air temperature at 2 m (°C); TDWP – Dew Point temperature at 2m (°C); WSPD – Wind speed module (m/s). Positive values indicate an overestimation of the CMCC-CM data with respect to ERA-Interim Reanalyses.

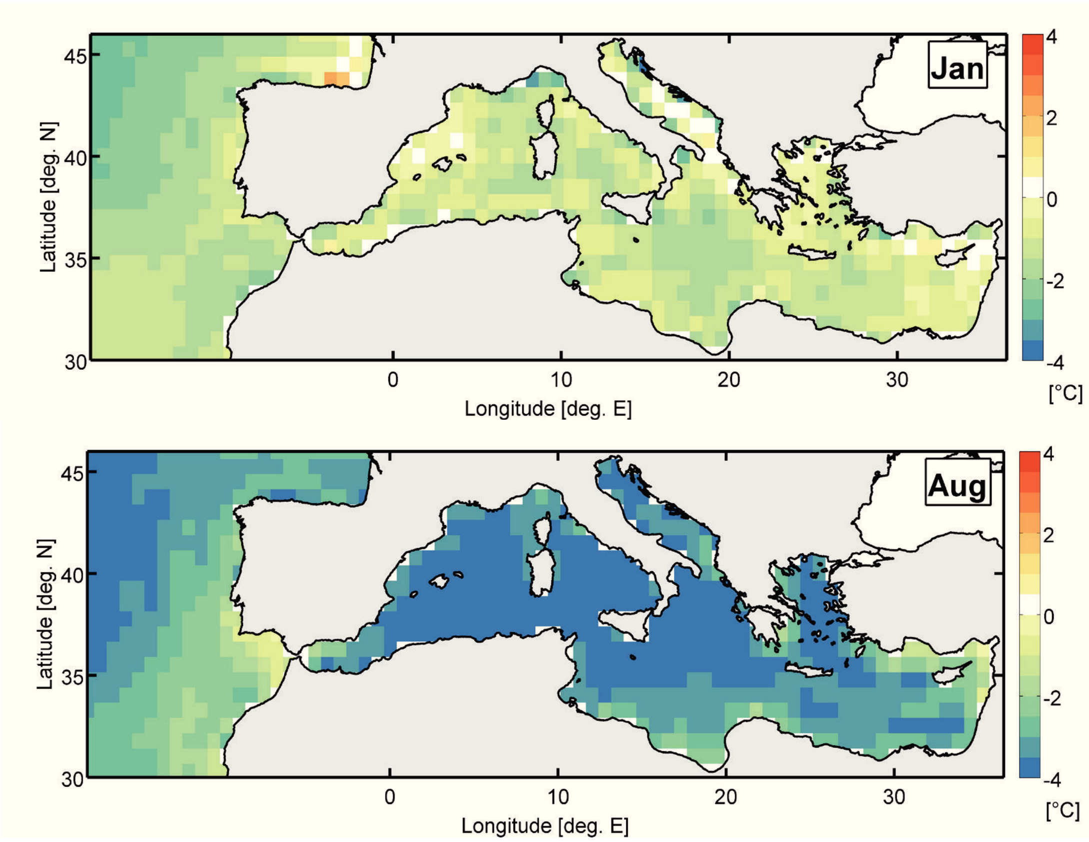

Figure 3. Mean monthly biases of air temperature at 2 m between the ERA-Interim and CMCC-CM for January (top) and August (bottom) in the period 1979-2010. Positive values indicate an overestimation of the CMCC-CM data with respect to ERA-Interim Reanalyses.

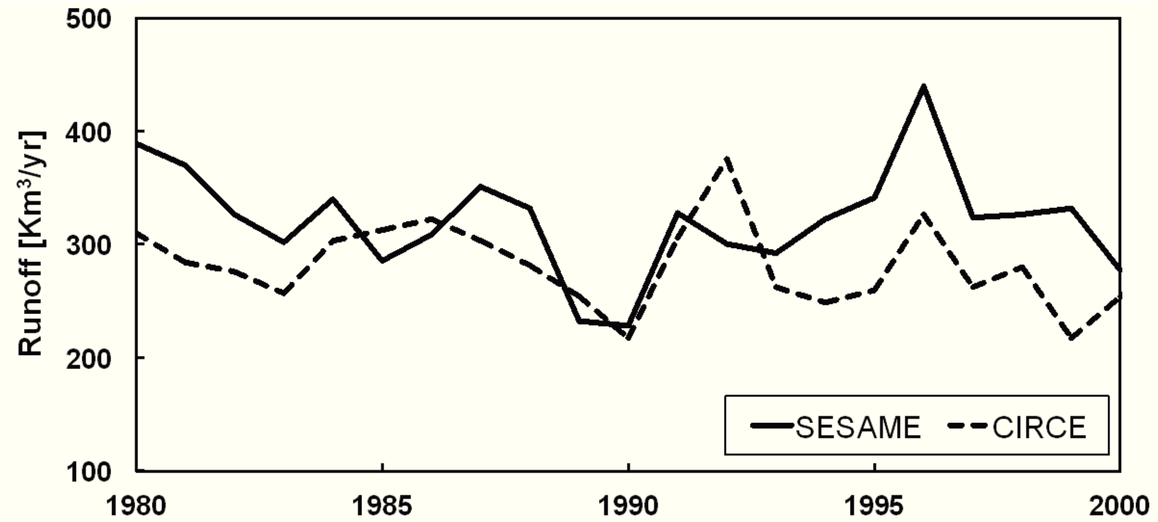

Figure 4. Time series of the total annual river runoffs (km^3/yr) for the Mediterranean Sea estimated in CIRCE (Gualdi et al., 2013) and SESAME projects (Ludwig et al., 2010).

SYNTHESIS OF THE NUMERICAL EXPERIMENTS

In the following table are summarized the main characteristics of the MFS16 model, the external forcing, and the numerical experiment carried out within this activity. The current implementation of the model with the climate model forcing will be referred as MFS16CM.

Table 1. Summary of the MFS16 numerical experiment setup and external forcing functions.

MFS16 setup	**Value**	**Reference**
Horizontal resolution	1/16°	Oddo et al., 2009
Vertical resolution	3-600m (72 levels)	Oddo et al., 2009
Time step	540s	*This work*
Horizontal Diffusion	Bilaplacian	Oddo et al., 2009
Vertical turbulence scheme	Richardson number scheme	Madec, 2008
Forcing function	**Origin**	**Reference**
Atmospheric Fields	CMCC-CM (6 hourly)	Scoccimarro et al., 2011
Open boundary conditions	CMCC-CM (monthly)	Scoccimarro et al., 2011
River runoff	CIRCE (monthly)	Gualdi et al., 2013
Initial conditions (T, S)	SeaDataNet climatology (monthly)	SeaDataNet
Numerical Experiment	**Time window**	**Reference**
Spin up period	7 years	
Current Climate	1980-2010	
RCP8.5 Scenario	2011-2050	Moss et al. (2010)
Available Outputs	**Description**	
Time frequency and type	Monthly mean fields; time series in marine regions (see Fig. 1)	
3D state variables	Water temperature, salinity, horizontal and vertical current velocities	
2D state variables	Evaporation, precipitation, short wave radiation, wind speed.	

CURRENT SCENARIO RESULTS AND VERIFICATION

The general circulation of the Mediterranean Sea reproduced in the MFS16CM experiment refers to the evolution of the system as induced by the large-scale climate variability. Such a characteristic of the adopted forcing fields may not enable the model to timely capture known oceanic features, which would require the adoption of a dedicated regional atmospheric model. Nevertheless, a comparison with the reanalyses data of Adani et al. (2010) was carried out to verify the reliability of simulated variability and trends in the current climate time window, namely 1980-2010.

In this analysis we present results for the entire Mediterranean basin and two sub-basins, the Adriatic and Aegean Seas, which are known to have a key role in the Mediterranean thermohaline circulation (Robinson et al., 2001).

The simulated monthly mean surface temperature (Fig. 5) is in good agreement with the reanalysis data for the three regions, with a good reproduction of the amplitude and timing of the annual cycle. The model tends to overestimate the extreme summer and winter temperature values, but with a maximum root mean squared error of 1°C.

The simulated volume temperature agrees to different extents with the reanalyses, according to the considered region (Fig. 6). In the case of the Mediterranean Sea, the two time series have very similar characteristics, even if after the year 2000 the model temperatures begin to diverge toward higher values. Such an increase of temperatures at the basin scale clearly indicates that the atmospheric forcing of the CMCC-CM start to respond to the CO_2 accumulation occurred in previous decades. The results obtained for the two sub-basins indicate a good agreement of the MFS16CM simulation with the REAN data, especially after the year 1990. In both domains, differences are more pronounced in the period 1995-2000, with a marked overestimation of winter cooling process.

The overall performance of the MFS16 model in reproducing the time evolution of the seawater temperature reanalyses of Adani et al. (2010) is satisfactory, bearing in mind that the latter were produced by means of data assimilation techniques.

In figure 7 are illustrated the monthly and annual time series of the surface salinity, upward water flux, rivers runoff, and short wave radiation for the whole Mediterranean Sea. The salinity exhibits a clear seasonal cycle, with mean amplitude of 0.25 psu, which coherently follows the net upward water flux pattern. The latter variable represents the balance between the evaporation (E), precipitation (P), and riverine (R) water fluxes, expressed through the relation E-P-R (Madec, 2008; see also http://www.nemo-ocean.eu, version 3.4). In the period 1980-2010, the evaporation process in the Mediterranean Sea lead to mean upward water flux of 707.7 mm/yr, which is in the range of values reported by Mariotti et al. (2002). The riverine contribution to the water budget of the system shows the typical seasonal cycle with largest discharges during the winter period and peak values up to 900 km^3/yr. The mean freshwater discharge for the whole period was of 246.4 km^3/yr, in agreement with estimates provided by Ludwig et al. (2009). Finally, the short wave radiation in the simulated period was characterized by a low variability, with a nearly constant annual amplitude of ~200 W/m^2.

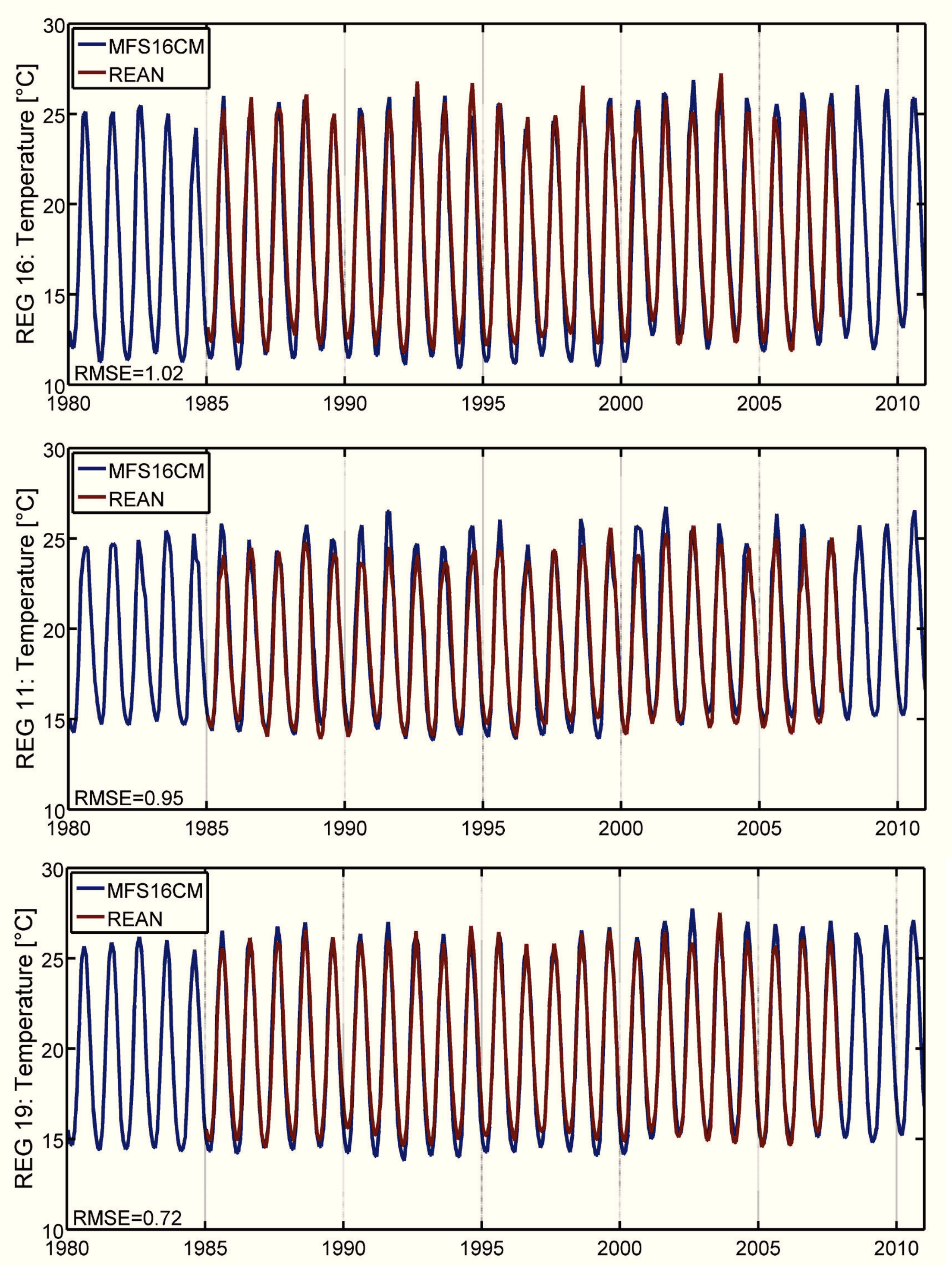

Figure 5. Time series of the monthly surface water temperature of the current climate MFS16 simulation (MFS16CM) and the reanalyses of Adani et al. (2010) (REAN) for the Adriatic Sea (top, Reg. 16), Aegean Sea (middle, Reg. 11), and the whole Mediterranean Sea (bottom, Reg. 19). The spatial domain of each region is illustrated in Fig. 1.

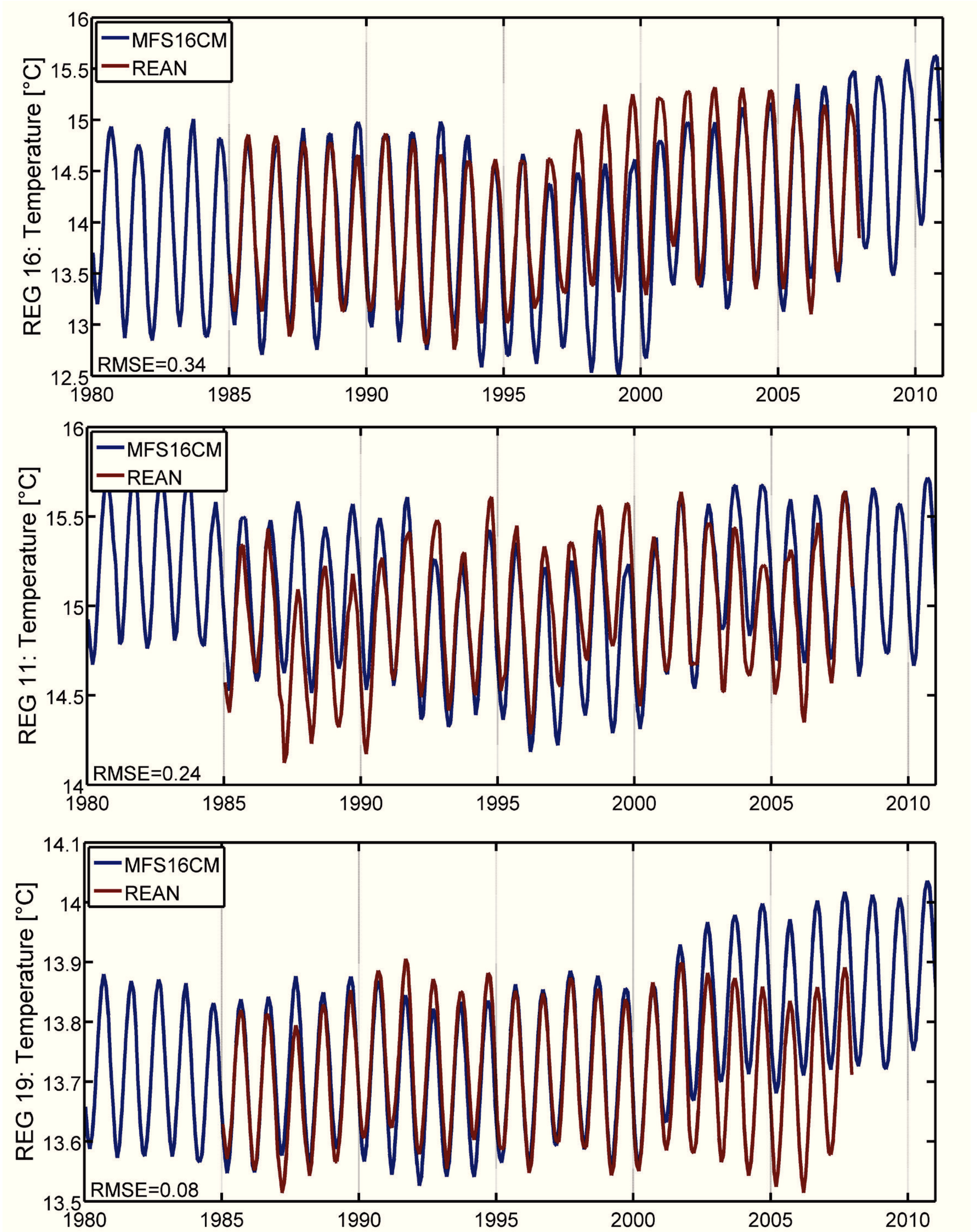

Figure 6. Time series of the monthly volume water temperature of the current climate MFS16 simulation (MFS16CM) and the reanalyses of Adani et al. (2010) (REAN) for the Adriatic Sea (top, Reg. 16), Aegean Sea (middle, Reg. 11), and the whole Mediterranean Sea (bottom, Reg. 19). The spatial domain of each region is illustrated in Fig. 1.

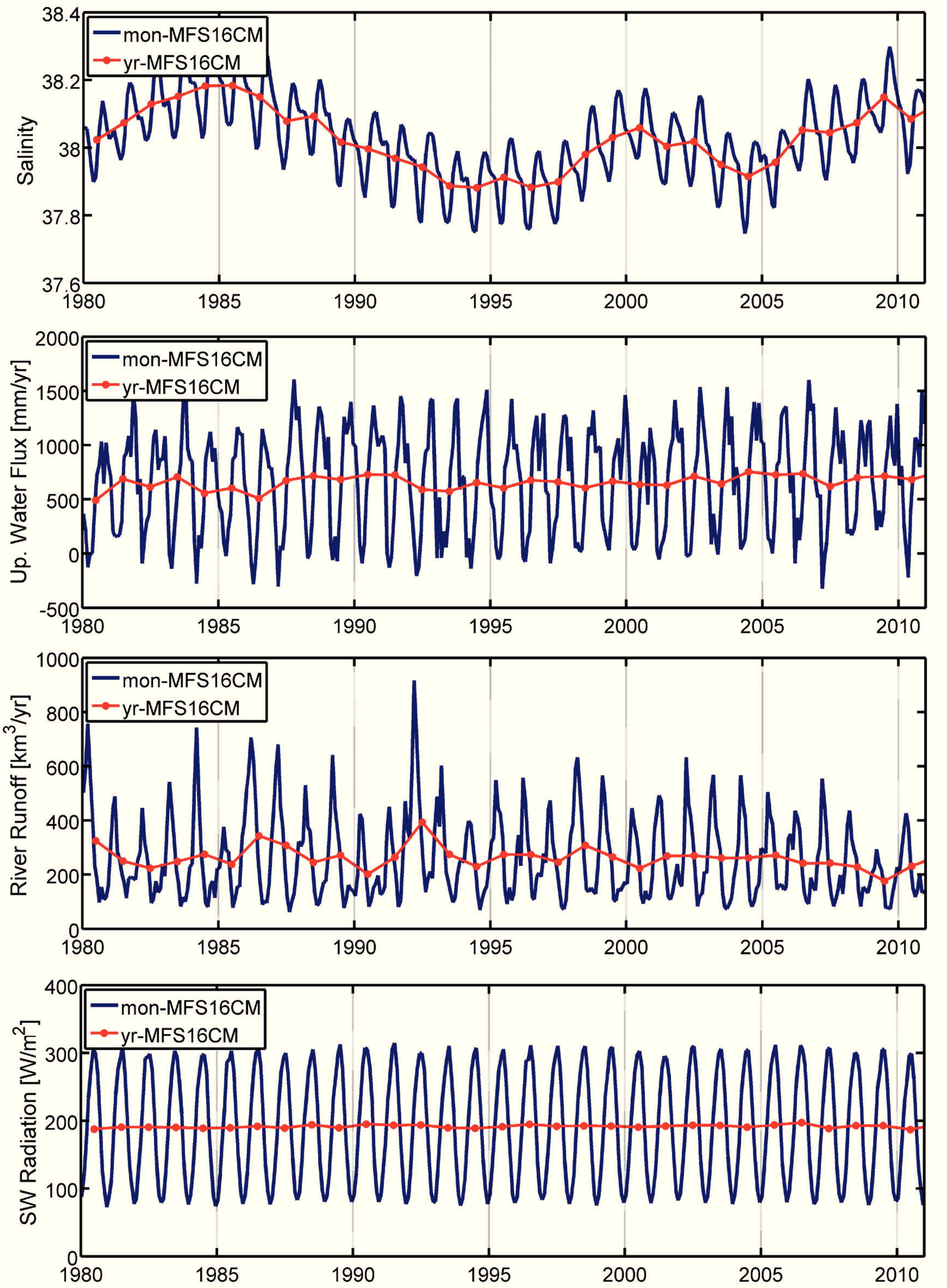

Figure 7. Time series of the monthly (blue) and annual (red) surface salinity, upward net water flux, rivers runoff, and short wave radiation in the current climate MFS16CM simulation for the whole Mediterranean Sea (Region 19, see definition in Fig. 1).

MEDITERRANEAN SEA EVOLUTION IN THE FUTURE SCENARIO

According to the findings of the current climate experiment verification, the Mediterranean Sea dynamics under the RCP8.5 scenario was simulated by applying the same bias correction of the current climate simulation. This assumes that the identified current climate biases represent a background condition for the CMCC-CM simulation and, thus, it has to be coherently maintained throughout the scenario experiment.

This section presents the time evolution of sea surface temperature (SST) and salinity (SSS), for the entire Mediterranean Sea and western and eastern basins analysed for the period 2000-2050. The principal characteristics of the SST and SSS monthly-simulated data are presented in Table 2 by means of synthetic statistical descriptors.

The sea surface temperature time series for the three basins (Fig. 8) exhibit an annual amplitude of about 12°C, which is nearly uniform over the future scenario. Minimum values of the mean amplitude are similar, while the maximum variation of the SST amplitude is 2°C higher in the Western Mediterranean Basin. The difference between the mean sea surface temperatures of the 2040-2049 and 2000-2009 simulated periods shows a increase of about 1°C, that reflects the global increasing trend of SST described in Scoccimarro et al. (2011).

The evolution of sea surface salinity is characterized by significant differences between the western and eastern basins (Fig. 9). The difference in the mean salinity over the period 2000-2050 is equal to 1.4, with a lower value for the western basin. The western part of the Mediterranean Sea presents also a reduced variability in the annual cycle of the SSS. After year 2040, a remarkable reduction of the surface values occurs in the Western basin, as a consequence of the inflow through the Gibraltar Strait of Atlantic waters with low salinity. The freshening of the Atlantic waters in the CMCC-CM simulation and in other CMIP5 experiments was induced by the progressive melting of the Arctic sea ice in a warming ocean (Gualdi S., *personal communication*).

This signal is partially recognizable also in the Eastern basins during the same period, but the surface Atlantic waters were modified by evaporation and mixing process toward higher salinity values. The Eastern Mediterranean shows the largest annual amplitude, namely 0.31.

The difference of SSS decadal mean values for the entire Mediterranean Sea indicates a moderate reduction, which is mostly driven by the freshening of the surface water entering into the system from Gibraltar.

The increase of surface warming is an indicator of increased stratification and reduced mixing (Somot et al., 2008; Lazzari et al., 2013). The evolution of summer (JJA) and winter (DJF) seasonal mixed layer depth (MLD) was investigated to detect relevant trends in those regions characterized by the presence of marked hydrographical mixing structures (e.g., Provencal basin, Ionian Sea) and at the whole basin scale. The mixed layer depth was defined by locating the gradient of the turbulent mixing coefficient (turbocline depth).

The summer MLD in the three considered basins (Fig. 10) present a nearly constant value of ~10.5 m, without remarkable changes during the future scenario. Conversely, the winter evolution of the mixed layer depth shows a large variability in the Ionian Sea, with mean and standard deviation values equal to 79.7 m and 16.1 m, respectively. The Provencal basin exhibits a relatively smaller variability (standard deviation of 5.7m), but a moderate MLD reduction occurs through the future scenario being the difference between the mean in the last (2040-2049) and first (2000-2009) decade equal to 4 m (8%). The MLD of the entire Mediterranean Sea has a mean value of 60.8 m and is characterized by a rather small variability, with a standard deviation of 4.8 m.

Table 2. Descriptive statistics of Sea Surface Temperature (SST, °C) and Sea Surface Salinity monthly data for the entire Mediterranean Sea and western and eastern basins in the period 2000-2050. The selected statistics are: mean value, the annual minimum-maximum range referred as amplitude, the minimum and maximum values of the annual amplitude. In addition, the difference between the mean value for the 2040-2049 and 2000-2009 periods is also reported. See Fig. 1 for regions location.

SST (2000-2050)	Mean	Amplitude	Minimum Amplitude	Maximum Amplitude	Difference (2040-2049) – (2000-2009)
REG. 17 (Western MedSea)	19.6	12.1	10.8	14.1	0.88
REG. 18 (Eastern MedSea)	21.7	11.80	11.1	12.6	1.07
REG. 19 (Entire MedSea)	20.8	11.9	11.1	13.1	1.01
SSS (2000-2050)	**Mean**	**Amplitude**	**Minimum Amplitude**	**Maximum Amplitude**	**Difference (2040-2049) – (2000-2009)**
REG. 17 (Western MedSea)	37.1	0.17	0.10	0.30	-0.32
REG. 18 (Eastern MedSea)	38.5	0.31	0.24	0.40	-0.03
REG. 19 (Entire MedSea)	38.0	0.25	0.21	0.29	-0.11

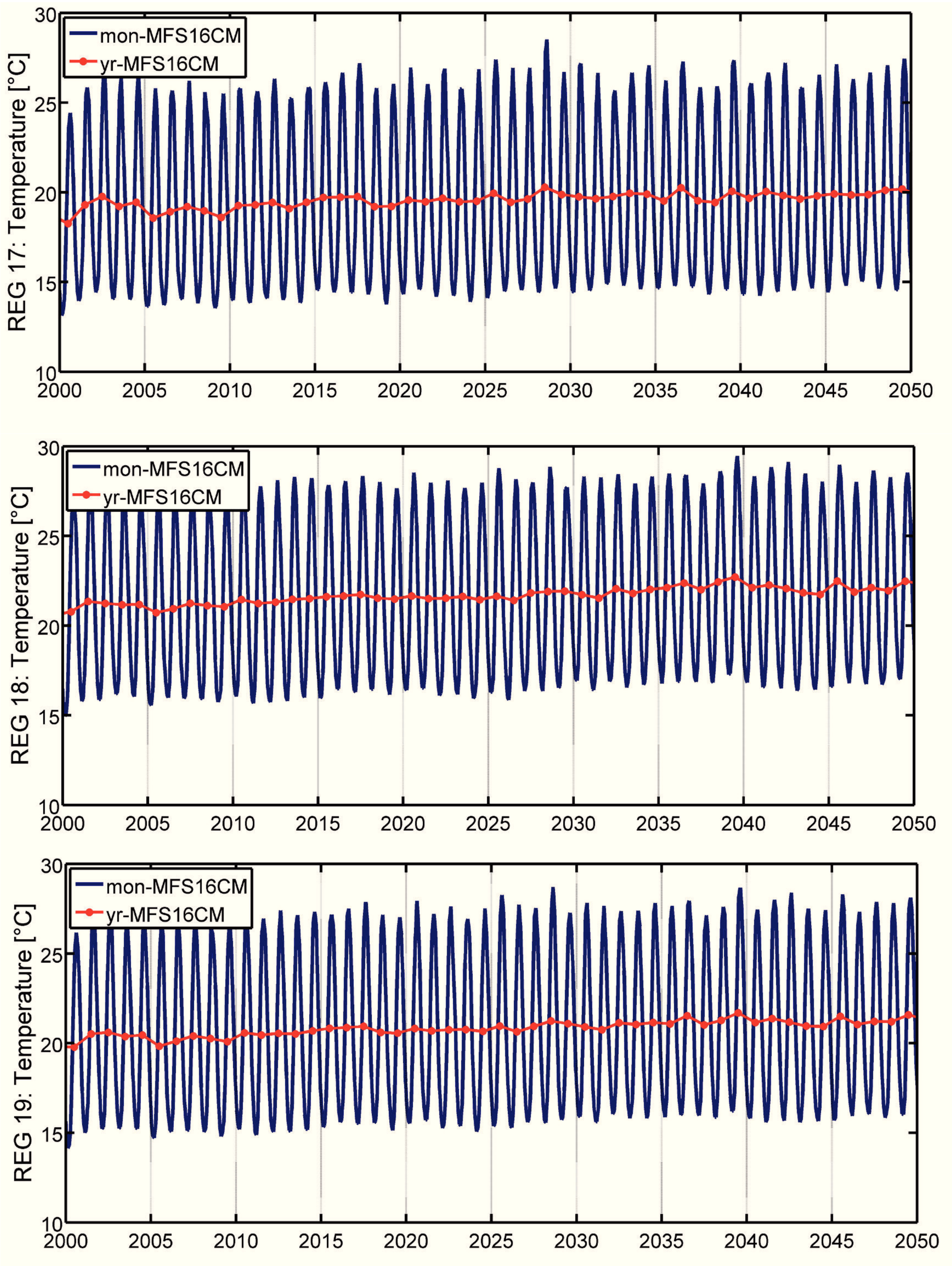

Figure 8. Time series of the sea surface water temperature of the scenario MFS16 simulation (MFS16CM) for the Western basin (top, Reg. 17), Eastern basin (middle, Reg. 18), and the whole Mediterranean Sea (bottom, Reg. 19). The spatial domain of each region is illustrated in Fig. 1.

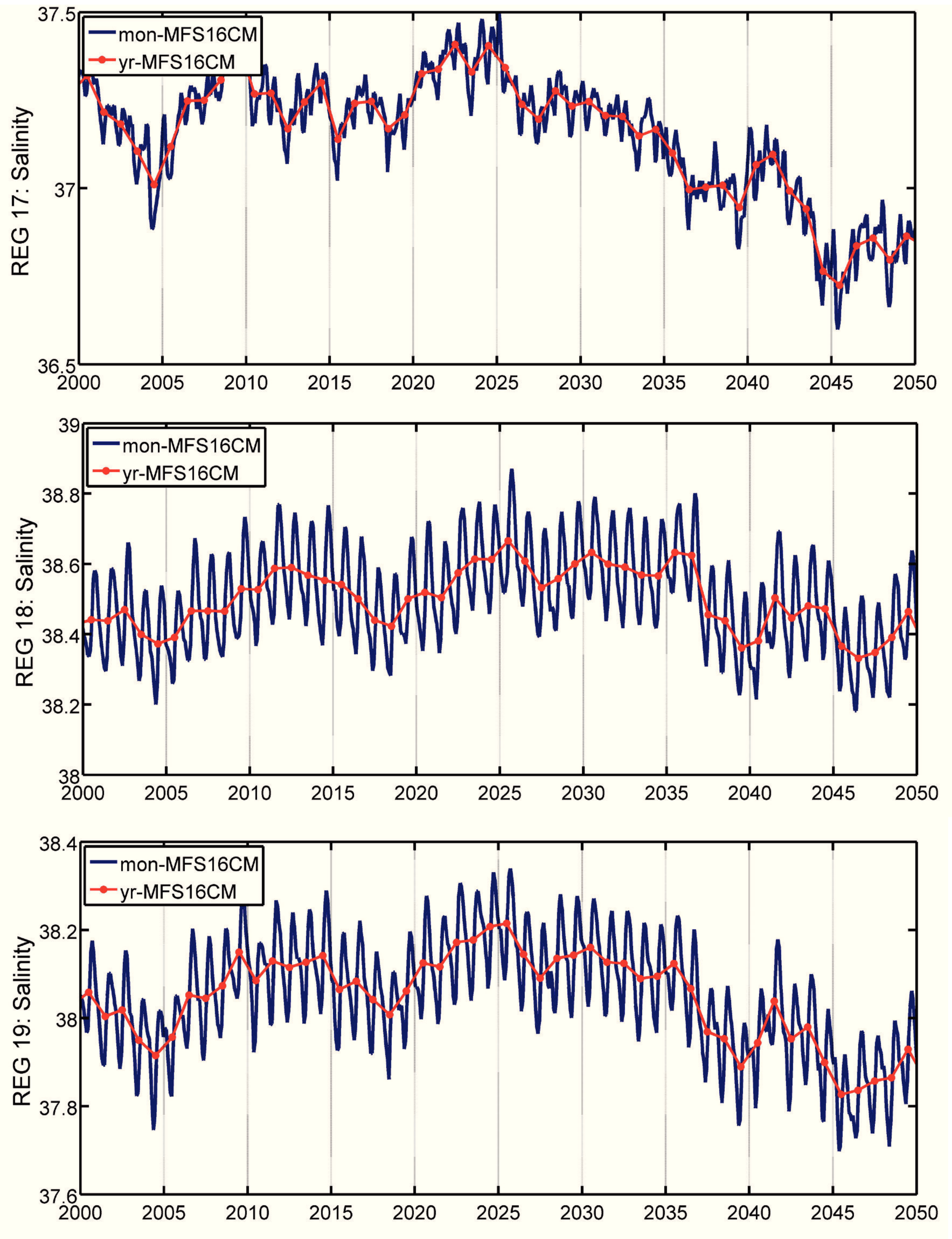

Figure 9. Time series of the sea surface salinity of the scenario MFS16 simulation (MFS16CM) for the Western basin (top, Reg. 17), Eastern basin (middle, Reg. 18), and the whole Mediterranean Sea (bottom, Reg. 19). The spatial domain of each region is illustrated in Fig. 1.

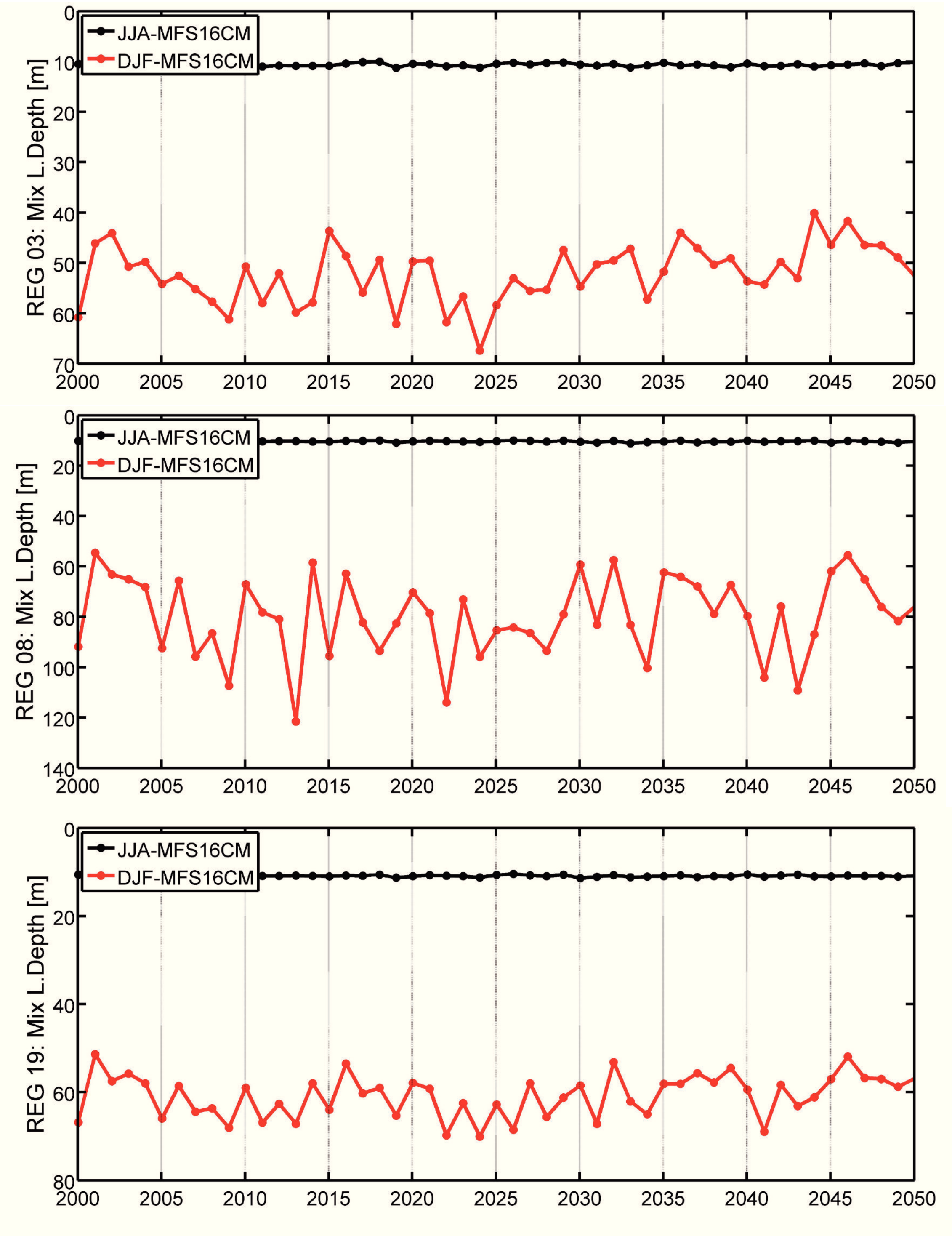

Figure 10. Time series of summer (JJA) and winter (DJF) seasonal Mixed Layer Depths of the scenario MFS16 simulation (MFS16CM) for the Provencal basin (top, Reg. 3), Ionian Sea (middle, Reg. 8), and the whole Mediterranean Sea (bottom, Reg. 19). The spatial domain of each region is illustrated in Fig. 1.

SYNTHESIS OF FUTURE SCENARIO EVOLUTION AT REGIONAL SCALE

In this section, the evolution of Sea Surface Temperature (Tab. 3), Sea Surface Salinity (Tab. 4), and winter (DJF) Mixed Layer Depth (Tab. 5) for each region of the Mediterranean Sea is synthesized by means of descriptive statistics. The selected metrics were computed for 5 decades in the period 2000-2050

Table 3. Descriptive statistics of the decadal Sea Surface Temperature (SST, °C) simulated monthly data for the different marine regions depicted in Fig. 1. The metrics computed for each decade are: mean, standard deviation, and range (the period averaged value of the annual minimum-maximum range).

SST	2000-2009			2010-2019			2020-2029			2030-2039			2040-2049		
[°C]	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range
01_ALB	18.70	3.37	9.38	19.02	3.31	9.09	19.26	3.42	9.84	19.18	3.33	9.39	19.15	3.37	9.50
02_ALG	19.53	4.29	11.79	19.84	4.31	11.71	20.09	4.41	12.36	20.16	4.23	11.74	20.25	4.32	11.89
03_PROV	18.44	4.52	12.39	18.80	4.53	12.22	19.06	4.69	12.94	19.14	4.41	12.17	19.35	4.52	12.23
04_TYR	19.30	4.78	13.23	19.74	4.76	12.87	19.92	4.93	13.56	20.08	4.56	12.63	20.14	4.71	12.95
05_SICS	19.54	4.50	12.37	19.96	4.59	12.61	20.10	4.64	12.95	20.24	4.43	12.41	20.34	4.54	12.57
06_NADR	17.43	5.64	15.99	18.03	5.63	15.56	18.24	5.77	16.10	18.34	5.53	15.74	18.53	5.59	15.46
07_SADR	18.75	4.65	12.90	19.37	4.57	12.61	19.55	4.75	13.10	19.62	4.45	12.52	19.80	4.52	12.50
08_ION	20.16	4.67	12.73	20.70	4.66	12.65	20.81	4.80	13.02	20.97	4.48	12.17	21.14	4.58	12.42
09_SICC	20.67	4.64	12.76	21.08	4.70	12.83	21.22	4.80	13.36	21.45	4.51	12.55	21.53	4.68	12.82
10_CMED	21.18	4.34	11.84	21.61	4.43	12.27	21.69	4.47	12.30	22.05	4.23	11.65	22.09	4.39	12.10
11_AEG	19.72	3.91	10.70	20.08	3.98	11.11	20.11	3.89	10.71	20.65	3.91	10.69	20.65	3.94	10.95
12_CREC	21.00	3.95	10.69	21.32	4.00	10.97	21.44	4.01	10.89	21.88	3.95	10.62	21.90	4.00	10.95
13_NLEV	21.32	4.24	11.53	21.79	4.31	11.68	21.94	4.36	11.75	22.41	4.25	11.36	22.46	4.28	11.64
14_SLEV	21.99	4.21	11.38	22.43	4.26	11.59	22.60	4.31	11.53	23.05	4.15	11.21	23.02	4.24	11.58
15_ELEV	22.70	4.48	12.24	23.07	4.58	12.55	23.19	4.53	12.15	23.81	4.46	12.10	23.81	4.59	12.61
16_ADR	18.33	4.96	13.86	18.94	4.90	13.50	19.13	5.07	14.02	19.21	4.79	13.51	19.39	4.85	13.42
17_WMED	19.07	4.39	12.12	19.44	4.40	11.89	19.67	4.53	12.60	19.75	4.28	11.85	19.86	4.39	12.04
18_EMED	21.08	4.29	11.68	21.50	4.36	12.01	21.61	4.40	11.99	22.01	4.22	11.53	22.05	4.33	11.89
19_MEDS	20.26	4.35	11.91	20.67	4.40	12.02	20.82	4.47	12.29	21.10	4.26	11.71	21.17	4.37	12.01

Table 4. Descriptive statistics of the decadal Sea Surface Salinity (SSS) simulated monthly data for the different marine regions depicted in Fig. 1. The metrics computed for each decade are: mean, standard deviation, and range (the period averaged value of the annual minimum-maximum range).

SSS	2000-2009			2010-2019			2020-2029			2030-2039			2040-2049		
	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range
01_ALB	35.66	0.13	0.17	35.68	0.06	0.14	35.70	0.11	0.15	35.41	0.10	0.14	35.09	0.13	0.18
02_ALG	36.13	0.17	0.27	36.10	0.12	0.27	36.25	0.20	0.30	35.86	0.20	0.33	35.56	0.17	0.33
03_PROV	36.85	0.15	0.24	36.84	0.10	0.25	36.93	0.16	0.29	36.71	0.15	0.27	36.46	0.19	0.34
04_TYR	37.45	0.13	0.23	37.50	0.13	0.22	37.62	0.10	0.21	37.40	0.12	0.25	37.20	0.22	0.34
05_SICS	37.67	0.13	0.29	37.75	0.13	0.31	37.80	0.12	0.29	37.70	0.15	0.29	37.52	0.17	0.34
06_NADR	37.36	0.17	0.37	37.40	0.14	0.37	37.45	0.14	0.37	37.32	0.20	0.46	37.10	0.20	0.47
07_SADR	37.76	0.69	1.89	38.07	0.76	1.84	38.24	0.60	1.63	38.13	0.69	1.90	38.26	0.61	1.53
08_ION	38.60	0.12	0.23	38.85	0.15	0.32	38.88	0.10	0.22	38.86	0.11	0.27	38.85	0.11	0.21
09_SICC	38.57	0.13	0.26	38.74	0.13	0.27	38.80	0.13	0.28	38.69	0.13	0.27	38.63	0.18	0.33
10_CMED	37.43	0.18	0.41	37.49	0.17	0.39	37.58	0.18	0.40	37.46	0.23	0.43	37.24	0.22	0.47
11_AEG	38.18	0.11	0.28	38.34	0.13	0.30	38.35	0.12	0.29	38.31	0.14	0.26	38.16	0.15	0.29
12_CREC	38.39	0.29	0.84	38.42	0.28	0.78	38.49	0.31	0.74	38.60	0.30	0.74	38.45	0.29	0.72
13_NLEV	38.84	0.18	0.47	38.93	0.17	0.43	39.00	0.18	0.49	39.04	0.18	0.49	38.90	0.17	0.43
14_SLEV	39.06	0.14	0.35	39.12	0.15	0.38	39.16	0.15	0.39	39.23	0.15	0.38	39.06	0.15	0.37
15_ELEV	38.86	0.18	0.45	38.91	0.21	0.46	38.96	0.19	0.46	38.99	0.18	0.45	38.83	0.20	0.49
16_ADR	38.95	0.15	0.36	38.97	0.16	0.39	39.05	0.14	0.35	39.10	0.16	0.34	38.92	0.19	0.40
17_WMED	38.33	0.27	0.70	38.60	0.31	0.75	38.67	0.24	0.64	38.63	0.26	0.70	38.66	0.24	0.60
18_EMED	37.20	0.11	0.17	37.23	0.07	0.17	37.32	0.08	0.17	37.12	0.10	0.15	36.90	0.14	0.20
19_MEDS	38.43	0.11	0.30	38.53	0.12	0.32	38.58	0.12	0.33	38.57	0.12	0.30	38.41	0.12	0.31

Table 5. Descriptive statistics of the decadal winter (DJF) Mixed Layer Depth (MLD,m) simulated monthly data for the different marine regions depicted in Fig. 1. The metrics computed for each decade are: mean, standard deviation, and range (minimum-maximum range of the period).

MLD (DJF)	2000-2009			2010-2019			2020-2029			2030-2039			2040-2049		
[m]	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range	Mean	Std	Range
01_ALB	51.87	5.34	15.56	51.78	5.15	15.68	51.11	3.26	9.12	49.30	2.73	6.99	44.19	4.57	15.00
02_ALG	35.03	4.01	12.37	36.58	3.68	10.23	34.58	3.97	11.08	31.70	3.58	9.67	30.19	4.91	13.97
03_PROV	44.27	1.82	5.01	44.61	4.41	11.68	48.86	4.18	11.33	43.93	4.70	14.97	41.52	4.09	10.82
04_TYR	51.28	4.59	13.60	53.14	5.66	16.19	57.20	5.47	17.88	49.65	3.94	13.31	47.28	4.99	14.21
05_SICS	58.95	5.17	14.99	61.94	3.51	10.16	62.84	4.55	13.04	59.76	6.34	17.01	58.09	4.38	13.35
06_NADR	45.75	3.72	13.18	46.43	5.36	14.92	51.93	3.74	10.12	45.83	4.16	12.52	45.44	5.15	16.39
07_SADR	39.10	2.10	5.95	38.64	1.77	4.59	39.35	1.78	6.01	38.66	2.09	6.52	38.69	1.64	5.08
08_ION	95.49	18.34	48.59	109.34	14.05	42.79	110.07	11.02	27.40	101.45	14.38	40.40	100.83	14.10	42.82
09_SICC	73.96	15.36	41.26	84.18	19.90	63.02	88.88	12.52	40.93	74.68	14.28	42.87	79.37	19.45	53.51
10_CMED	45.82	3.06	7.93	44.93	3.92	11.12	48.32	2.87	8.91	45.00	3.36	11.44	44.73	5.45	19.17
11_AEG	58.70	5.75	16.41	60.34	5.78	14.76	62.83	4.19	12.87	57.54	4.18	14.32	58.88	5.70	17.98
12_CREC	91.29	12.42	32.21	91.09	13.02	39.36	94.65	11.44	29.95	95.82	13.66	43.05	93.17	6.80	19.95
13_NLEV	61.93	4.07	12.41	60.17	7.37	16.66	66.65	7.60	22.38	61.48	7.47	25.52	61.53	5.27	16.68
14_SLEV	66.30	6.89	18.85	70.03	8.28	22.02	71.75	11.69	36.49	67.10	9.29	25.08	68.79	6.04	16.79
15_ELEV	56.67	4.25	12.54	57.14	4.88	11.03	62.12	8.13	21.19	58.73	7.60	22.09	57.62	7.18	21.27
16_ADR	65.92	5.66	17.88	66.38	4.04	11.33	70.18	8.96	27.98	66.27	9.14	24.81	66.32	6.44	18.41
17_WMED	77.48	12.41	33.93	86.77	9.76	30.02	87.48	7.62	19.62	81.40	9.87	27.34	80.99	9.78	29.31
18_EMED	49.23	2.87	7.47	50.82	4.05	10.28	53.66	3.62	9.48	48.55	3.89	11.03	46.54	3.86	12.28
19_MEDS	63.54	6.04	16.96	65.23	6.46	16.67	68.70	6.13	16.63	63.98	6.36	19.84	64.56	6.34	19.13

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