Product Information Document (PIDoc)

SeaDataCloud Temperature and Salinity Climatology for the Black Sea (Version 1)

SDC_BLS_CLIM_TS_V1

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SDC_BLS_CLIM_TS_V1

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SeaDataCloud Temperature and Salinity Climatologies for the Black Sea (Version 1)

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Short description

The SDC_BLS_CLIM_TS_V1 product contains Temperature and Salinity Climatologies for Black Sea including seasonal and monthly fields covering the 3 time spans: 1955-1994, 1995-2017, and 1955-2017 and seasonal fields for 6 decades starting from 1955 to 2014. The climatological fields were computed from the merged Black Sea dataset that combines data extracted from 3 major sources: 1) SeaDataNet infrastructure, 2) World Ocean Database 2018, and 3) Coriolis Ocean Dataset for Reanalysis. The computation was done with the DIVAnd (Data-Interpolating Variational Analysis in n dimensions), version 2.3.1.

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	C. Troupin	16/07/2019	Revision
	V. Myroshnychenko	16/07/2019	Final release
	M. Fichaut	23/07/2019	Addition of the "How to cite" and "product DOI " info

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Abstract

The SDC_BLS_CLIM_TS_V1 product contains Temperature and Salinity Climatologies for the Black Sea including seasonal and monthly fields covering 3 time spans: 1955-1994, 1995-2017, and 1955-2017 and seasonal fields for 6 decades starting from 1955 to 2014. The climatological fields were computed from the merged Black Sea dataset that combines data extracted from 3 major sources: 1) SeaDataNet infrastructure, 2) World Ocean Database 2018, and 3) Coriolis Ocean Dataset for Reanalysis. The computation was done with the DIVAnd (Data-Interpolating Variational Analysis in n dimensions), version 2.3.1.

1. Data

The input dataset for computation of the Black Sea Temperature and Salinity climatological fields includes data retrieved from the SeaDataCloud (1) internal data source – the SeaDataNet infrastructure – that were integrated with the data from external data sources. Data have been integrated from the following datasets:

1. SeaDataCloud (SDC) Temperature and Salinity Historical Data Collection for the Black Sea (Version 1) - SDC_BLS_DATA_TS_V1 (2).
2. SeaDataCloud Restricted Temperature and Salinity Historical Data Collection for the Black Sea (Version 1) - SDC_BLS_DATA_TS_V1_RESTRICTED.
3. Data extracted from the World Ocean Database 2018 - WOD18 (3).
4. Data extracted from the COriolis Ocean Dataset for Reanalysis - CORA 5.1 (4).

1.1. Source datasets

1.1.1. SeaDataCloud Temperature and Salinity Historical Data Collection for the Black Sea

The SeaDataCloud Temperature and Salinity Historical Data Collection for the Black Sea contains temperature and salinity data of the water body (profiles, surface and underway measurements) retrieved from the SeaDataNet infrastructure at the end of 2017. The detailed description of the collection is provided in (5).

All data in the collection have been quality controlled according to procedures described in (5). The duplicates and bad data (e.g. stations on land, empty depth levels and empty profiles) were excluded from the collection. The collection covers the period 1868 – 2017.

Table 1.1 Data Statistics: total numbers.

	Cruises	Stations			Values
		All	Profiles	Underway	
All samples	2286	137723	119160	18563	4240346
Temperature	2282	137370	118807	18563	4238207
Salinity	2116	129731	111168	18563	4111531

Spatial and temporal distributions of data are presented in Figure 1.1 and Figure 1.2. The data are practically absent in the Sea of Azov. The data gaps also can be observed along the southern coastline.

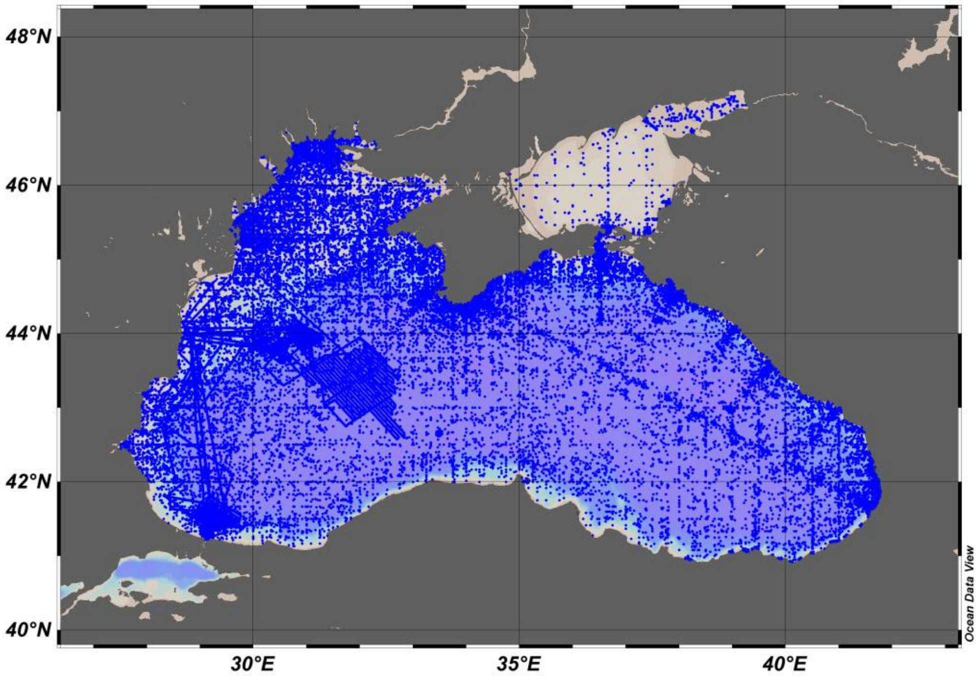


Figure 1.1 Spatial distribution of observations

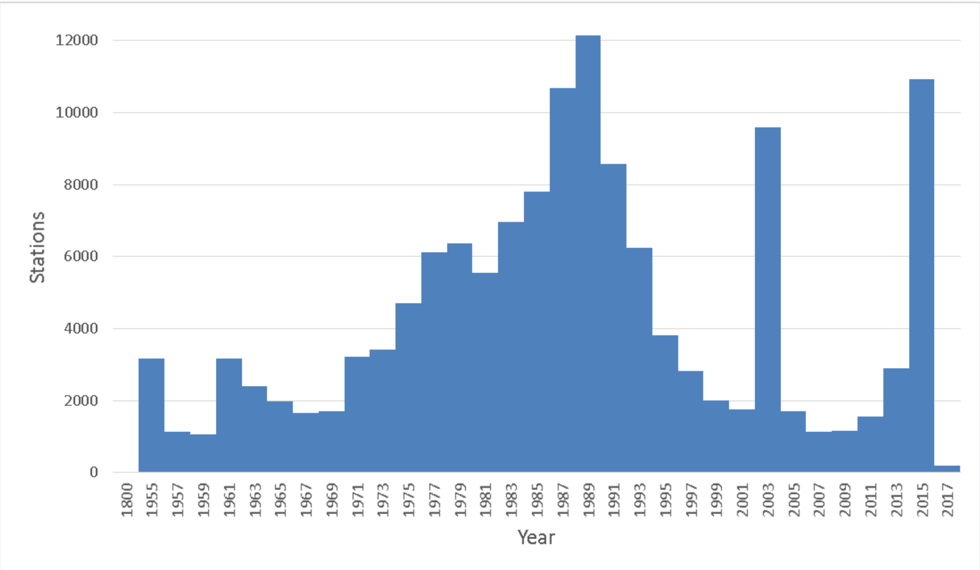
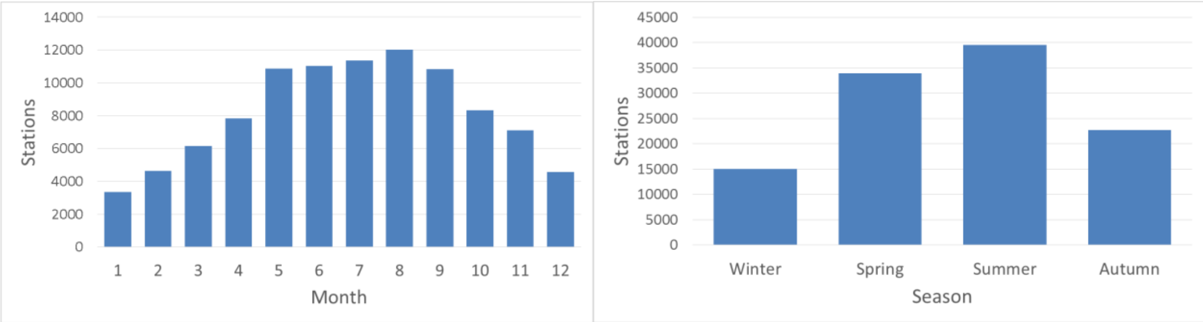


Figure 1.2 Temporal distribution of observations

The number of observations before 1955 is rather small – just about 3000. The most intensive oceanographic observations were performed in the Black Sea in the period 1970 – 1995. The peaks in 2002 and in 2015 represent underway data from two cruises.

The monthly and seasonal distributions, as expected, have dome-like shape with maximum number of stations in summer and minimum in winter (Figure 1.3).



a) b)

Figure 1.3 Monthly (a) and seasonal (b) distributions of observations (excluding underway data).

1.1.2. SeaDataCloud Restricted Temperature and Salinity Historical Data Collection

The SeaDataCloud Restricted Temperature and Salinity Historical Data Collection for the Black Sea contains data on temperature and salinity of water body retrieved from the SeaDataNet infrastructure at the end of 2017. All data in the collection have been quality controlled according to procedures described in (5).

The collection covers the period 1985 – 2016. Spatial and temporal distributions of data are presented in Figure 1.4 and Figure 1.5. Since the collection includes only restricted data, the data coverage is rather scarce. However it should be noted, as it has been combined with the SDC_BLS_DATA_TS_V1 collection, it fills data gaps along the southern coast but not in the Sea of Azov.

The monthly distribution of restricted data is uneven, while the seasonal distribution displays dome-like shape with maximum in summer and minimum in winter (Figure 1.6).

Table 1.2 Data Statistics related to the SDC restricted dataset.

Cruises	Stations	All samples	Temperature values	Salinity values
356	10528	770730	770172	770497

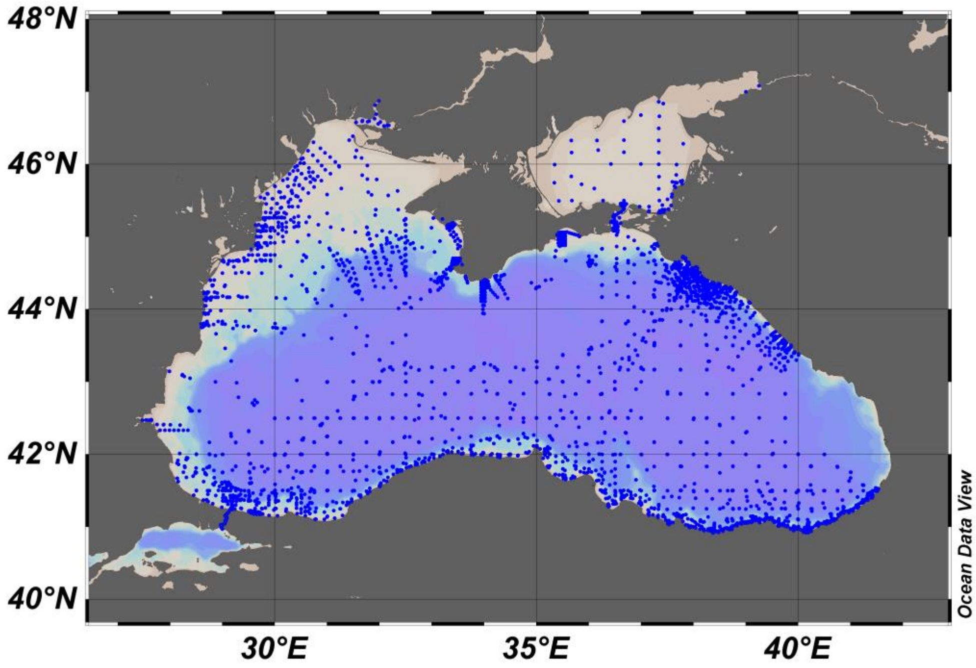


Figure 1.4 Spatial distribution of SDC restricted observations.

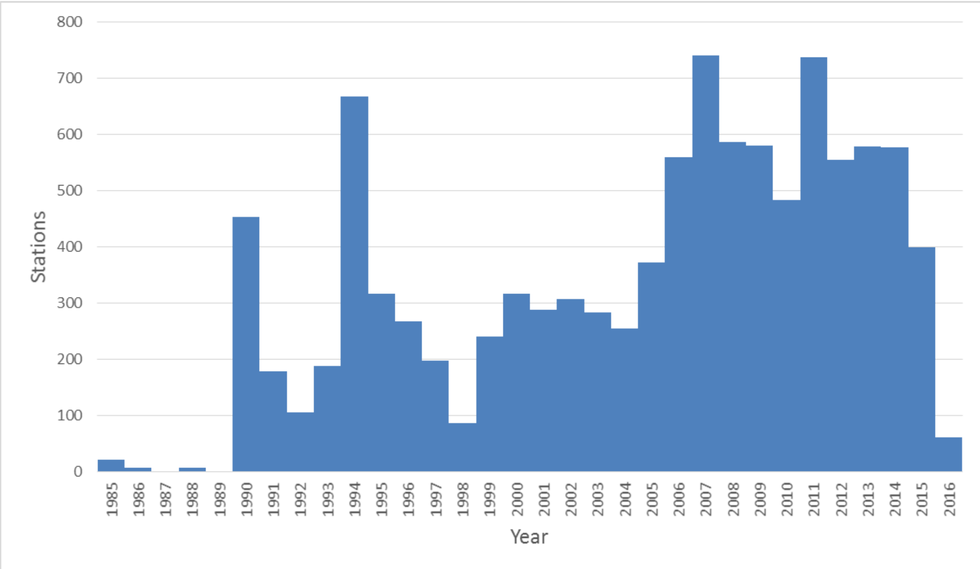
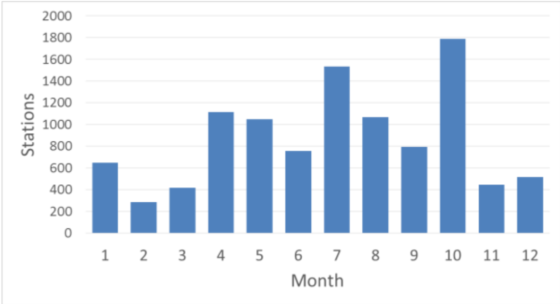


Figure 1.5 Temporal distribution of SDC restricted observations.

(a) 

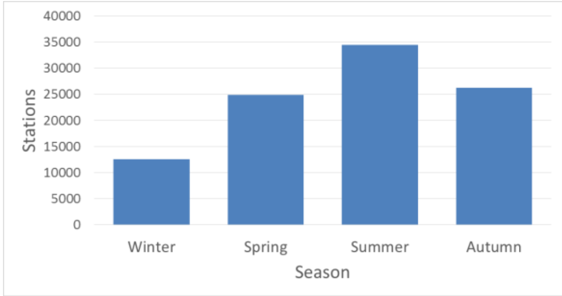
(b) 

Figure 1.6 Monthly (a) and seasonal (b) distributions of observations (excluding underway data)

1.1.3. World Ocean Database 2018

The Black Sea Temperature and Salinity data were downloaded from the WOD18 website (https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html) and imported to ODV (6) collection.

Table 1.3 Data Statistics

Period	Stations	All samples	Temperature values	Salinity values
1890-2018	118780	5419176	5367036	5156030

Spatial and temporal distributions of data are presented in Figure 1.7 and Figure 1.8. The whole Black Sea including the Sea of Azov is evenly covered by observations. The number of observations before 1955 is significant: > 23,000 stations, however these data are out of scope of the current work, which covers the period 1955-2017. The temporal distribution of data in that period is similar to the distribution of data from the SeaDataCloud collection excluding underway data (see Figure 1.2). The majority of data comes from the period 1970 – 1995 when the most intensive oceanographic monitoring campaigns were performed in the Black Sea.

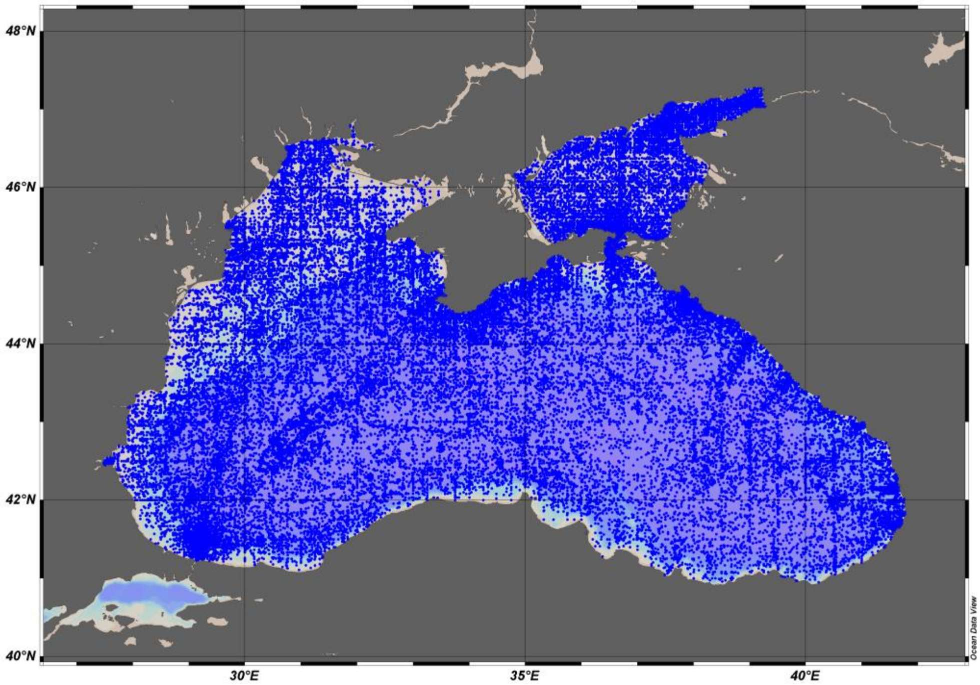


Figure 1.7 Spatial distribution of WOD18 observations

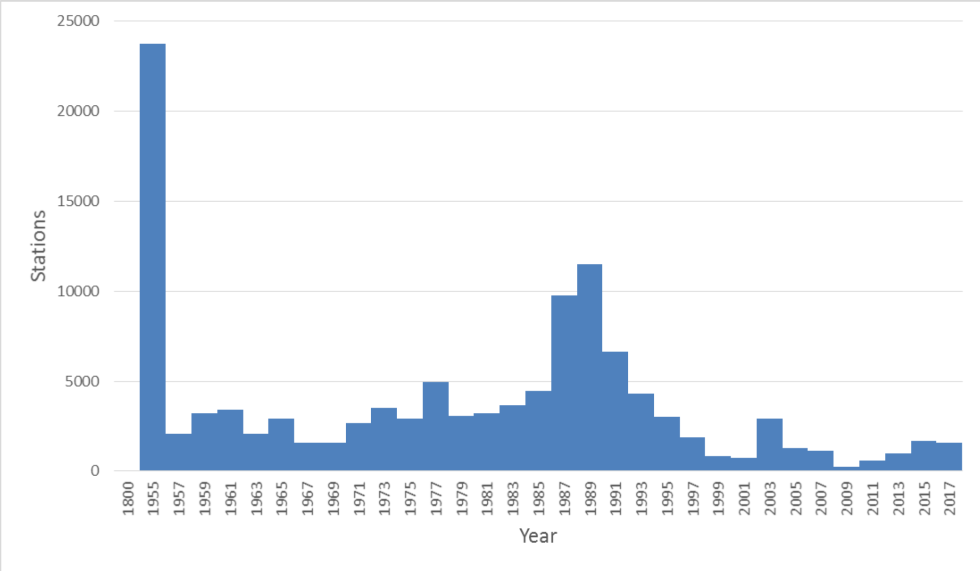
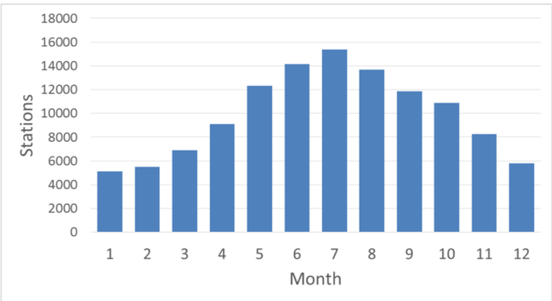


Figure 1.8 Temporal distribution of WOD18 observations.

The monthly and seasonal distributions, as expected, have dome-like shape with maximum in summer and minimum in winter (Figure 1.9).

(a) 

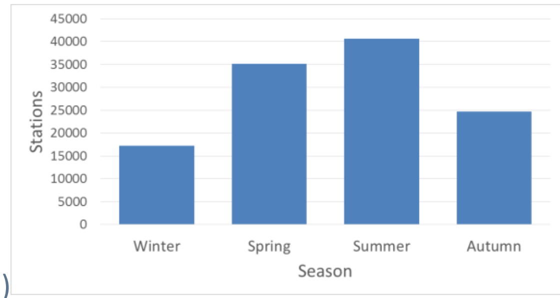
(b) 

Figure 1.9 Monthly (a) and seasonal (b) distribution of observations

1.1.4. COriolis Ocean Dataset for Reanalysis (CORA 5.1)

The CORA 5.1 Black Sea Temperature and Salinity data were obtained from the COPERNICUS Marine and Environment Monitoring Service (http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=INSITU_GLO_TS_REP_OBSERVATIONS_013_001_b), product INSITU_GLO_TS_REP_OBSERVATIONS_013_001_b. The data that come as a set of NetCDF files in ARGO 3.0 format (7) were reformatted to ODV spreadsheet and imported to ODV collection for QC and analysis. The statistics in Table 1.4 are provided for the dataset that was cleaned from non-relevant data (on land, out of Black Sea domain, in estuaries).

Table 1.4 Data Statistics

Period	Stations	All samples	Temperature values	Salinity values
1955-2017	111070	5552399	4672477	5156030

Spatial and temporal distributions of data are presented in Figure 1.10 and Figure 1.11. The majority of stations in CORA 5.1 Black Sea dataset are coming from the underway observations, which tracks are well recognized in the spatial distribution plot. Though the number of underway stations is high (~60000, or more than 55%), the respective amount of data is relatively low because usually there is only 1 sample per station. The temporal distribution of data is uneven with very little amount before 1980s.

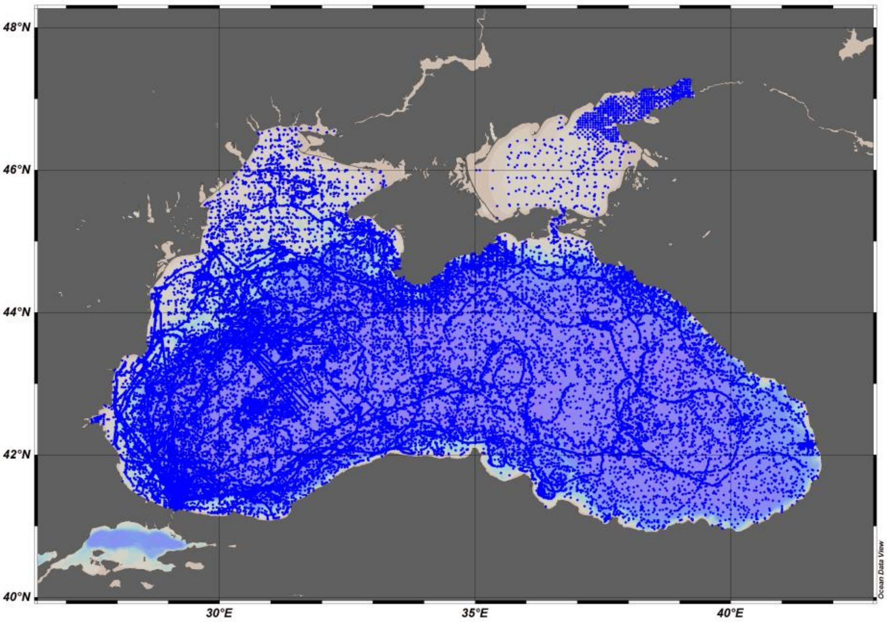


Figure 1.10 Spatial distribution of CORA 5.1 observations.

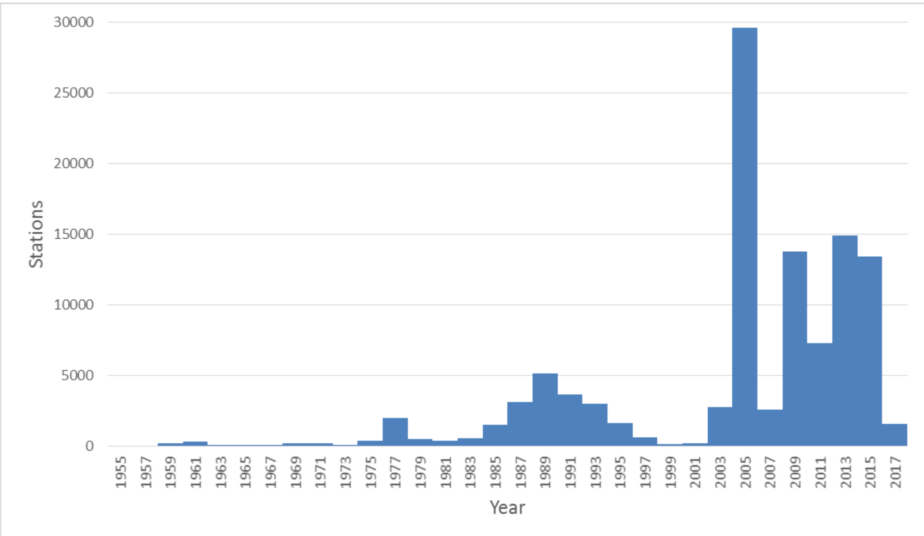


Figure 1.11 Temporal distribution of CORA 5.1 observations

The monthly and seasonal distributions of observations are uneven being dependent on timing and frequency of underway measurements (Figure 1.12).

(a) (b)

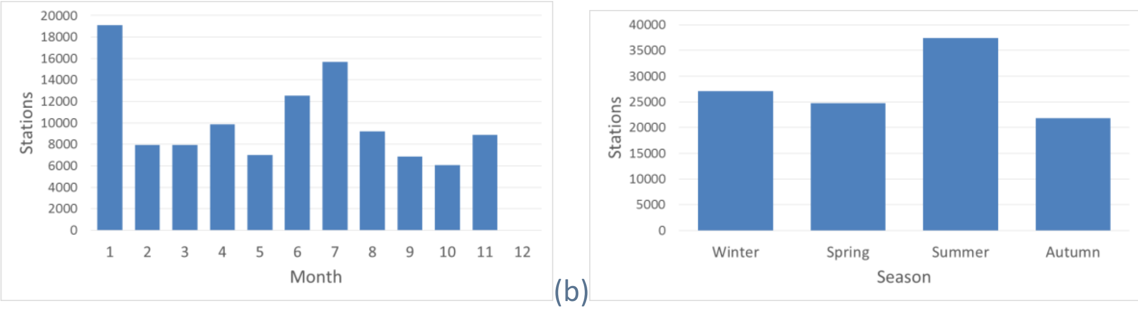


Figure 1.12 Monthly (a) and seasonal (b) distributions of observations

1.2. Integrated dataset

Datasets integration was performed through the following steps:

- Excluding internal duplicates
  - 0 in SDC datasets which have been already cleaned from duplicates
  - 1128 in WOD18
  - 20091 in CORA 5.1
- Identifying and excluding overlapping data
  - in WOD18 46515 stations overlapping with SDC
  - in CORA 5.1 8698 stations overlapping with SDC and 25149 overlapping with WOD18
- Merging non-overlapping data
- Excluding climatically non-relevant data, i.e. those acquired in river estuaries or in adjacent lakes (called “limans” in Black Sea region)

In the merging procedure:

- The SDC_BLS_DATA_TS_V1 dataset was taken as a primary,
- The SDC_BLS_DATA_TS_V1_Restricted dataset was added as it is,
- Then the non-overlapping part of the WOD18 dataset was added, and, finally
- Non-overlapping part of the CORA dataset was added.

The content of the resulted integrated Black Sea Temperature and Salinity dataset is provided in Table 1.5. The climatology products are being calculated for the period 1955 – 2017, therefore the statistics are provided for the whole dataset, and for subset 1955 - 2017 - further “climatology dataset”.

Both SDC datasets are represented in the integrated dataset practically completely, while from WOD18 and CORA 5.1 61% and 52% of data were included respectively. The main reason for no inclusion is duplicates.

In the Black Sea climatology dataset 57% of observations (stations) originate from two SDC datasets while the WOD18 and CORA 5.1 are contributing approximately equally to the remaining 43%.

Table 1.5 Content of integrated dataset

	Period	SDC unrestricted	SDC restricted	WOD18	CORA 5.1	Total
Original datasets		137723	10528	118780	111070	
Integrated dataset	1868-2018	133332	10285	71469	57847	272933
% of each sub-set		**49%**	**4%**	**26%**	**21%**	
Climatology data set	1955-2017	130466	10285	48227	57847	246825
% of each sub-set		**53%**	**4%**	**20%**	**23%**	

1.2.1. General characteristics of the climatology dataset

The climatology dataset contains both profiles and underway data (Table 1.6). The spatial and temporal distribution of profiles and underway data in the integrated dataset for period 1955 - 2017 is presented in Figure 1.13 - Figure 1.17. The profile observations quite evenly cover the Black Sea domain, while the underway observations exhibit significant irregularity.

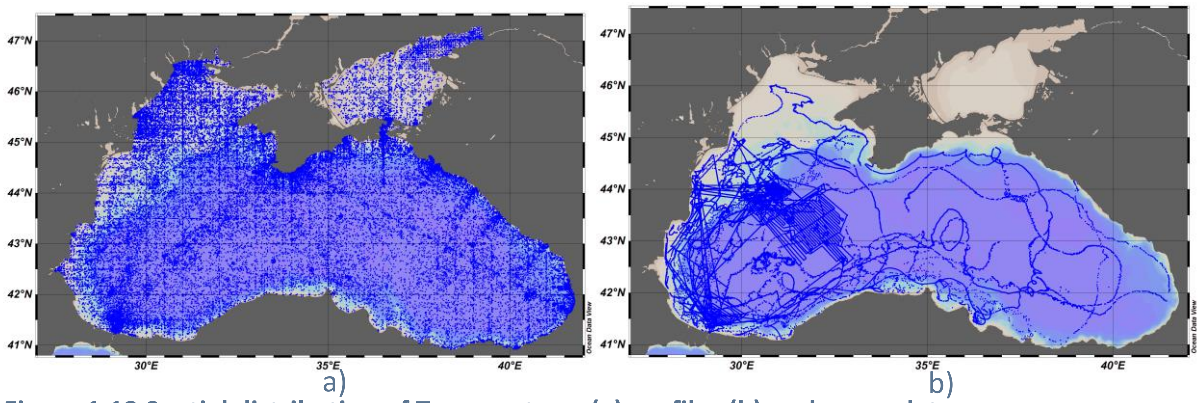


Figure 1.13 Spatial distribution of Temperature: (a) profiles (b) underway data.

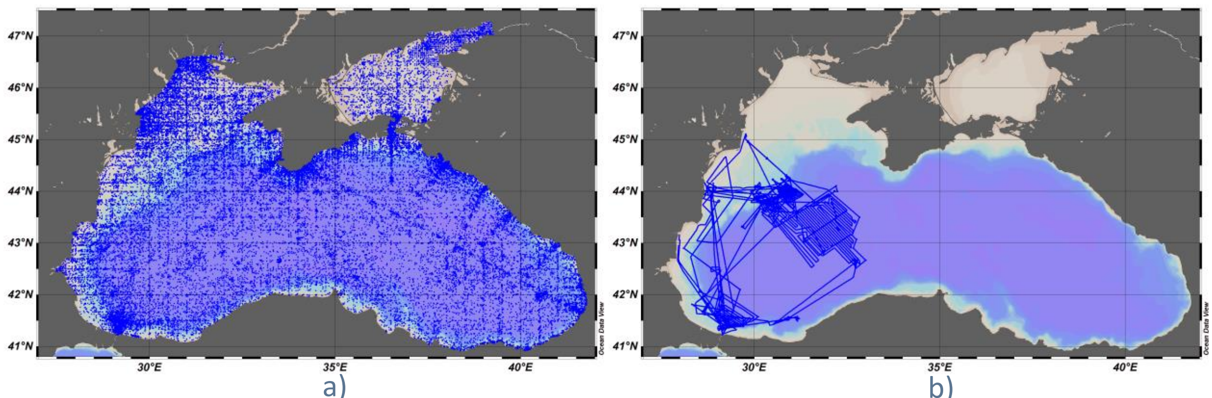


Figure 1.14 Spatial distribution of Salinity: (a) profiles (b) underway data.

The temporal distribution of observations in the integrated dataset for climatology is irregular with the largest number of profiles obtained in 1980 – 1990-es, and peaks of underway data in the last 2 decades.

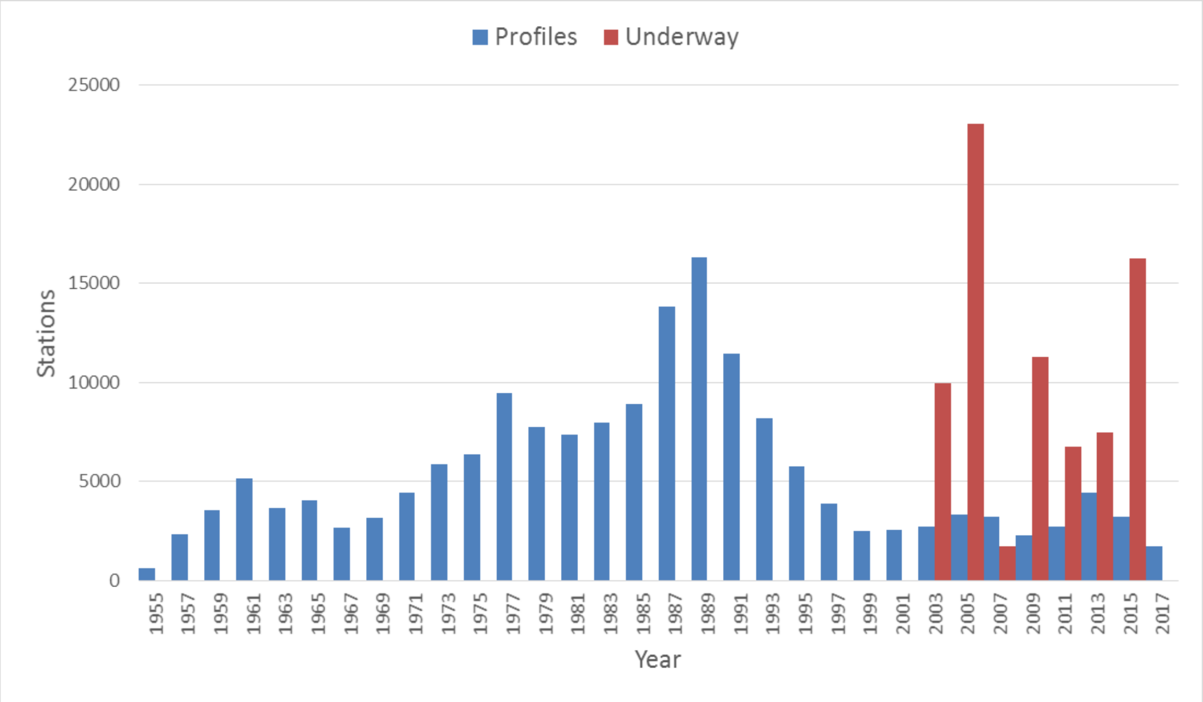


Figure 1.15 Temporal distribution of observations

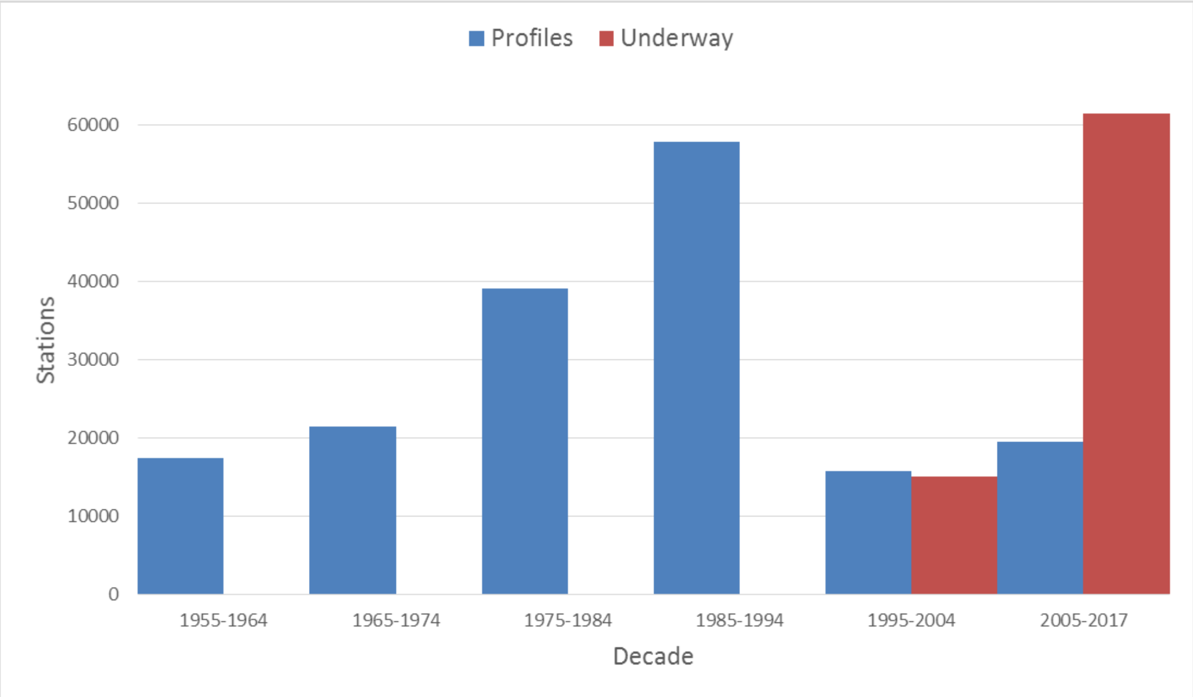
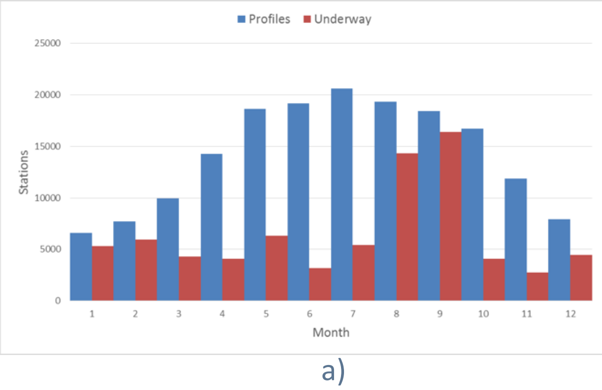


Figure 1.16 Decadal distribution of observations



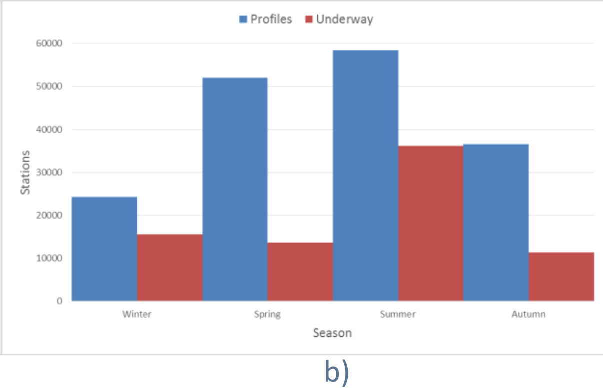


Figure 1.17 Monthly (a) and seasonal (b) distributions of observations for the period 1955 - 2017

The monthly and seasonal distributions of profiles have expected dome-like shape with maximum in summer (more observations) and minimum in winter (less observations), while the distribution of underway observations is irregular.

Including data from external data sources significantly increased data availability. In certain decades (e.g. 1955-1964) the contribution from external data sources reaches 50% (Figure 1.18).

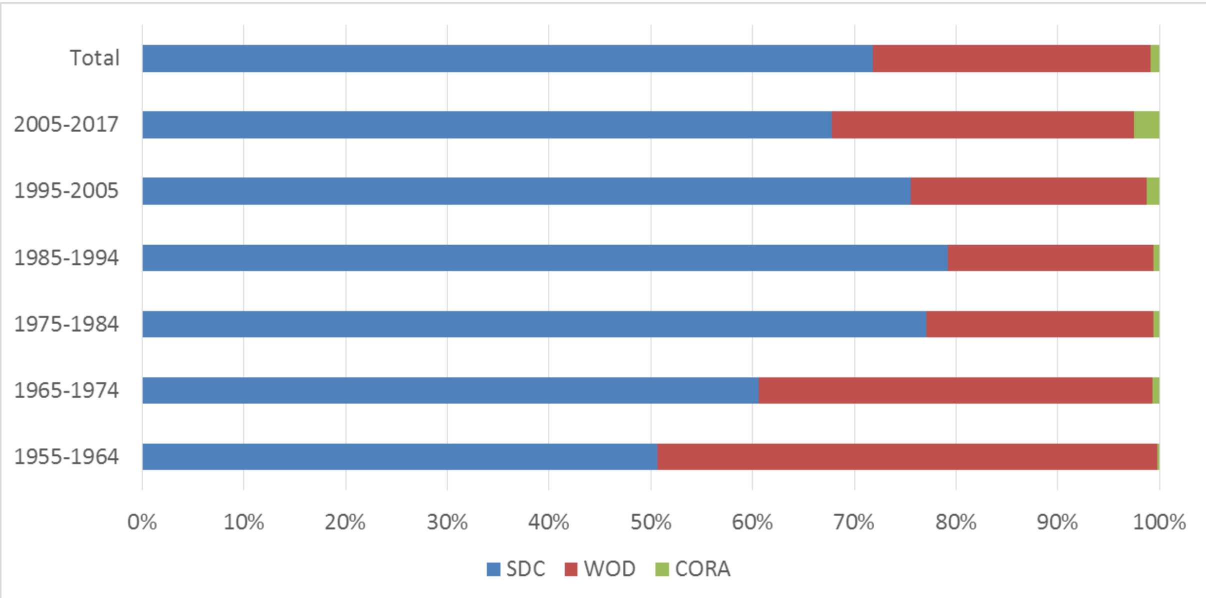


Figure 1.18 Statistics of profiles in the climatology dataset per data source

A more detailed view of decadal data coverage is provided in Figure 1.19 and Figure 1.20 for periods 1955-1965 and 1995-2004 that contain the least amount of data per decade.

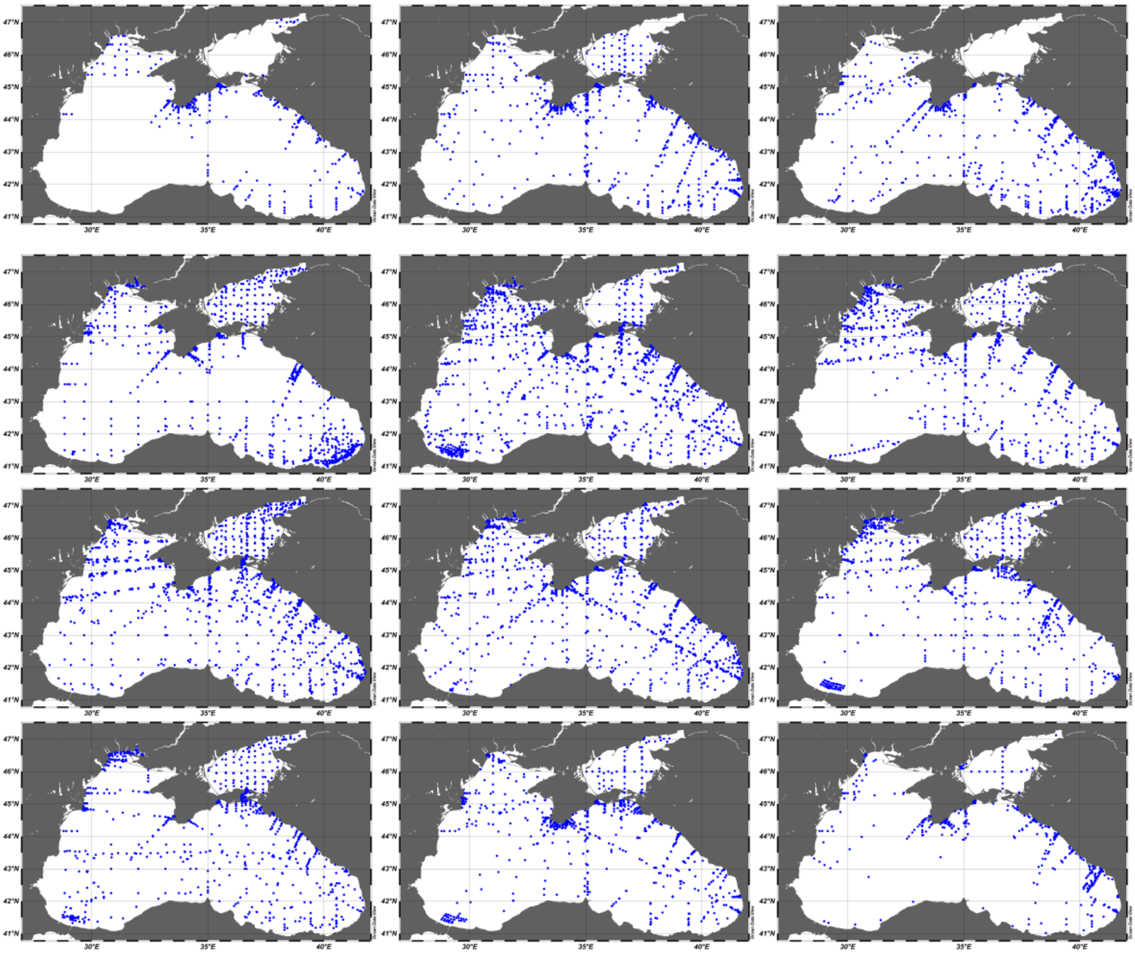


Figure 1.19 Monthly spatial distribution of observations for period 1955 – 1964

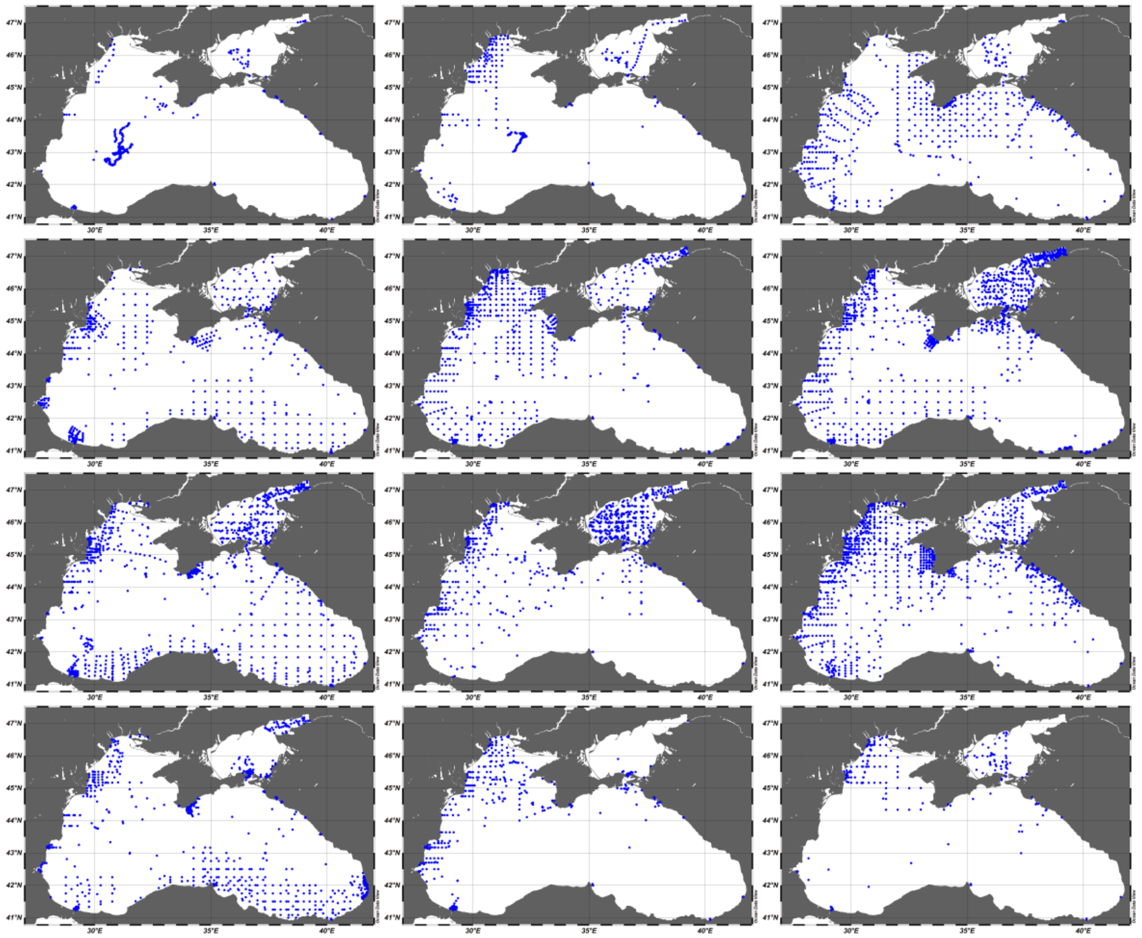


Figure 1.20 Monthly spatial distribution of profiles observations for period 1995 - 2004

During the period 1955 -1964 there are significant data coverage gaps in January and December, less significant gaps are observed in other months too. The situation in the time period 1995-2004 is even worse with serious gaps in data coverage in most of months.

Considering the data availability the following sets of climatic fields were decided to be produced:

1. Seasonal and monthly Temperature and Salinity fields for the whole period 1955 – 2017 and sub-periods 1955 – 1994, 1995 - 2017. (In recent years more and more scientific publications (8, 9) report about climatic changes that Black sea undergoes in last two decades, therefore the two sub-periods were added to climatology set in order to respond to needs of researchers.)
2. Seasonal Temperature and Salinity fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2017.

For vertical grid the depth levels of WOA18 (10) were taken.

1.2.2. Note about underway data

The content of the climatology dataset subdivided per data type is provided in Table 1.6. The majority of underway data are coming from CORA 5.1: almost the whole CORA 5.1 share in the climatology dataset is underway data.

Table 1.6 Content of climatology dataset by data type.

Data type	SDC un restricted	SDC restricted	WOD18	CORA 5.1	Total
Profiles	111902	10285	46644	1450	170281
Underway	18563		1583	56397	76543
Total	130466	10285	48227	57847	246825

Underway data needs to be used with precautions in climatology calculations, as they may be a source for bias and for artificial anomalies in climatic fields. The reason for this is the very irregular distribution of underway data in time and space. Moreover, as the underway data are usually obtained in the surface layer only, they create irregularities in vertical distribution of data as well. The problem can be tackled either by subsampling the data prior to calculations or by decreasing weight of such data in process of calculations. In certain cases it may be necessary to exclude underway data from calculations totally. **As for climatic products described in this document, the underway data were heavily subsampled (only ~5% used).**

2. Methodology

2.1. Data Quality Control

All source datasets underwent quality control (QC) according to procedures used by the respective producers. For example, the QC procedures, which were applied to two SDC datasets, are described in details in (5). Each data value in the source datasets was supplied with the quality flag (11).

The preview of WOD18 and CORA 5.1 datasets with ODV tools revealed presence of a significant number of anomalous data that were originally flagged as good, therefore an additional QC was applied to before data integration in particular:

- Identifying and flagging obvious outliers,
- Identifying and flagging bad profiles,
- Applying a basic range check.

One more issue was revealed in the WOD18 subset: most of temperature values in the thermocline were flagged as "probably bad" perhaps due to high gradient, which in Black Sea goes up to 4 C°/m, why the WOD18 threshold is 0.7. In reality the flagged values are good and they were recovered (i.e. flagged as "good") in order to be utilized in the climatic calculations.

Note about QC of MBT and XBT profiles.

The Climatology dataset contains ~10 000 MBT and XBT profiles originating from WOD18, and ~3000 originating from SDC subsets. It is known issue that most of MBT and XBT profiles require depth correction. Unfortunately the instrument information is missing for 94% of these profiles, therefore the depth correction was not performed. In obvious cases the depth values in profile were flagged as bad resulting in exclusion of the respective temperature values from the climatology calculations.

2.2. DIVA implementation and settings

Computation of the Black Sea Temperature and Salinity climatic fields was done with DIVAnd (12) version 2.3.1. DIVAnd has been implemented in the programming language Julia (https://github.com/gher-ulg/DIVAnd.jl) and is used in conjunction with the Jupyter notebooks (https://jupyter.org/) – the web-based interactive computational environment for creating and sharing documents that contain live code, equations, visualizations and narrative text. This is particularly convenient for climatology generation, because the input files, analysis parameters, visualisations and outputs can be defined directly in a notebook, and also the task of parameters tuning is much easier.

2.2.1. Domain definition

The Black Sea is a semi-enclosed sea connected to the Mediterranean Sea by the narrow Turkish straits system consisting of Bosporus and Dardanelles. The Black Sea domain with boundaries 40.5°N – 47.5°N, 27°E – 42°E includes also the adjacent shallow Sea of Azov at the NE, which is connected to the Black sea via Kerch strait (Figure 2.1).

Figure 2.1 Black Sea

The bottom topography of the Black Sea is bowl-shaped with an average depth of 2000 m in the central part. In the most of the basin the shelf does not exceed 10-15 km width except the NW part. The NW part of Black Sea receives the discharge of the largest rivers of its drainage basin: Danube and Dnieper.

Spatial extent defined for climatology: 27.5° - 41.875°E, 40.875° - 47.25°N.

Horizontal resolution: 1/8°.

Horizontal grid dimensions: 116 x 52

Vertical resolution: 67 depth levels (as in WOA18): 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000, 1050, 1100, 1150, 1200, 1250, 1300, 1350, 1400, 1450, 1500, 1550, 1600, 1650, 1700, 1750, 1800, 1850, 1900, 1950, and 2000 m.

Temporal resolution:

- Monthly for periods
  1955 – 2017;
  1955 – 1994;
  1995 – 2017.
- Seasonal for periods
  1955 – 1964;
  1965 – 1974;
  1975 – 1984;
  1985 – 1994;
  1995 – 2004;
  2005 – 2017;
  1955 – 1994;
  1995 – 2017;
  1955 – 2017.

Seasons definition: months 1, 2, 3 = winter; 4, 5, 6 = spring; 7, 8, 9 = summer; 10, 11, 12 = autumn.

Background field: seasonal for period 1955 – 2014.

2.2.2. DIVAnd settings

Bathymetry: GEBCO 30 sec bathymetry (14) subsampled with 1/4 ratio.

Mask (Figure 2.2) has the same dimensions (116x52x67) as the climatology grid. The mask was produced from the bathymetry, additionally these regions have been masked:

- Sea of Marmara
- Adjacent lakes
- Grid cells with wrong depth (mainly in the Sea of Azov)
- Some isolated grid cells

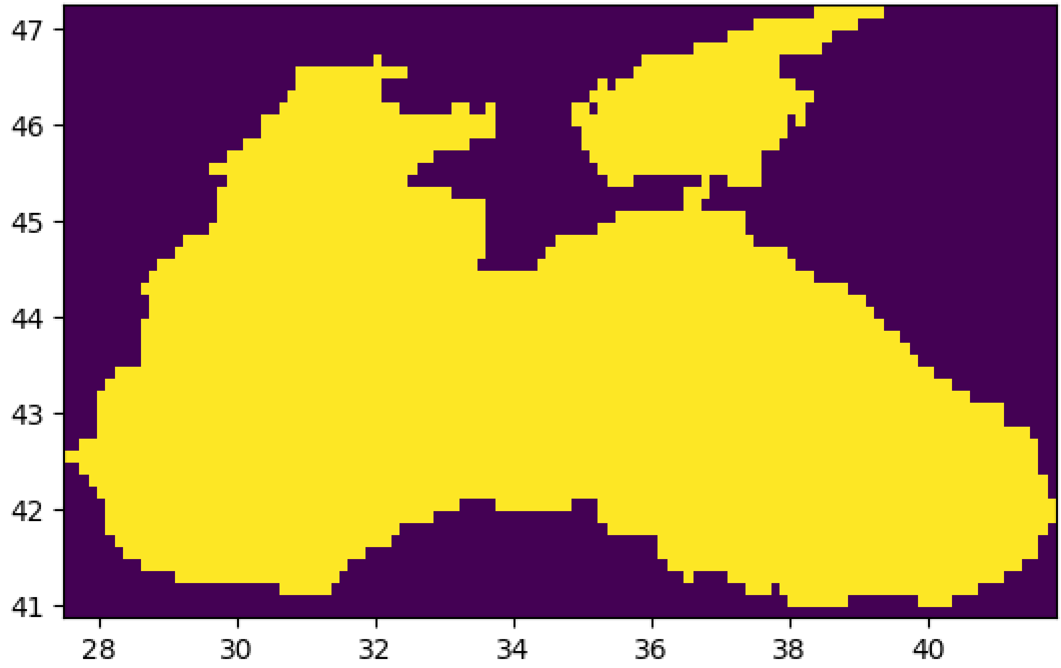


Figure 2.2 Mask at depth = 0 m

DIVAnd parameters

Parameter name	Note	Temperature background field	Salinity background field	Temperature climatology	Salinity climatology
Horizontal correlation length	km	200	200	150	150
Vertical correlation length [m]	depth dependent for 67 levels: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000, 1050, 1100, 1150, 1200, 1250, 1300, 1350, 1400, 1450, 1500, 1550, 1600, 1650, 1700, 1750, 1800, 1850, 1900, 1950, 2000	100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 300, 300, 300, 300, 300, 300, 300	5, 5, 10, 20, 50, 100, 100, 100, 100, 100,100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 300, 300, 300, 300, 300, 300, 300	15, 15, 15, 15, 15, 15, 15, 15, 15, 15, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 25, 30, 40, 50, 50, 50, 50, 50, 50, 50, 50, 50, 70, 80, 100, 100, 100, 100, 100, 100, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 300, 300, 300, 300, 300, 300, 300	15, 15, 15, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10, 15, 15, 15, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 25, 30, 40, 50, 50, 50, 50, 50, 50, 50, 50, 50, 70, 80, 100, 100, 100, 100, 100, 100, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 300, 300, 300, 300, 300, 300, 300
epsilon2		0.5	0.1	0.3	0.1
epsilon2 adjustment	With weights of the observations	weight_RtimesOne (0.1,0.1,20,30)	weight_RtimesOne (0.1,0.1,10,30)	weight_RtimesOne (0.1,0.1,20,30)	weight_RtimesOne (0.1,0.1,10,30)
niter_e	Number of iterations (should be 1 in case of epsilon2 adjustment)	1	1	1	1
MEMTOFIT	Contols memory allocation	250 (for 16 Gb RAM)	250	250	250
solver	"indirect" if not enough memory	direct	direct	direct	direct
fitcorrlen	If "true" then DIVAnd will calculate correlation length	false	false	false	false
surfextend	If "true" then DIVAnd will add extra layer on top to improve the first layer	true	true	true	true
minfield	Minimum of parameter	-1	0	-1	0
background_epsilon2_factor	to better control paramter at depth	0.05	0.05		
coeff_derivative2	small penalty on the 2nd derivative	[0.,0.,1e-9]	[0.,0.,1e-10]	[0.,0.,1e-9]	[0.,0.,5e-11]

2.2.3. A-posteriori Quality Control

DIVAnd provides several options for calculating QC scores for each observation value, which then can be used for discarding outliers. However for the products described in this document we used traditional Three-Sigma criteria, i.e. the data that are out of 3 standard deviations from a mean were considered as outlier candidates. The standard deviation was calculated per depth layer separately for the following sub-regions: Sea of Azov, NW shelf, near Bosporus area, SE area, and the rest of the Black Sea. Then the residuals, obtained with DIVAnd for global (1955 – 2017) monthly fields, were compared with the standard deviation values, and those values, where residual exceeded 3 sigma were flagged with QF=7 (value in excess). The flagged data were then exported into text file in order to substitute the original ones in the climatology dataset. Then the QF assignments were analysed with the help of ODV by expert who took decision which of them to accept and which not. The updated climatology dataset was then reused in next iteration of climatology computation.

3. Climatology

3.1. Brief overview of the Black Sea thermohaline features

The Black Sea has a two-layered structure of the waters (15): surface salinity keeps at about 18 due to freshwater inflow from large rivers, while in deep waters it increases to 22.33. The permanent strong halocline is observed at about 70 – 150 m (Figure 3.1). As a result, the water column is strongly stratified with respect to salinity, and thus density. The only source of salty waters is exchange with Mediterranean through Bosporus strait.

Temperature is seasonally variable at the surface and decreases with depth to a feature called the cold intermediate layer (CIL) with a temperature minimum at about 50m (Figure 3.1) after which temperature gradually increases to ~9.1°C at 2000 m. It should be noted that due to climate change the CIL in recent decade(s) is getting less pronounced.

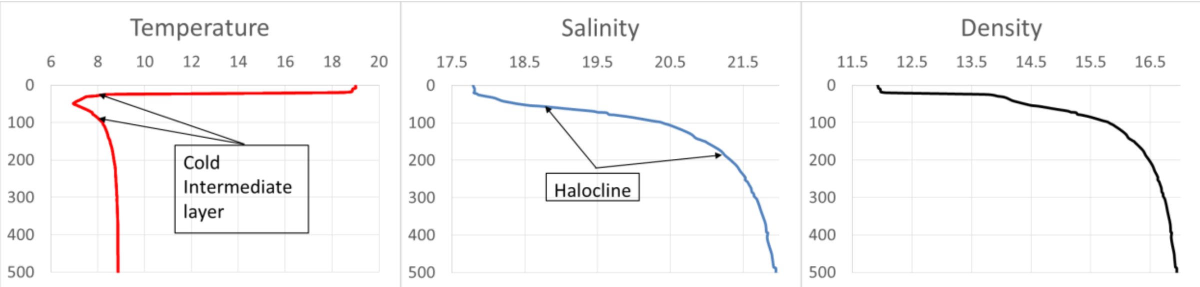


Figure 3.1 Typical Black Sea temperature, salinity, and density profiles.

The most remarkable circulation feature is the cyclonic meandering Rim Current, the interior of which is formed either by one elongated cell covering the entire basin or by two separate cyclonic cells occupying the western and eastern halves of the basin (16). The periphery of the Rim Current is characterized by appearance of eddy processes, some of which are more pronounced and persistent (e.g. Batumi Eddy) as presented in Figure 16.

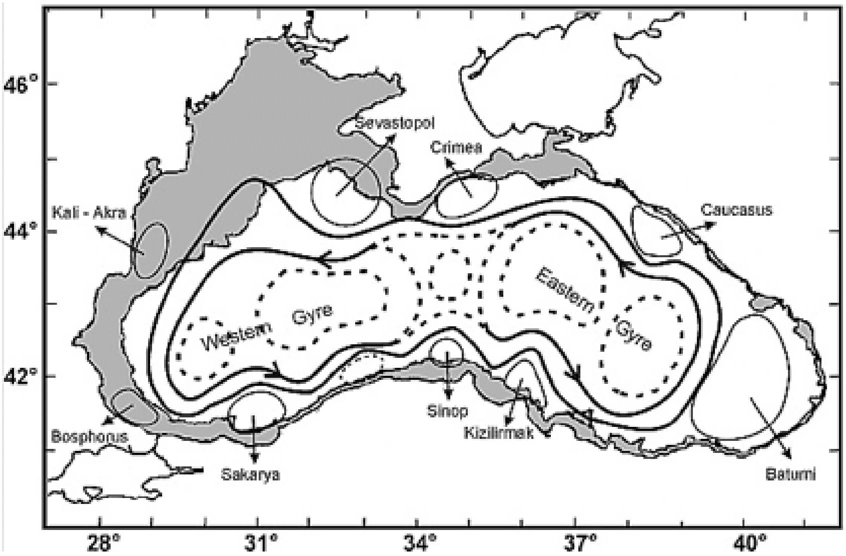


Figure 3.2 Schematic diagram for the main features of the upper layer (17).

3.2. Temperature

Figure 3.3 shows the monthly climatological fields of temperature at the surface: winter temperatures vary from -1 C° in the NW part and in the Sea of Azov to 10 C° in South. The summer temperatures reach 28 C°.

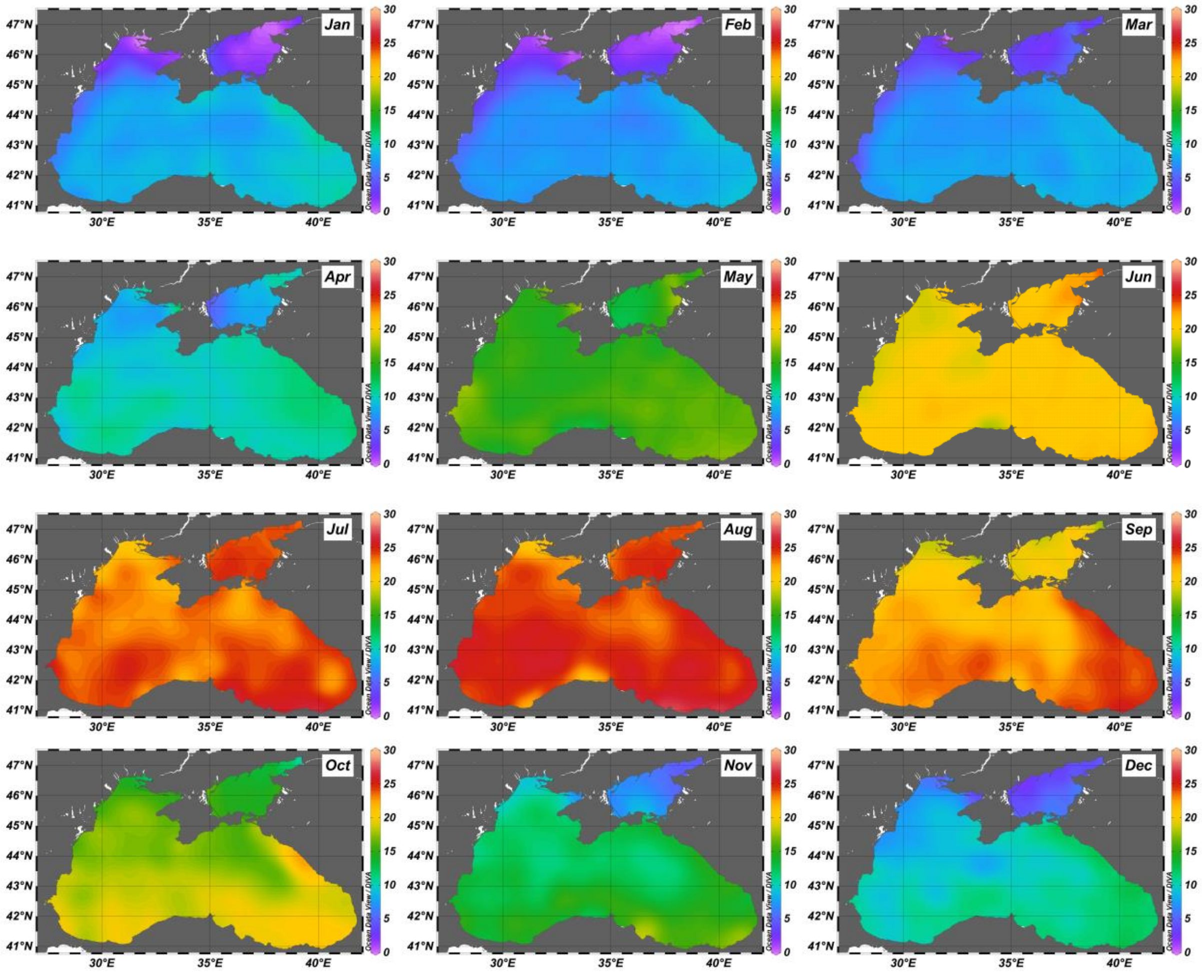


Figure 3.3 Annual variation of Temperature at surface (DIVAnd analysis for 1955-2017).

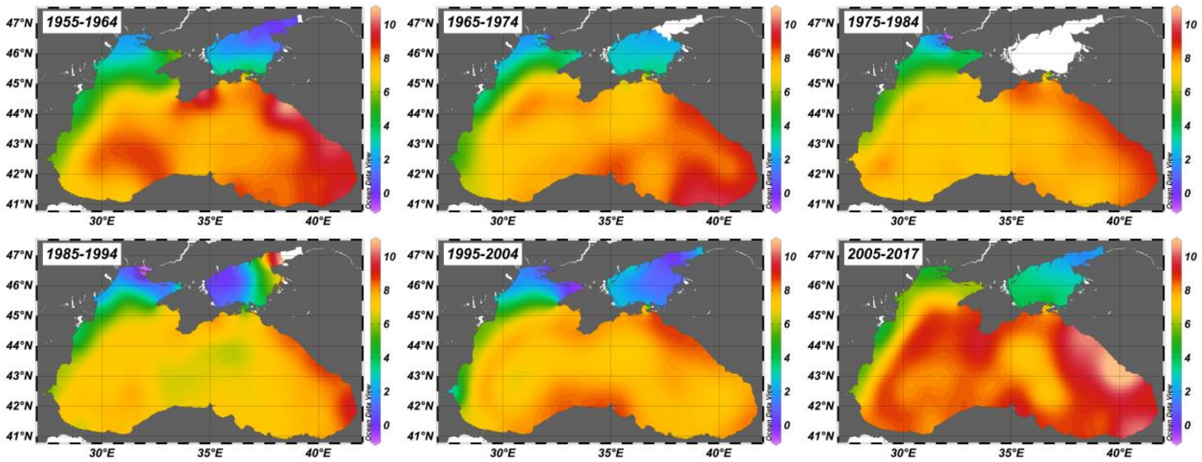


Figure 3.4 Variation of winter Temperature (Jan, Feb, Mar) at the surface in 6 decades in period 1955-2017

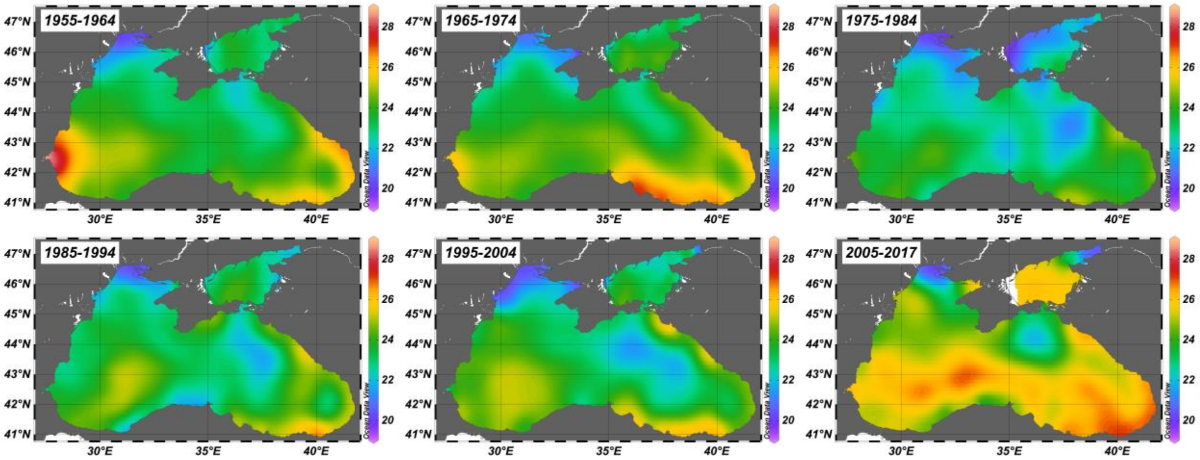


Figure 3.5 Variation of summer Temperature (Jul, Aug, Sep) at the surface in 6 decades in period 1955-2017

3.3. Salinity

The shallow NW part of the Black Sea and the Sea of Azov receive most of the river fresh water inflow, and salinity here goes down to 11 and up to 0 in river estuaries. The annual cycle of fresh water input is well traced in Figure 3.6.

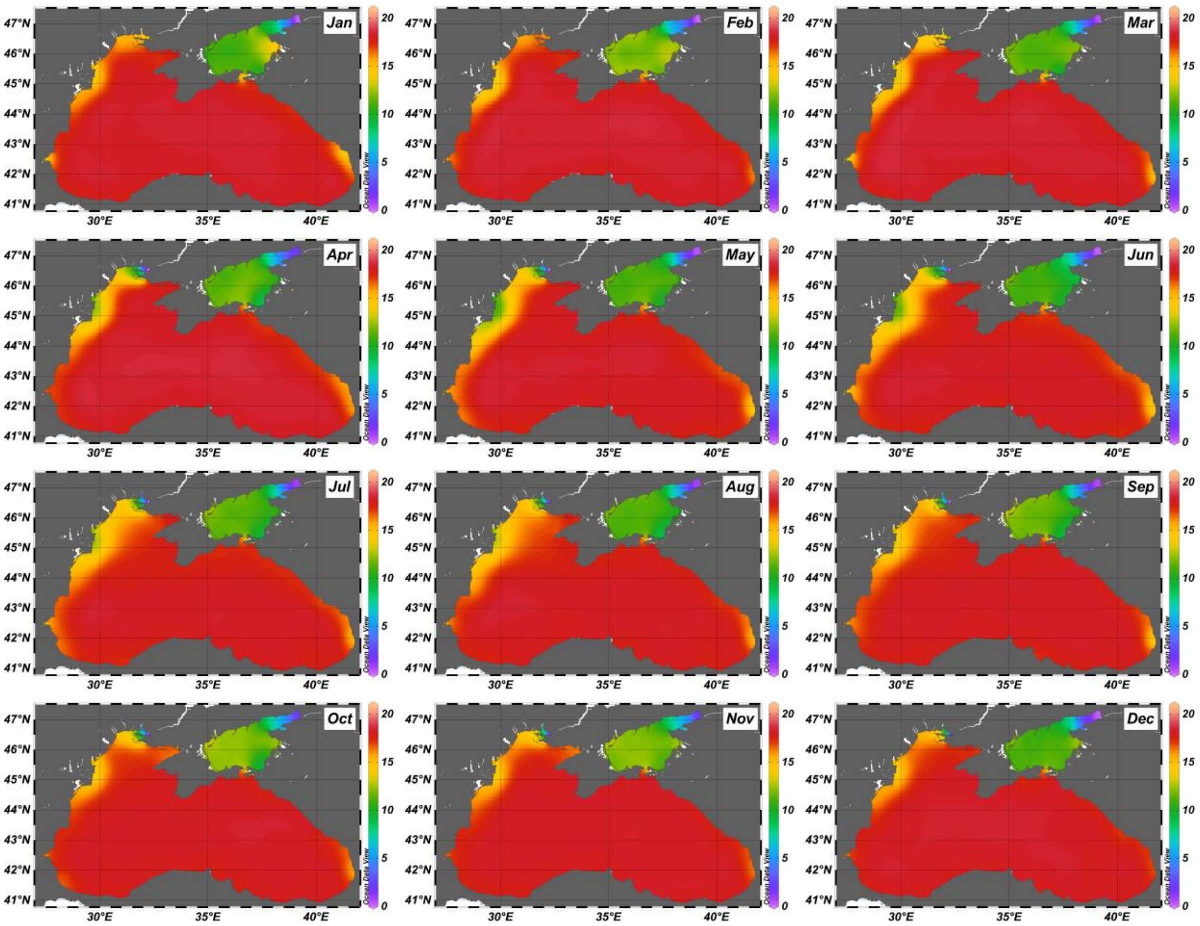


Figure 3.6 Annual variation of Salinity at the surface (DIVAnd analysis for 1955-2017)

Annual evolution of main circulation features (Rim Current, Batumi Eddy – see Figure 3.2) as well as intrusion of saline Mediterranean waters through Bosporus strait (Figure 2.1) are well visible in salinity maps for depth range 70 – 130 m (Figure 3.7).

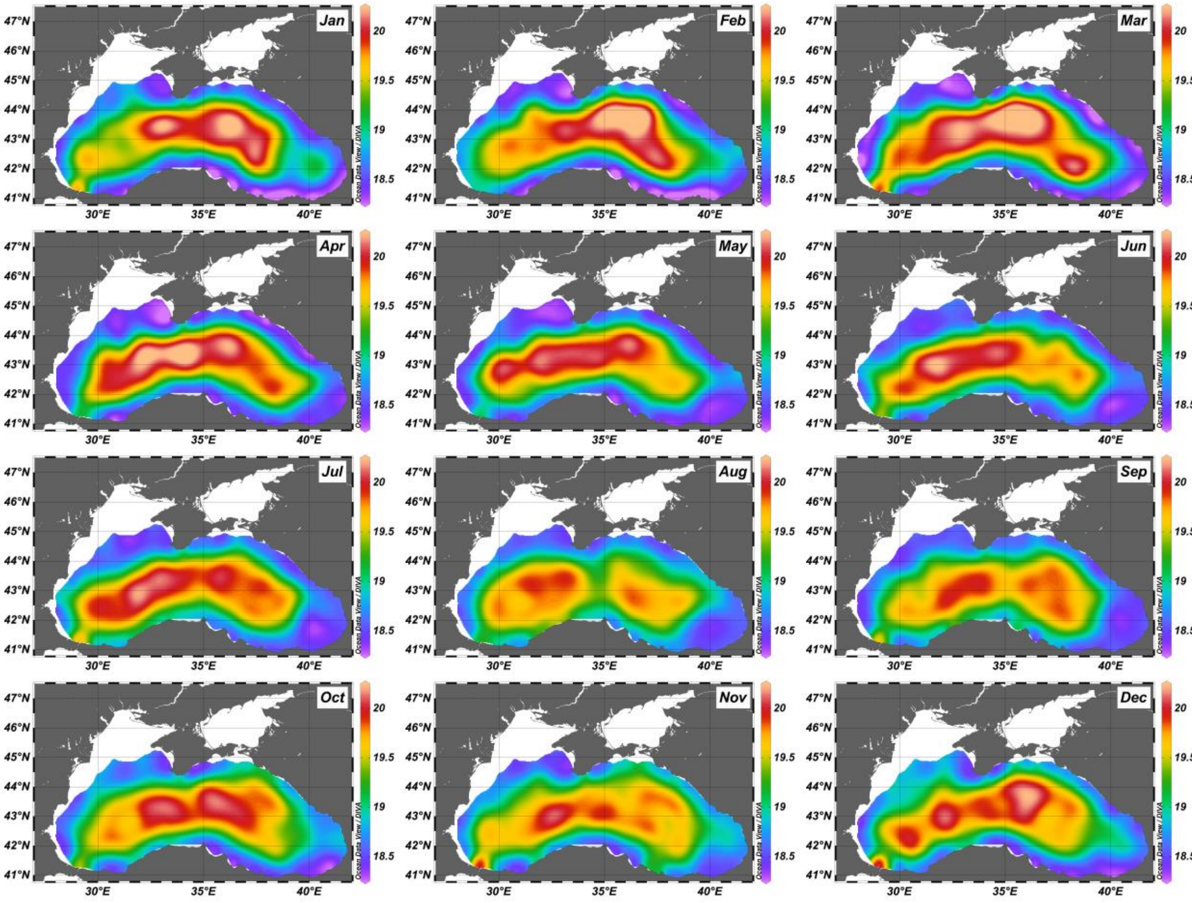


Figure 3.7 Annual variation of Salinity at 70 m (DIVAnd analysis for 1955-2017)

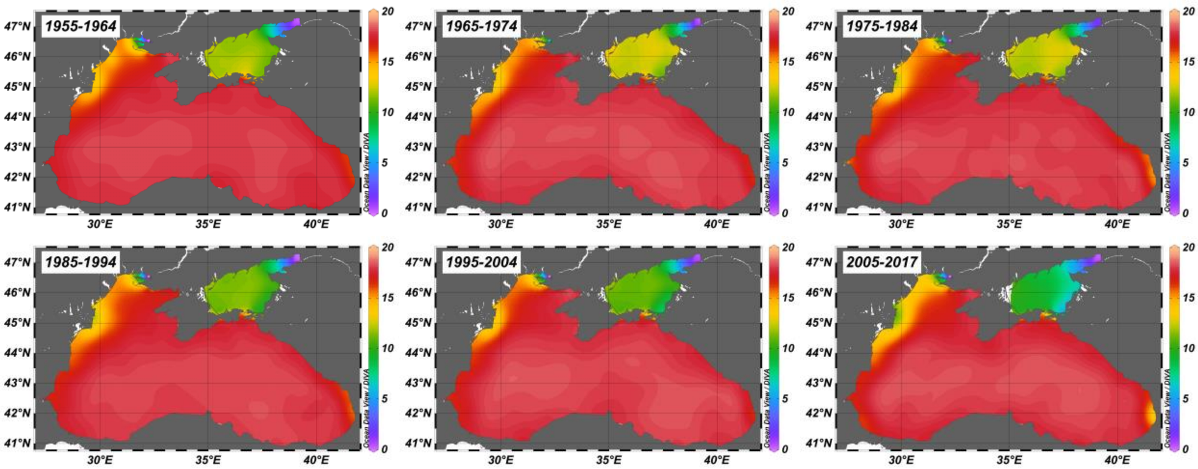


Figure 3.8 Variation of summer Salinity (Jul, Aug, Sep) at the surface in 6 decades in period 1955-2017

3.4. Error fields

Each parameter field in the climatology is supplied with the respective relative error field. Since we are using DIVAnd for calculation of climatogical fields the relative error is lower than in case of classical DIVA because the DIVAnd performs true n-dimensional analysis of data, while classical DIVA was constructing 3D fields from the 2D fields that were processed separately layer by layer. Thus, in DIVAnd the data gaps in a layer are compensated by taking into account the data from surrounding layers, while in classical DIVA it was not possible.

Significant addition of data from external data sources also contributed to decrease or the relative error (Figure 3.9) and allowed practically the elimination of the areas where the relative error exceeds 0.3 (the threshold above which the result is considered as less trustable).

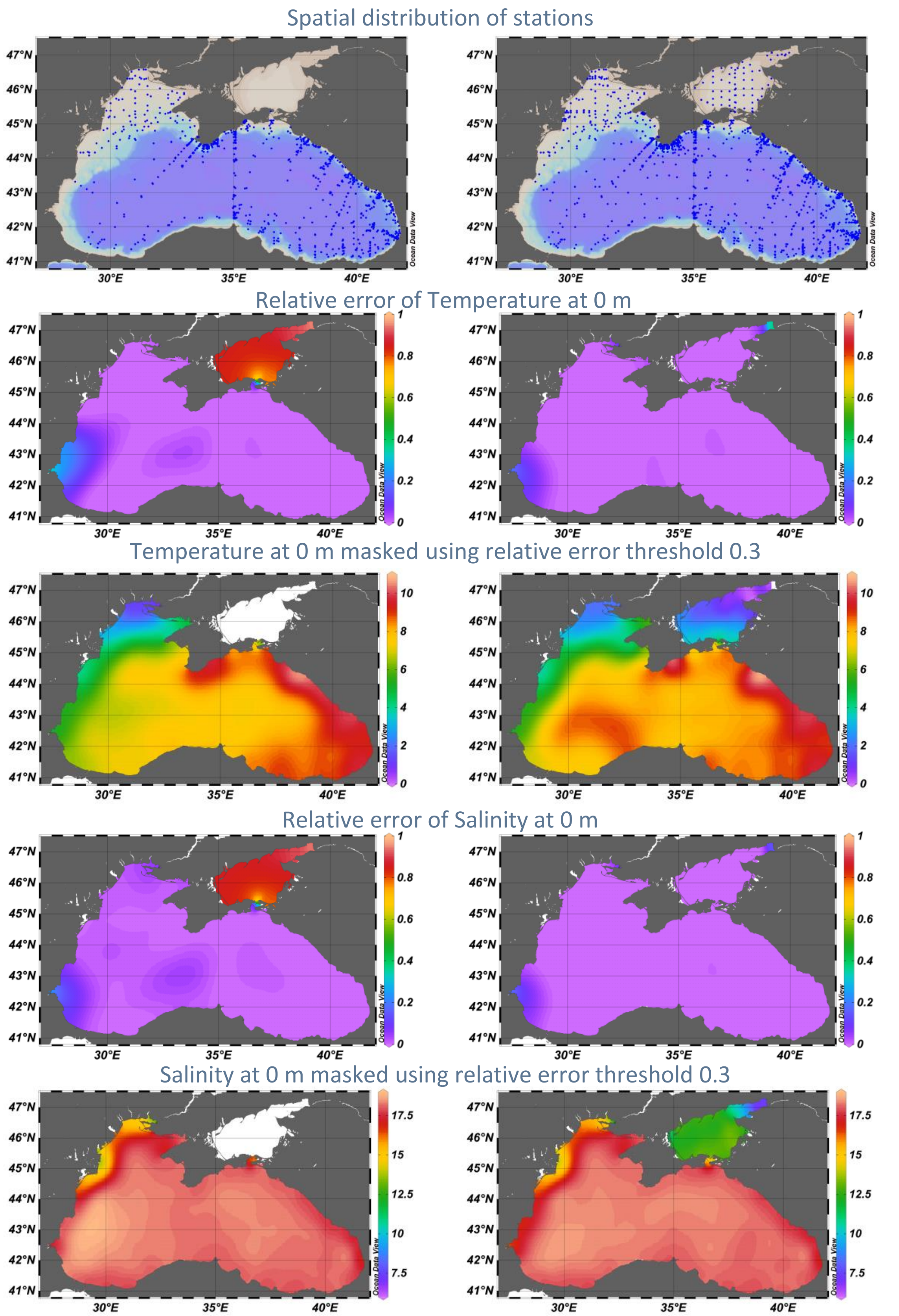


Figure 3.9 Comparison of results for 1955-1964 decade, obtained from SDC data only (left panel) and with including external data (right panel)

4. Consistency analysis

The consistency analysis was performed against the well-known and widely used product of the NOAA NODC Ocean Climate Laboratory – the World Ocean Atlas (10). The latest version of the World Ocean Atlas was released in September 2018 (WOA18). Seasonal climatological fields of Temperature and Salinity (objectively analysed mean) are available at resolution1/4° for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, and 2005-2017. The monthly fields at resolution 1/4° are available for time spans 1981-2010, 2005-2017, and 1955-2017.

Comparison of selected Temperature and Salinity fields is presented at Figure 4.4. The maps have similarities and differences. The WOA18 maps are smoother and have less details, while SDC maps look more noisy but seem to be more realistic. For example, in SDC temperature map the temperature gradient in NW Black Sea in January is stronger; in SDC salinity map the areas of river inflows are more pronounced, the Sea of Azov has a more natural salinity distribution.

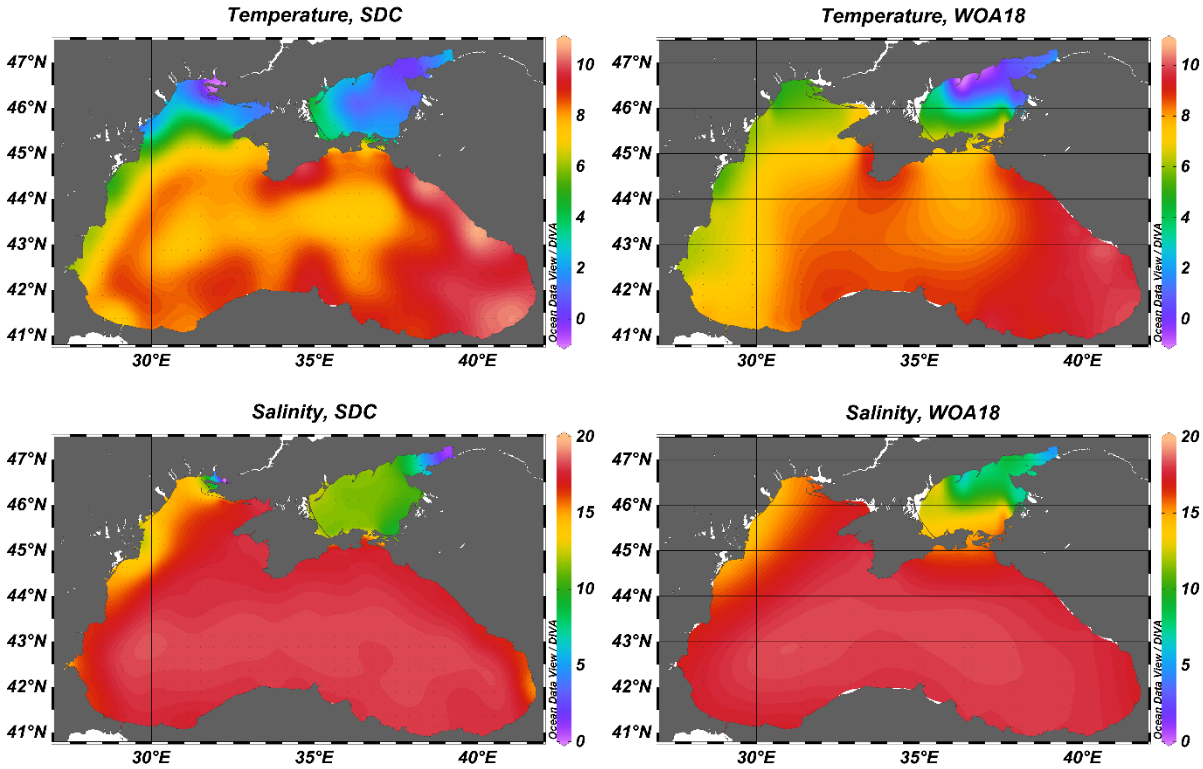


Figure 4.1 SDC and WOA18 temperature (January) and salinity (July) maps at the surface for time span 1955-2017.

Most of differences between two products are observed in upper 300 m layer. For example, the known from observations effect of isohalines domeing in the middle of the sea due to Rim Current is well pronounced at SDC maps, while at WOA18 maps it is not that strong though the map is smoother. Moreover, in depth range 70 – 130 m at SDC salinity maps we can see the Bosporus plume and Batumi Eddy (Figure 4.2), while at WOA18 maps these Black Sea features are missing.

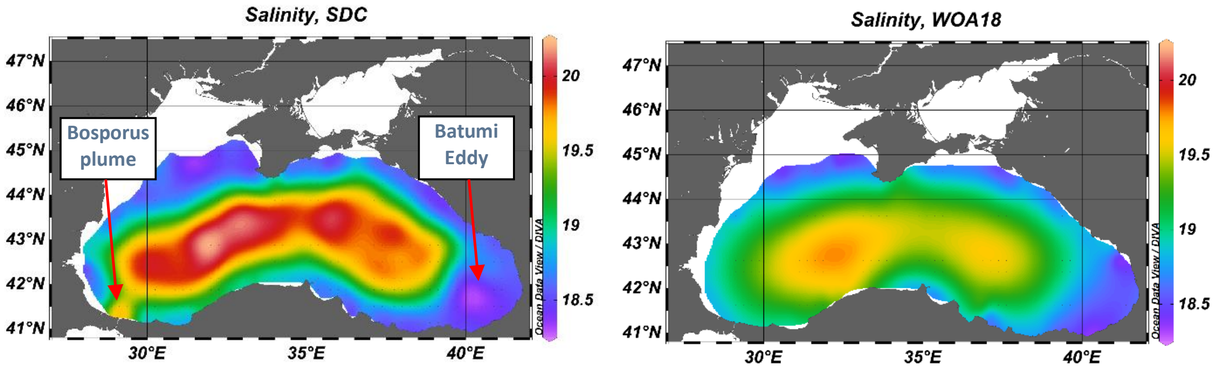


Figure 4.2 SDC and WOA18 salinity maps at 70 m, July.

The differences between WOA18 and SDC climatology fields can be both positive and negative and reach as much as several ppt for salinity and several degrees for temperature as it is shown at Figure 4.3, where WOA18 temperature in NW Black Sea is 3° larger than SDC temperature, while it is 2° lower in the SE coastal zone.

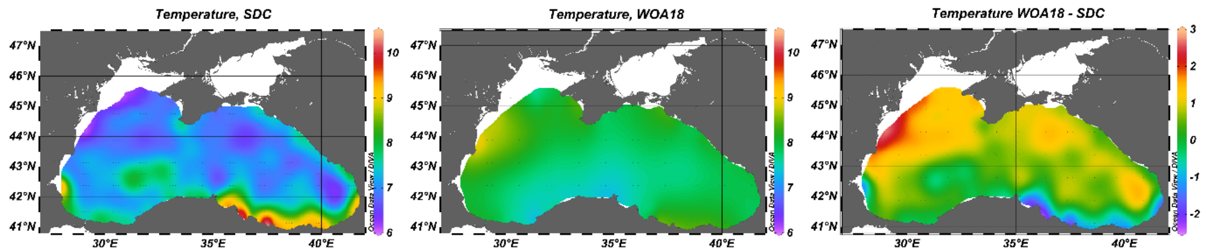


Figure 4.3 Difference between SDC and WOA18 temperature at 45m, July.

To quantify the differences between WOA18 and SDC climatologies the statistical indexes BIAS and RMSE were calculated for monthly fields for time span 1955 – 2017 and for seasonal fields – the decadal ones and for time span 1955 – 2017. Comparison was performed for matching grid nodes at 0.125, 03.75, 0.625, and 0.875 degree. The global BIAS indexes (i.e. calculated for the 3d grid and whole time span) in Table 4.1 are close to zero suggesting overall correspondence of WOA18 and SDC fields, however relatively large RMSE indexes suggest presence of significant differences, possibly dependent on depth and time.

Table 4.1 Statistical indexes of difference between WOA18 and SDC climatology

Fields	Time span	Temperature		Salinity	
		BIAS	RMSE	BIAS	RMSE
Seasonal	1955 - 1964	-0.07	0.54	0.01	0.21
Seasonal	1965 - 1974	-0.06	0.51	-0.01	0.21
Seasonal	1975 - 1984	0.08	0.50	-0.06	0.22
Seasonal	1985 - 1994	0.03	0.42	-0.03	0.21
Seasonal	1995 - 2004	-0.09	0.89	-0.08	0.33
Seasonal	2005 - 2017	-0.03	0.47	0.03	0.28
Seasonal	1955 - 2017	0.02	0.39	-0.03	0.22
Monthly	1955 - 2017	0.01	0.46	-0.04	0.24

More detailed analysis was performed for monthly fields. The main differences are observed in upper layer 0 – 300 m, while below 300 m both BIAS and RMSE are close to zero that explains low values in Table 4.1.

The extremes of temperature BIAS (WOA18 – SDC) up to 1.2C° are observed in summer months in the upper layer (Figure 4.4): the negative BIAS in 0-25 m depth range follows by positive BIAS with maximum at about 50 m. The RMSE values are also highest for the same times and depths.

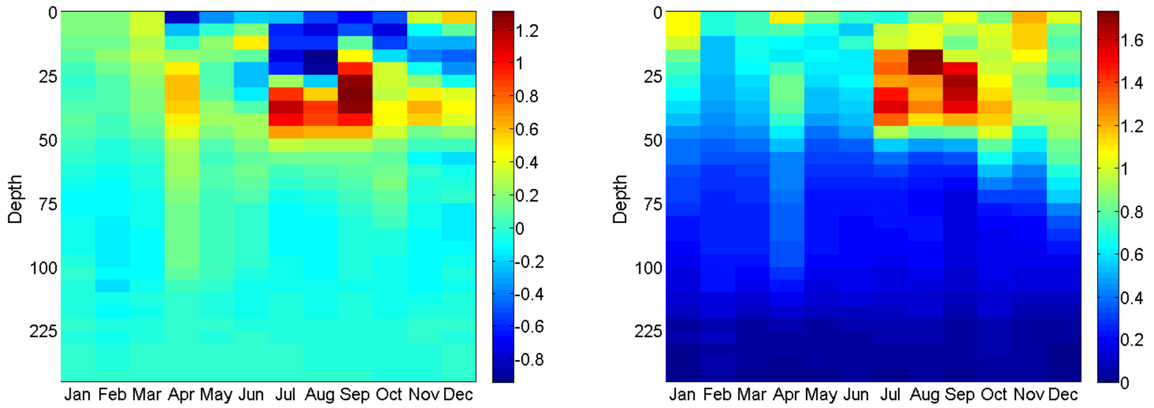


Figure 4.4 Hovmoller plots of BIAS (left) and RMSE (right) indexes of WOA18 – SDC monthly temperature fields (upper 300 m).

The maximum of positive salinity BIAS (WOA18 – SDC) up to 0.4 is observed through the year in level 2 = 5m, while the negative values up to -0.2 are observed in depth range 60 – 200m. The RMSE values are highest at the surface (up to 0.9) and in the same depth range 60 – 200m (up to 0.4).

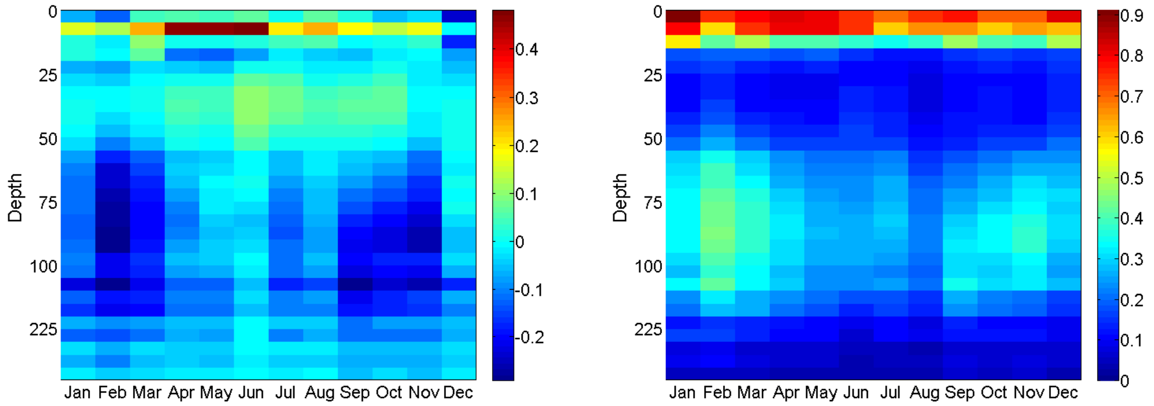


Figure 4.5 Hovmoller plots of BIAS (left) and RMSE (right) indexes of WOA18 – SDC monthly salinity fields (upper 300 m).

The BIAS in upper 0-300 layer is confirmed by comparison of average profiles that were produced from climatology for Black Sea internal area for January and July (Figure 4.6). In January WOA18 and SDC temperature profiles practically coincide, while in July WOA18 temperature is lower in thermocline (0-25m) and higher in CIL (45-55 m). The WOA18 salinity is lower than SDC salinity for the whole halocline layer in both months.

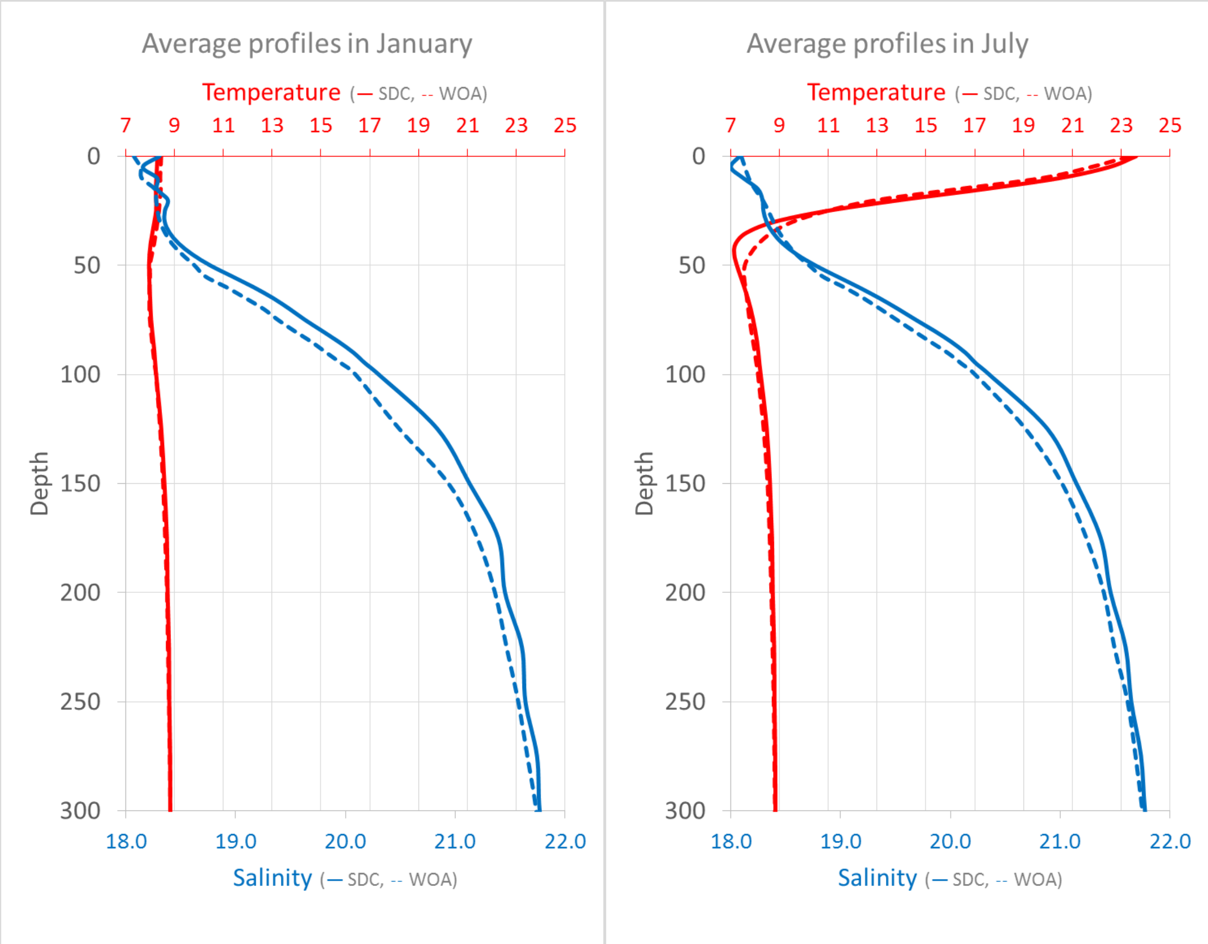


Figure 4.6 Average profiles of Temperature and Salinity for area 42 – 44.5N, 31-38E

Following factors should be taken into account to interpret these results:

1) The dataset used for computation of SDC climatology is twice as large as the WOD18 dataset used for WOA18. The difference in data could lead to the difference in obtained climatic fields.
2) The horizontal resolution of WOA18 climatology is half the resolution of the SDC climatology, thus we expect more smooth fields with less details from WOA18 compared to SDC, particularly in areas with high horizontal gradient: areas of rivers inflow, near Kerch and Bosporus straits, along the coast. The BIAS, and particularly RMSE index in such areas should be elevated.
3) The radii of influence (214-321 km), used for calculation of WOA18 climatology (18, 19), are significantly larger than the horizontal correlation length (150 km) used for calculation of SDC climatology. These differences are more pronounced in gradient areas, and also reflected in extremes: i.e. in WOA18 values of maximums should be lower than in SDC while values of minimums higher.
4) Unlike WOA18, which is based on 2-d data analysis, the SDC climatology is produced with 3-d data analysis. This also could be the reason for differences in vertical profiles particularly considering that the vertical correlation length used for SDC calculations is depth dependent.

5) Flagging temperature values in thermocline as bad in WOD18 (see note in section 1.1.3 above) and presumable eliminating them from WOA18 calculations could result in obtaining lower temperature in thermocline than it should be. In SDC climatology dataset these data were recovered, therefore the respective effect was eliminated.

Interpretation of the results of comparison SDC and WOA18 climatologies:

- Large temperature BIAS index values in upper layer in summer months as well as differences in respective average profiles are explained mainly by factor 5, but other factors are also important.
- Large salinity BIAS index values for halocline as well as differences in average profiles and fields in halocline zone are explained by factors 1 - 4.
- Large positive salinity BIAS index for level 2, also exposed as local minimum at 5m in average salinity profile, is a drawback of DIVAnd. DIVAnd in general has a problem with reproducing properly a parameter at boundary levels, particularly in case of steady gradient at deeper levels. In order to obtain more or less reliable salinity field at the surface we used parameter surfextend = true, which says DIVAnd to use an extra (fake) level in calculations. Indeed it helped to improve the field at the surface level, but resulted in the appearance of wrong local minimum at the 2nd level.
- Large salinity RMSE index in near surface layer - 0-15m – is explained by factors 2 and 3 due to differences between SDC and WOA18 climatologies in gradient zones.

The statistical indexes for seasonal fields are not analysed in this document but it should be noted that in certain decades and seasons they are high mainly due to scarcity of data. Due to higher sensitivity of DIVAnd to data scarcity some SDC climatological fields are less reliable than the respective WOA18 fields.

5. Technical Specifications

5.1. Product Format

The product is delivered in 4 files in NetCDF format. Each file contains four 4d arrays (3 space dimensions + 1 time dimension) named according to the following rule:

- *Parameter_Name* – 4d array for a parameter,
- *Parameter_Name_L1* – … parameter masked using relative error threshold 0.3,
- *Parameter_Name_L2* – … parameter masked using relative error threshold 0.5,
- *Parameter_Name_relerr* – relative error of parameter.

Content of NetCDF files:

1. **SDC_BLS_CLIM_T_1955_2017_0125_m.4Danl.nc** Temperature **m**onthly climatological fields for 3 time spans: 1955-1994, 1995-2017, and **1955-2017** at **0.125** degrees spatial resolution.
2. **SDC_BLS_CLIM_S_1955_2017_0125_m.4Danl.nc** Salinity **m**onthly climatological fields for 3 time spans: 1955-1994, 1995-2017, and **1955-2017** at **0.125** degrees spatial resolution.
3. **SDC_BLS_CLIM_T_1955_2017_0125_s.4Danl.nc** Temperature **s**easonal climatological fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2017, and 3 time spans: 1955:1994,1995:2017, and **1955-2017** at **0.125** degrees spatial resolution.
4. **SDC_BLS_CLIM_S_1955_2017_0125_s.4Danl.nc** Salinity **s**easonal climatological fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2017, and 3 time spans: 1955:1994,1995:2017, and **1955-2017** at **0.125** degrees spatial resolution.

Every NetCDF file, along with the fields attributes, contains a set of attributes describing the product:

- Name of the project,
- EDMO code of the product developer,
- Name of activity,
- Contact e-mail of developer,
- Source of observations,
- Keywords for the parameter and the area and their codes in SeaDataNet Vocabularies P35, P01, and C19,
- Product code and version and abstract,
- Bathymetry source,
- Acknowledgement,
- Links to documentation, data and visualization tools.

5.2. Product Usability

The climatic fields can be used as to support the general oceanographic studies, ocean modelling and forecast, processes studies, climate change studies etc. They can be used, for example, for initialization and verification of different ocean models, for investigation of climatic trends.

Since the Temperature and Salinity climatic fields are computed separately, the merged T-S field contains a number of T-S profiles with vertical instability. The effect of instability is observed mainly in profiles along the coastline and at NW shelf. The main source for vertical instability at the surface is the problematic salinity at the second depth level due to inability of DIVAnd to replicate properly the profiles with strong halocline and thermocline (the issue is described in chapter 4). The other reason can be differences in distribution of Temperature and Salinity data at different levels.

In the current version of the product **no** correction of the vertical instability and **no** correction of the MBT/XBT depth was performed. In obvious cases the MBT/XBT profile depth was flagged as bad thus eliminating the whole profile from the climatology calculations. The underway data were heavily subsampled (with up to 1 to 20 rate) prior being used for climatology computations.

The SDC climatology well reproduces main Black Sea features such as Rim Current, Western and Eastern Gyres, Bosporus plume, Batumi Eddy, gradients in river inflow areas. However, due to data scarcity some decadal seasonal climatological fields may have anomalies, which are not masked by relative error = 0.3, for example, when data are available only in the 1st or 3rd month of a season as on Figure 3.4 / for decade 1985-1994.

For the above reasons, it is advisable to consult the data set producer before using this climatology for any application.

5.3. Changes since previous version

The previous version of the product was released in framework of the SeaDataNet2 project and available at SEXTANT Catalogue (http://sextant.ifremer.fr/en/web/seadatanet) under the name "Black Sea Temperature and Salinity Climatology V1.1".

Compared to the previous version there are significant changes: the SDN product contained climatological fields calculated only for single interval 1900 – 2013, i.e. it did not contain fields for sub-periods and decades, which are present in the current product. The horizontal resolution was higher (0.1° in SDN product vs 0.125° in SDC product), while the vertical resolution was much coarser – 19 levels vs 67. The SDN product contained monthly fields only for 10 upper layers (0 – 250 m), and only annual – for the rest.

Two factors allowed us to obtain reasonable result for climatology with the increased vertical and temporal resolution:

- Inclusion of data from external data sources – WOD18 and CORA 5.1 – to the integrated dataset, that doubled the number of observations used for climatology in SDC product compared to SDN product,
- Usage of the DIVAnd, which performs true n-dimensional variational data analysis, instead the previous version of DIVA that was performing analysis per horizontal layer.

Annex 1 - Naming convention for SeaDataCloud climatologies

File naming conventions: [PRO]_[REG]_[PROD]_[V]_[YYYY1]_[YYYY2]_[T], where:

1. [PRO] - project
2. [REG] - region
3. [PROD] - product
4. [V] - variable
5. [YYYY1]_[YYYY2] - time coverage
6. [S] – spatial resolution
7. [T] - temporal resolution (m=monthly, s=seasonal, a=annual)

Project	Region	Product	Var	Time Coverage	Time Res	Full Name
SDC	BLS	CLIM	T	1955-1994 1995-2017 **1955-2017**	monthly	SDC_BLS_CLIM_T_1955-2017_0125_m
SDC	BLS	CLIM	S	1955-1994 1995-2017 **1955-2017**	monthly	SDC_BLS_CLIM_S_1955-2017_0125_m
SDC	BLS	CLIM	T	1955-1964 1965-1974 1975-1984 1985-1994 1995-2004 2005-2017 **1955-2017**	seasonal	SDC_BLS_CLIM_T_1955-2017_0125_s
SDC	BLS	CLIM	S	1955-1964 1965-1974 1975-1984 1985-1994 1995-2004 2005-2017 **1955-2017**	seasonal	SDC_BLS_CLIM_S_1955-2017_0125_s

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List of acronyms

Acronym	Definition
ARC	Arctic ocean
BAL	Baltic Sea
BLS	Black Sea
CDI	Common Data Index
CLIM	Climatology
CMEMS	Copernicus Marine Environment Monitoring Service
DATA	Aggregated Dataset
DIVA	Data-Interpolating Variational Analysis (software)
DOI	Digital Object Identifier
EC	European Commission
EDMO	European Directory of Marine Organisations (SeaDataNet catalogue)
GLO	Global Ocean
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange (IOC)
MED	Mediterranean Sea
NAT	North Atlantic Ocean
NWS	North West Shelf
ODV	Ocean Data View Software
QC	Quality Checks
QF	Quality Flags
RMSE	Root mean squared error
SDC	SeaDataCloud
SDN	SeaDataNet
TS	Temperature and Salinity
WOA	World Ocean Atlas
WP	Work Package