Product Information Document (PIDoc)

SeaDataCloud Temperature and Salinity Climatology for the Black Sea (Version 2)

SDC_BLS_CLIM_TS_V2

HORIZON **2020**

sdn-userdesk@seadatanet.org – www.seadatanet.org

SeaDataCloud - Further developing the pan-European infrastructure for marine and ocean data management

Grant Agreement Number: 730960

Product Name

SDC_BLS_CLIM_TS_V2

Extended name

SeaDataCloud Temperature and Salinity Climatologies for the Black Sea (Version 2)

Product DOI

https://doi.org/10.12770/847f1627-f39f-40af-b3b0-a2f6d29ff4dc

Short description

The SDC_BLS_CLIM_TS_V2 product contains Temperature and Salinity Climatologies for Black Sea including seasonal and monthly fields covering the 3 time spans: 1955-1994, 1995-2019, and 1955-2019 and seasonal fields for 5 decades starting from 1955 to 2004 plus 15 years period 2005-2019. 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, and 3) Coriolis Ocean Dataset for Reanalysis. The computation was done with the DIVAnd (Data-Interpolating Variational Analysis in n dimensions), version 2.6.2.

Authors

Volodymyr Myroshnychenko <volodymyr@ims.metu.edu.tr>

Simona Simoncelli <simona.simoncelli@ingv.it>

Dissemination

Public

Copyright terms

How to Cite

History

Version	Authors	Date	Comments
1.0	V. Myroshnychenko	03/12/2020	First version
	S. Simoncelli	06/12/2020	revision

Table of contents

Abstract....4
1. Data....5
1.1. Source datasets....5
1.1.1. SeaDataCloud dataset SDC_BLS_DATA_TS_V2....5
1.1.2. SeaDataCloud Restricted Temperature and Salinity Historical Data Collection....7
1.1.3. World Ocean Database....9
1.1.4. COriolis Ocean Dataset for Reanalysis (CORA 5.2)....10
1.2. Integrated dataset....12
2. Methodology....17
2.1. Data Quality Control....17
2.2. DIVA implementation and settings....18
2.2.1. Domain definition....18
2.2.2. DIVAnd settings....19
2.2.3. A-posteriori Quality Control....21
3. Climatology....22
3.1. Brief overview of the Black Sea thermohaline features....22
3.2. Temperature....23
3.3. Salinity....24
3.4. Error fields....26
4. Consistency analysis....28
5. Technical Specifications....32
5.1. Product Format....32
5.2. Product Usability....33
5.3. Changes since previous version....33
Annex 1 - Naming convention for SeaDataCloud climatologies....34
References....35
List of acronyms....37

Abstract

The SDC_BLS_CLIM_TS_V2 product contains Temperature and Salinity Climatologies for Black Sea including seasonal and monthly fields covering the 3 time spans: 1955-1994, 1995-2019, and 1955-2019 and seasonal fields for 5 decades starting from 1955 to 2004 plus 15 years period 2005-2019. 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, and 3) Coriolis Ocean Dataset for Reanalysis. The computation was done with the DIVAnd (Data-Interpolating Variational Analysis in n dimensions), version 2.6.2.

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 2) - SDC_BLS_DATA_TS_V2 (2).
2. SeaDataCloud Restricted Temperature and Salinity Historical Data Collection for the Black Sea (Version 1) - SDC_BLS_DATA_TS_V2_RESTRICTED.
3. Data extracted from the World Ocean Database (WOD (3)) as of Mar 2020.
4. Data extracted from the COriolis Ocean Dataset for Reanalysis - CORA 5.2 (4) as of Dec 2019.

1.1. Source datasets

1.1.1. SeaDataCloud dataset SDC_BLS_DATA_TS_V2

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 July 2019. 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 – 2019.

Table 1.1 Data Statistics: total numbers.

	Cruises	Stations			Values
		All	Profiles	Underway	
All samples	2411	123897	38759	162656	5130344
Temperature	2403	123511	38759	162270	5128177
Salinity	2255	115804	37349	153153	4970210

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.

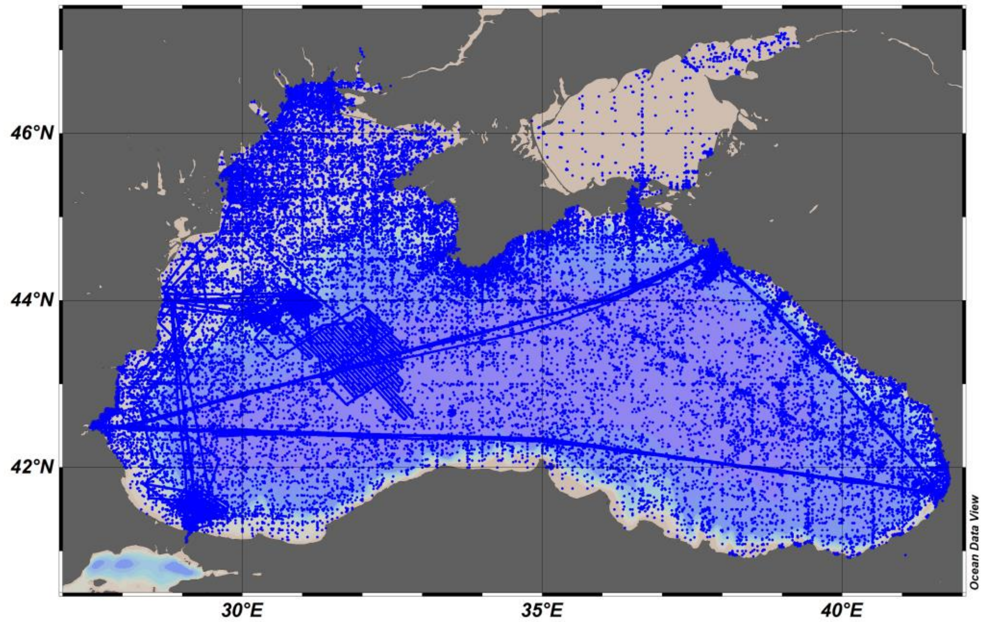


Figure 1.1 Spatial distribution of observations

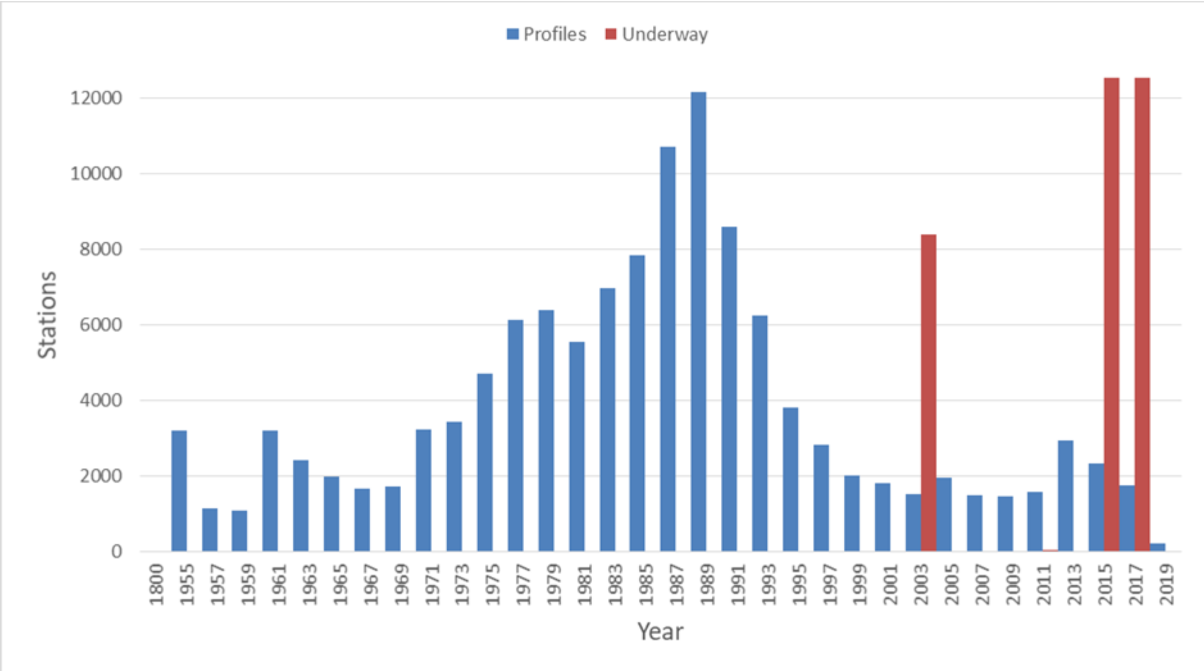
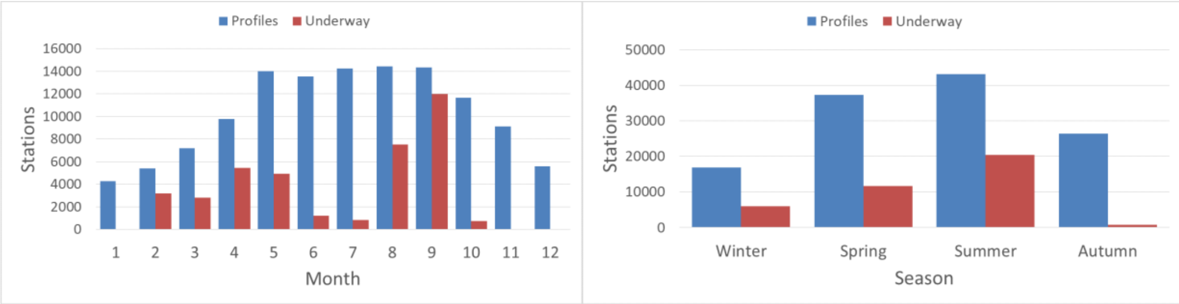


Figure 1.2 Temporal distribution of observations

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, 2015 and 2018 represent underway data from a few 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.

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 2019. 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_V2 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
324	10755	800629	799614	800272

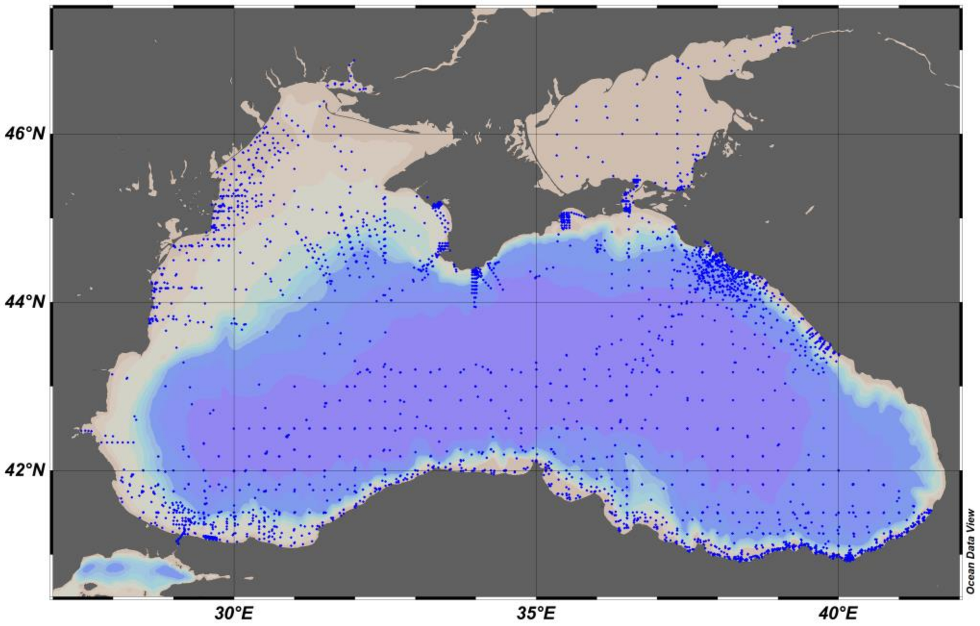


Figure 1.4 Spatial distribution of SDC restricted observations.

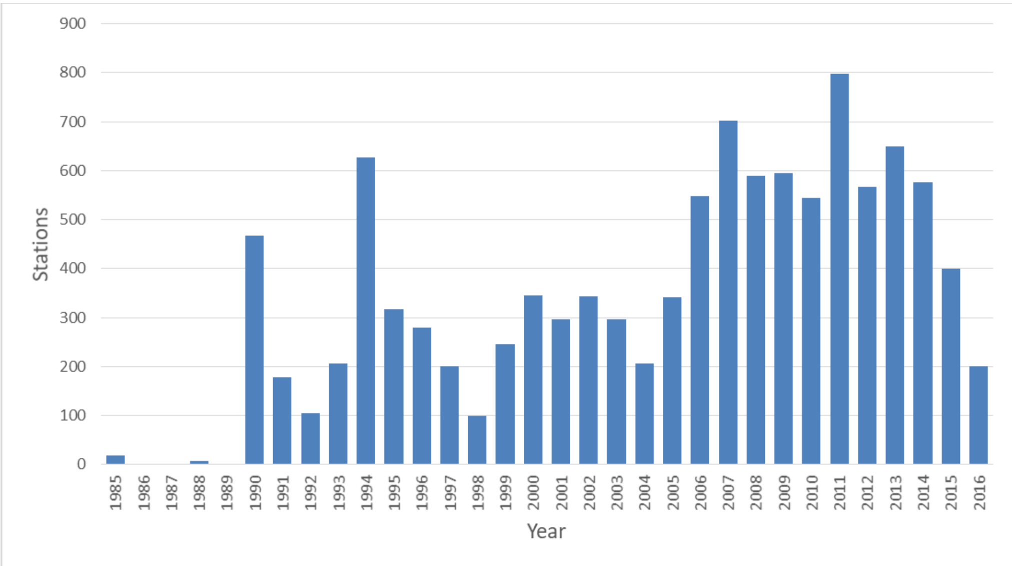


Figure 1.5 Temporal distribution of SDC restricted observations.

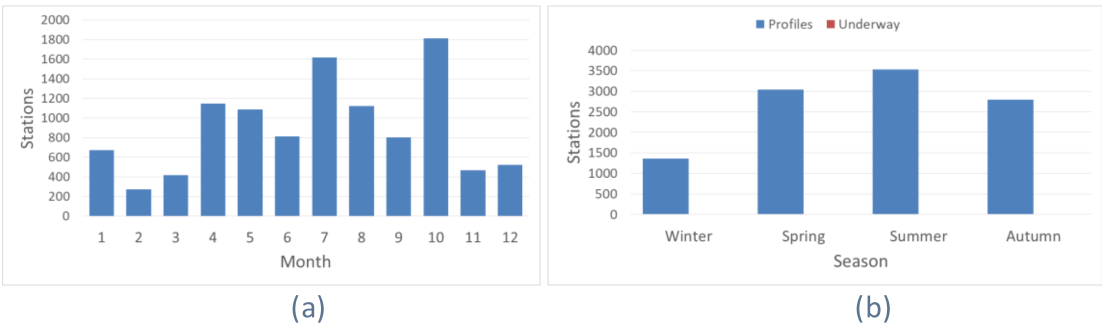


Figure 1.6 Monthly (a) and seasonal (b) distributions of observations

1.1.3. World Ocean Database

The Black Sea Temperature and Salinity data were downloaded from the WOD website (https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html) in April 2020 and imported to ODV (6) collection.

Table 1.3 Data Statistics

Period	Stations	All samples	Temperature values	Salinity values
1890-2019	119341	5795253	5742963	5532207

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 1955-2019. 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.

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

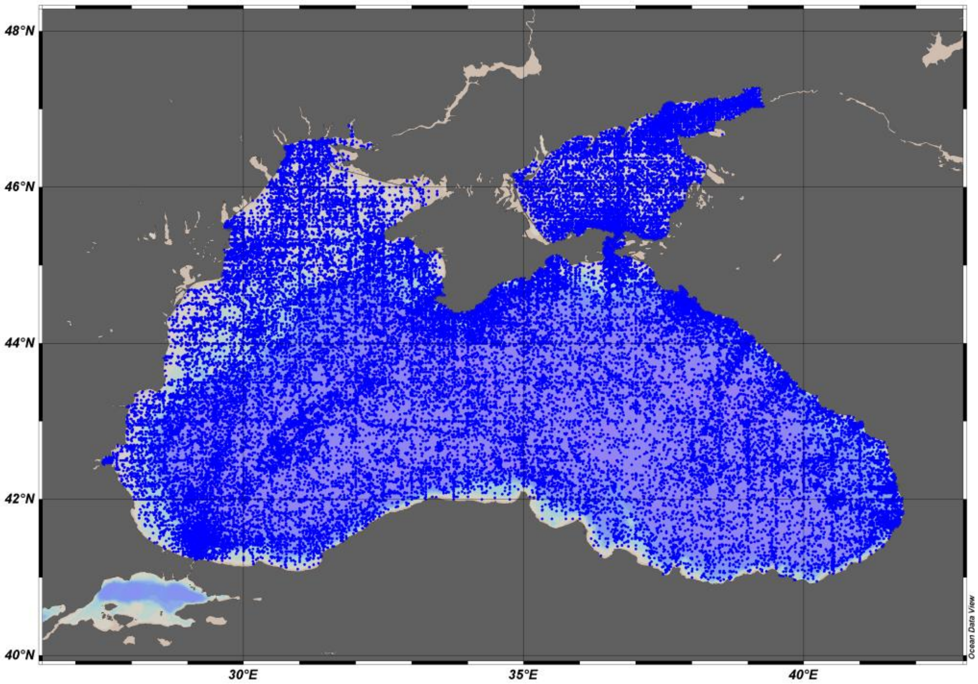


Figure 1.7 Spatial distribution of WOD observations as of April 2020

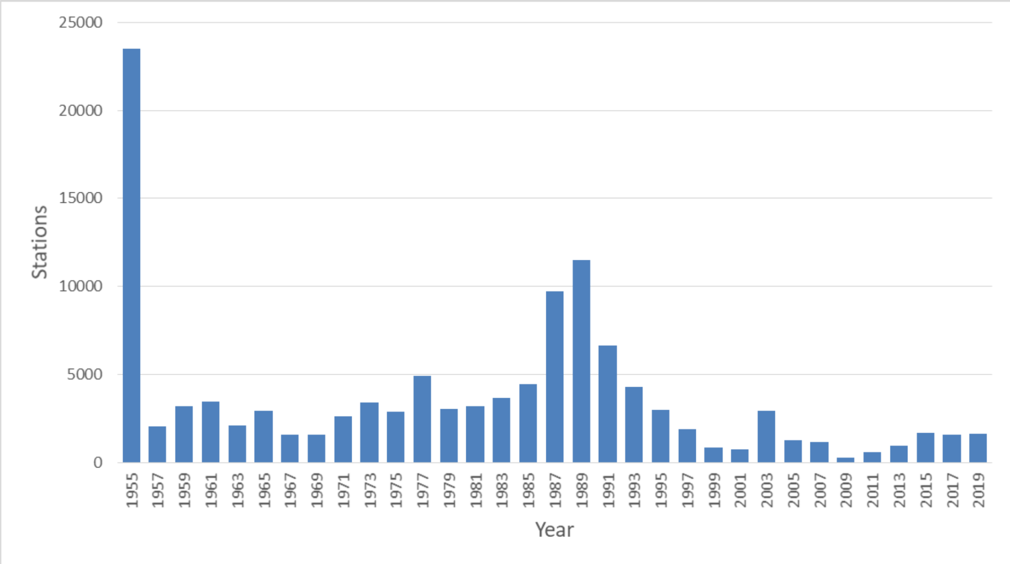


Figure 1.8 Temporal distribution of WOD observations.

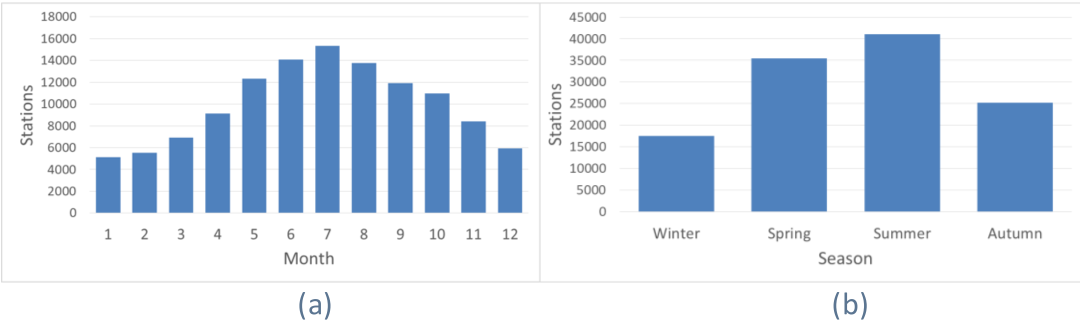


Figure 1.9 Monthly (a) and seasonal (b) distribution of observations

1.1.4. COriolis Ocean Dataset for Reanalysis (CORA 5.2)

The CORA 5.2 Black Sea Temperature and Salinity data (Dec 2019) 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
1955-2019	152985	5911649	5911261	5073061

Spatial and temporal distributions of data are presented in Figure 1.10 and Figure 1.11. The majority of stations in CORA 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.

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

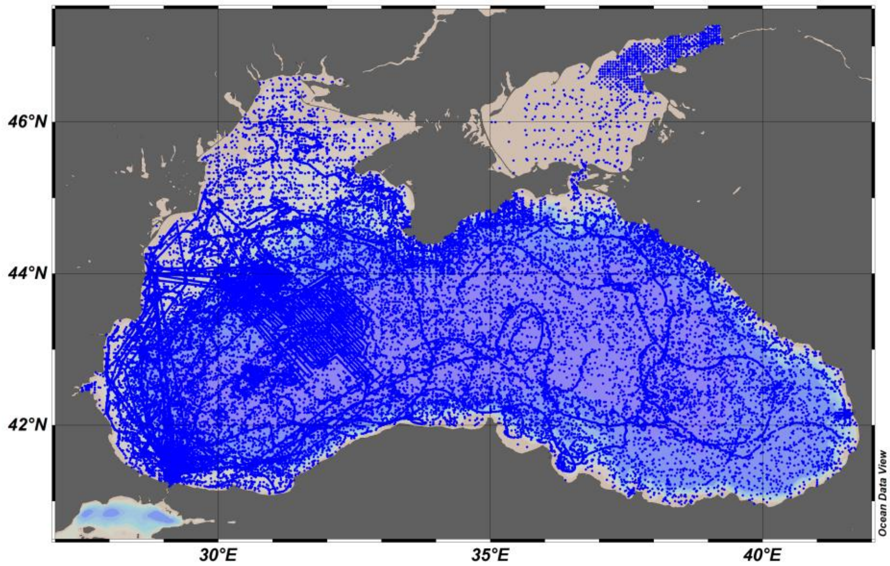


Figure 1.10 Spatial distribution of CORA observations.

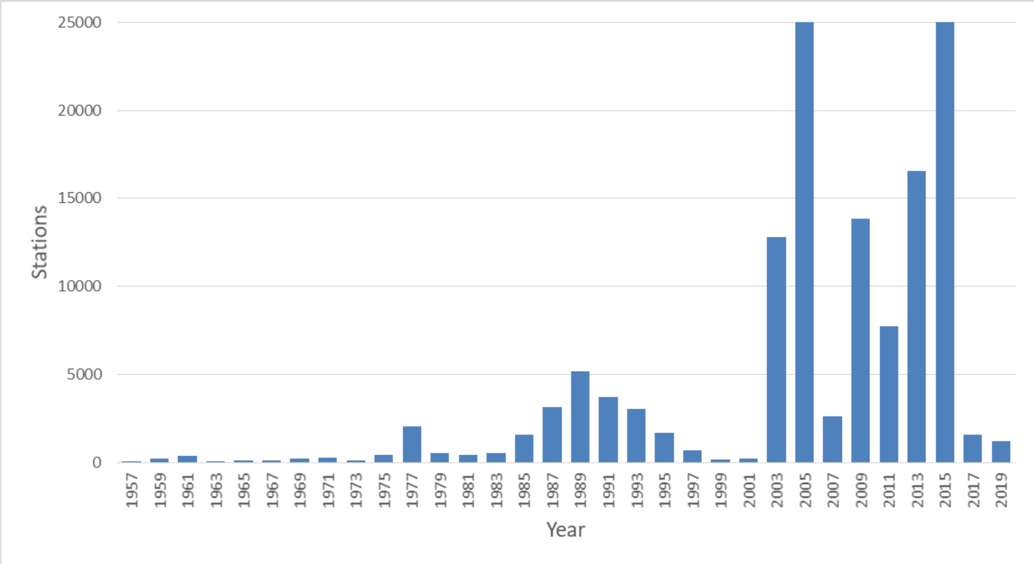


Figure 1.11 Temporal distribution of CORA observations

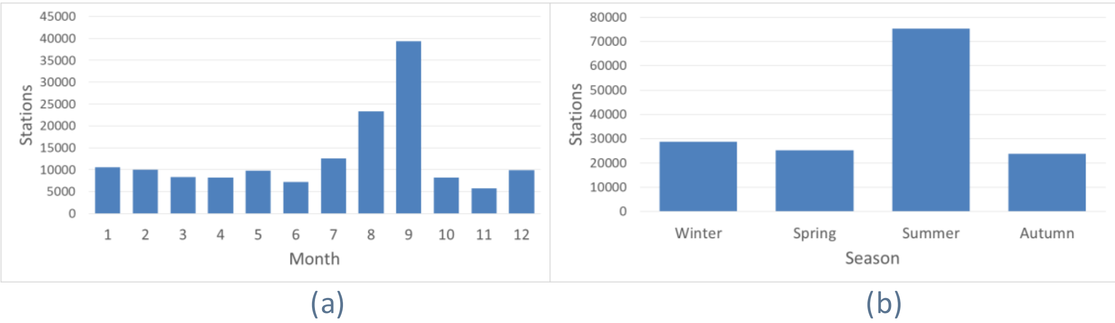


Figure 1.12 Monthly (a) and seasonal (b) distributions of observations

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
  - 1605 in WOD
  - 20915 in CORA
- Identifying and excluding overlapping data
  - in WOD 50249 stations overlapping with SDC
  - in CORA 38131 stations overlapping with SDC and 34985 overlapping with WOD
- Merging non-overlapping data

The merging was performed as follows:

- The SDC_BLS_DATA_TS_V2 dataset was taken as a primary,
- The SeaDataCloud restricted dataset was added as it is,
- Then the non-overlapping part of the WOD dataset was added, and, finally

- Non-overlapping part of the CORA dataset was added.

The merged dataset was cleaned up taking into account experience obtained with V1 product:

- Climatically non-relevant data were excluded (e.g. acquired in river estuaries, in adjacent lakes etc.)
- In order to avoid presence of "trajectory" effect in generated fields the underway data were subsampled using criteria: distance >= 5 miles or time interval >= 6 hours
- In order to minimize probability of appearance of density inversion in the TS profiles produced from generated T and S climatic fields **only** good data from the **coupled TS profiles** were taken into integrated dataset.

The cleaning procedure significantly decreased amount of data available for further analysis. Content of the resulted integrated Black Sea Temperature and Salinity dataset for climatology (further "climatology dataset") covering period 1955-2019 is provided in Table 1.5. More than 80% of profiles/stations come from two SDC datasets followed by 18% from WOD and just 1 % from CORA. In terms of values 2/3 are contributed by SDC and 1/3 by WOD.

Table 1.5 Content of the integrated dataset

	SDC unrestricted	SDC restricted	WOD	CORA	Total
No of stations	111175	9805	26746	1693	149419
% of total	74%	7%	18%	1%	
No of values	4806184	496452	2709402	11370	8023408
% of total	60%	6%	34%	0.14%	

The spatial and temporal distribution of data for period is presented in Figure 1.13 - Figure 1.16.

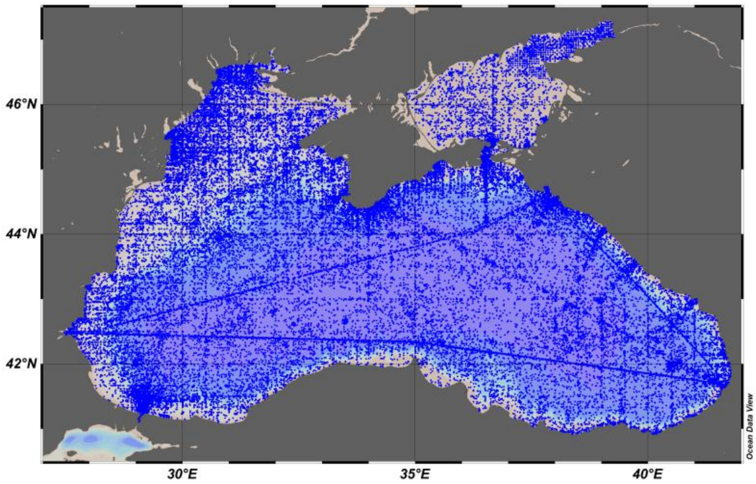


Figure 1.13 Spatial distribution of observations.

The temporal distribution of observations in the integrated dataset is irregular growing from minimum in 1955 to peak in 1990, then declining in early 2000th and starting to increase again after 2010 (thanks to ARGO floats).

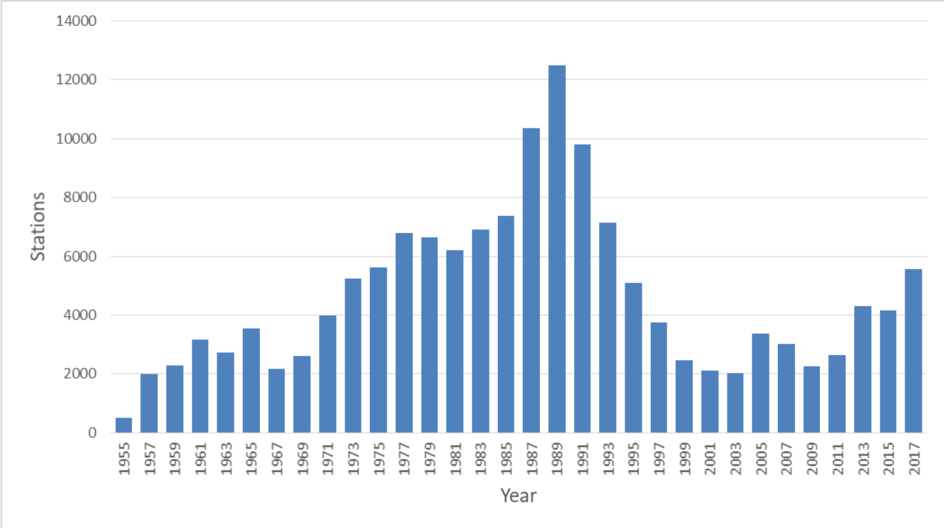


Figure 1.14 Temporal distribution of observations

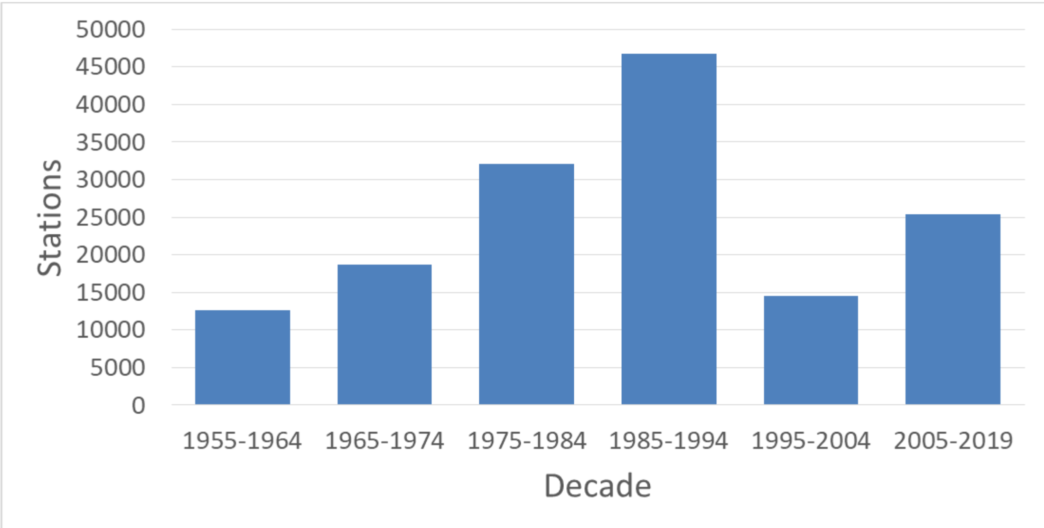
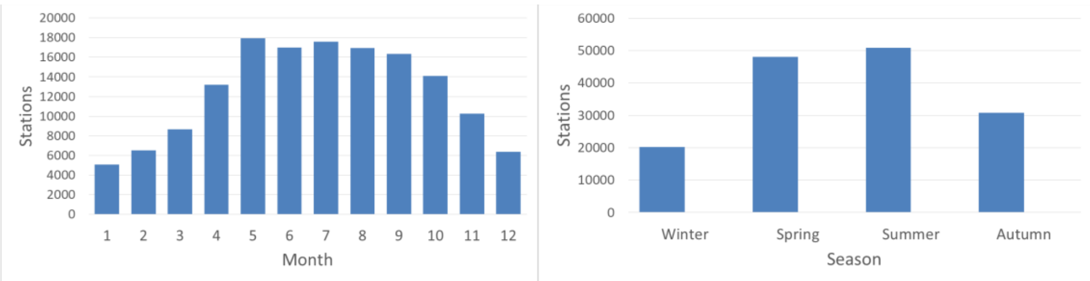


Figure 1.15 Decadal distribution of observations



a) b)

Figure 1.16 Monthly (a) and seasonal (b) distributions of observations for the period 1955 - 2019

The monthly and seasonal distributions have expected dome-like shape with maximum in summer (more observations) and minimum in winter (less observations).

Including data from external data sources significantly increased data availability. In certain decades (e.g. 1955-1964) the contribution from external data sources reaches 45% (Figure 1.17).

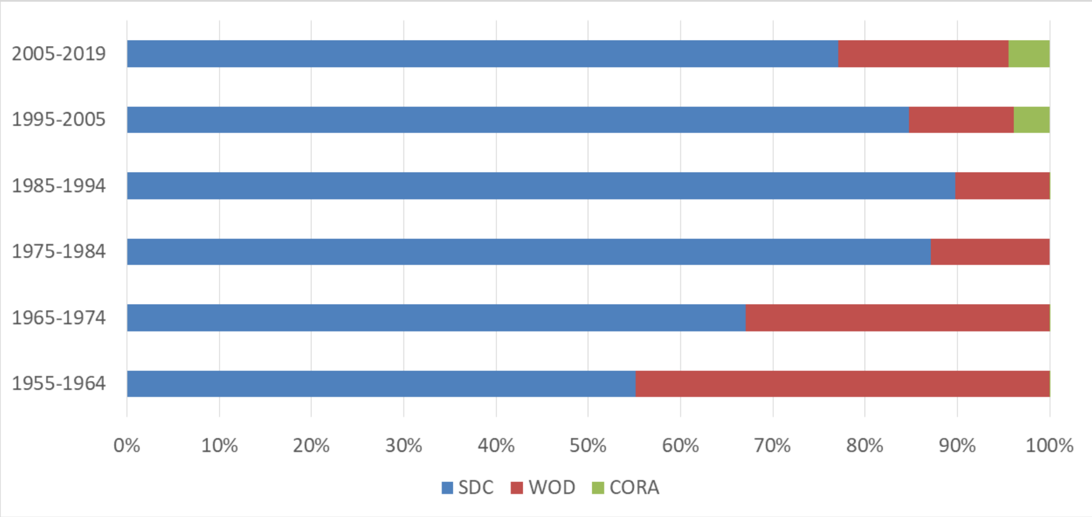


Figure 1.17 Statistics of profiles in the climatology dataset per data source

A more detailed view on decadal data coverage is provided in Figure 1.18 and Figure 1.19 for periods with minimum and maximum observations per decade respectively. During period 1955 -1964 there are significant data coverage gaps in January and December, while less significant gaps are observed in other months too.

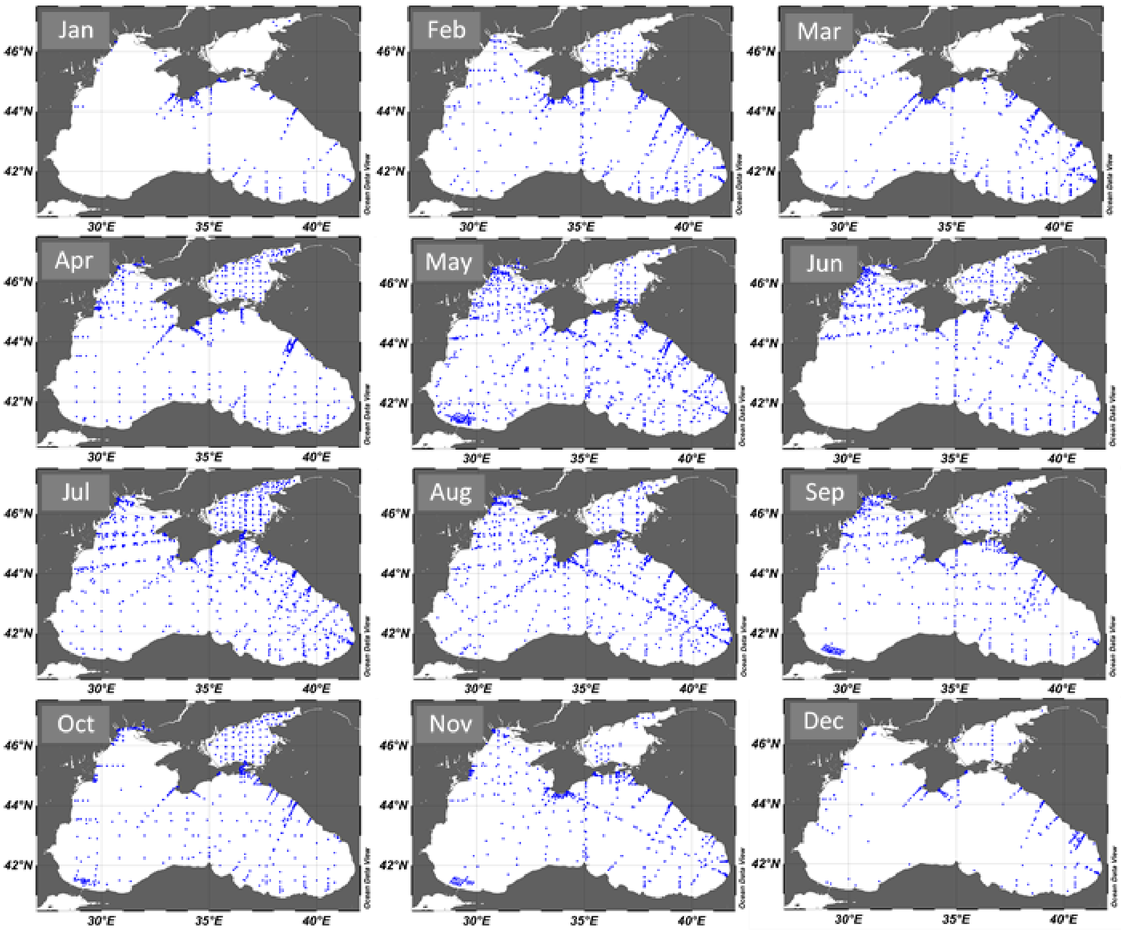


Figure 1.18 Monthly spatial distribution of observations for period 1955 – 1964

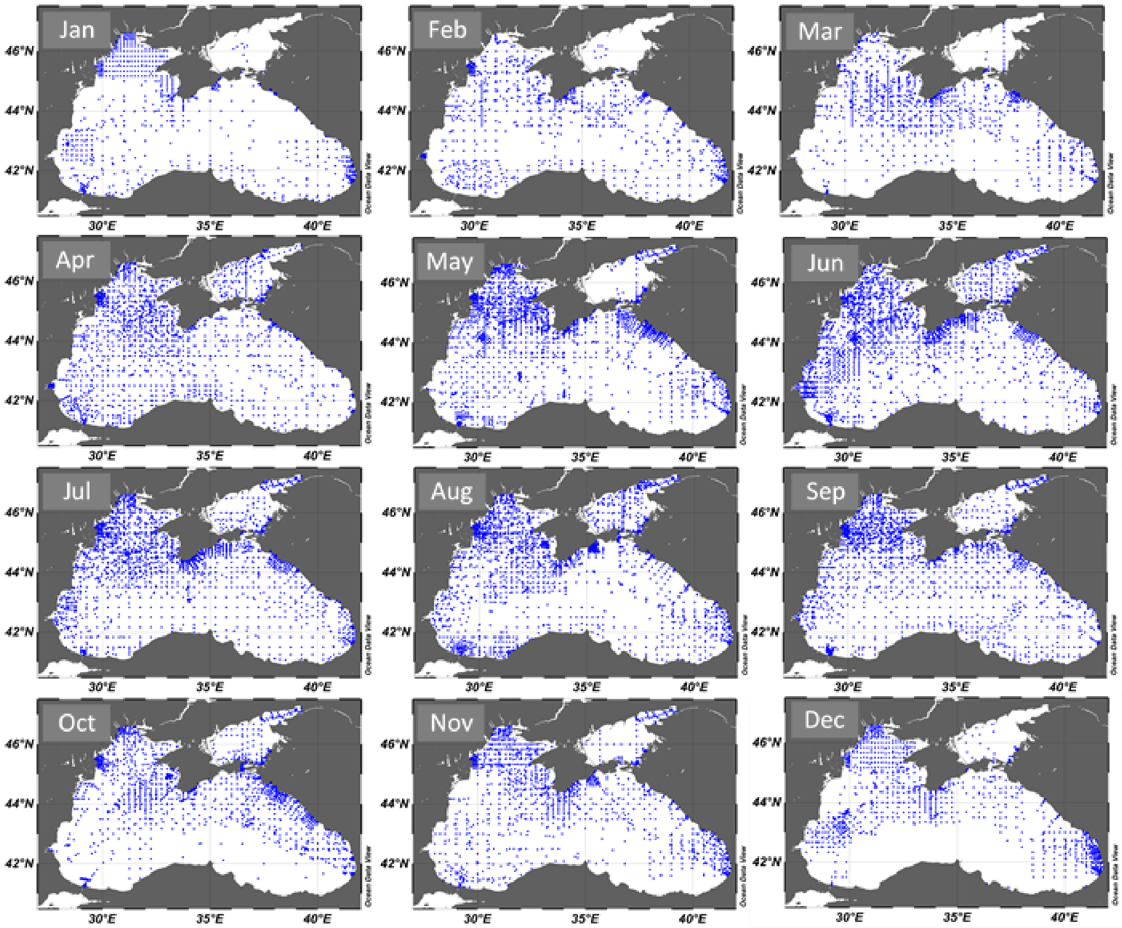


Figure 1.19 Monthly spatial distribution of observations for period 1995 - 2004

Even in the most successful for Black Sea oceanography decade 1984 – 1994 there are areas that are poorly covered with observations in some month, e.g. southern part of the sea in October and December.

Vertical distribution of observations (Figure 1.20) shows that data availability drastically decreases with depth. As the significant part of historical data was obtained with bottles at standard (at that time) levels, there are also data gaps in between, e.g. at 15, 40, and 125 m.

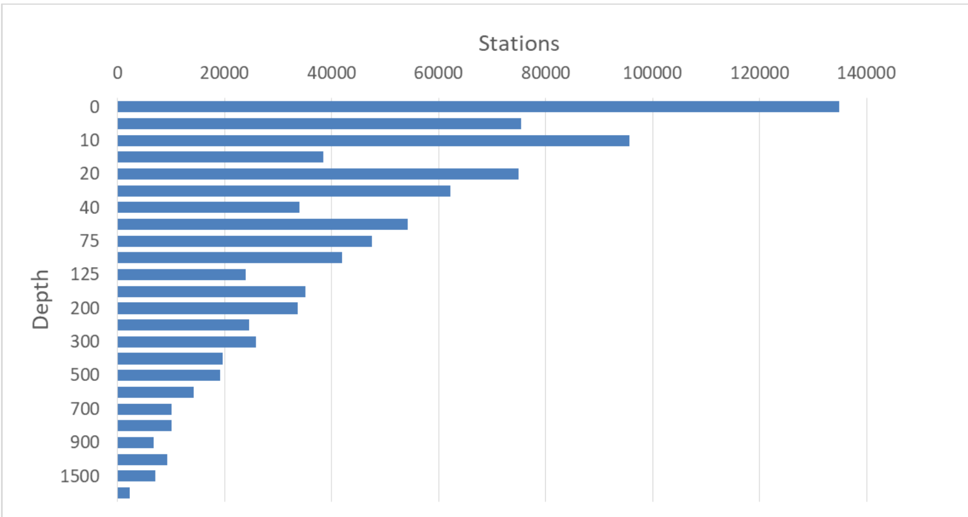


Figure 1.20 Vertical distribution of observations

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 1955-2019 and sub-periods 1955-1999, 2000-2019. (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 users' needs).
2. Seasonal Temperature and Salinity fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2019.

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

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 WOD and CORA datasets with ODV tools revealed presence of a significant number of anomalous data that were originally flagged as good, therefore the 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.

Two more issues were revealed in the WOD subset:

- Most of temperature values in the thermocline appeared to be flagged as "probably bad" due to high gradient, which in Black Sea goes up to 4 C°/m while the WOD 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.
- Detailed comparison of duplicate profiles revealed that many WOD profiles are shifted vertically comparing to SDC profiles, e.g. WOD profile starts from 10 m with the same values of T and S that SDC profile has on 0 m; WOD values at 20 m are the same that SDC values at 10 m and so on, i.e. WOD values shifted 1 depth level down compared to SDC. There is no reason to doubt about quality of SDC data therefore the depth in the respective WOD profiles was flagged as "probably bad". The flagging was applied to the identified duplicate profiles and to other suspicious profiles in a WOD cruise if all profiles in that cruise have upper depth different from 0 m, e.g. all profiles in a cruise start from 10 m or from 5 m. Flagged profiles were not included in the integrated dataset for climatology.

2.2. DIVA implementation and settings

Computation of the Black Sea Temperature and Salinity climatic fields was done with DIVAnd (12) version 2.6.2. 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 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 – 2019;
  1955 – 1999;
  2000 – 2019.
- Seasonal for periods
  1955 – 1964;
  1965 – 1974;
  1975 – 1984;
  1985 – 1994;
  1995 – 2004;
  2005 – 2019;
  1955 – 1999;
  2000 – 2019;
  1955 – 2019.

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

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 following areas have been masked:

- Sea of Marmara
- Adjacent lakes
- Grid cells with wrong depth (mistakes in GEBCO)
- Some isolated grid cells

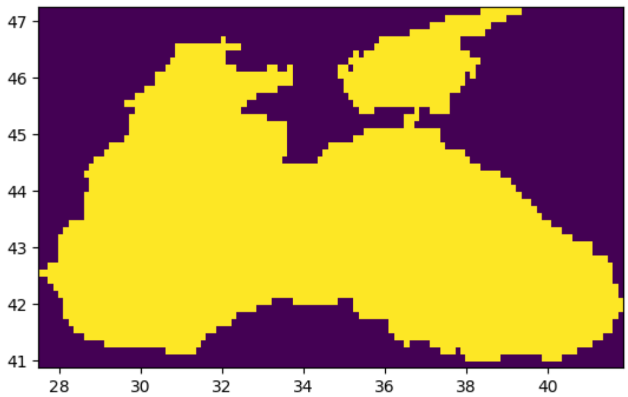


Figure 2.2 Mask at depth = 0 m

Table 6 **DIVAnd parameters**

Parameter name	Note	Temperature climatology	Salinity climatology
Horizontal correlation length	Adjusted (decreased) near Kerch strait, Bosporus and Dnieper inflow	150 km	
Vertical correlation length [m]	depth dependent for 67 depth 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	15, 20, 20, 20, 20, 20 20, 20, 20, 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*, 20, 20, 20, 20, 15 15, 15, 15, 15, 15 15, 15, 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 *20 for months 4,5,6
epsilon2		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)
niter_e	Number of iterations (should be 1 in case of epsilon2 adjustment)	1	1
Background field	Not used		
MEMTOFIT	Controls memory allocation	250	250
solver	"indirect" if not enough memory	direct	direct
fitcorrlen	If "true" then DIVAnd will calculate correlation length	false	false
surfextend	If "true" then DIVAnd will add extra layer on top to improve the first layer	true	true
minfield	Minimum of parameter	-1	0
coeff_derivative2	small penalty on the 2^{nd} derivative	[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. The most correct QC scores are produced with cross validation method which however is very expensive for computation. Unfortunately the computing resources that were available for calculation of the current product did not allow to use cross validation method therefore the standard three-Sigma criteria was used to identify and discard outliers.

In V1 Climatology the standard deviation was calculated per depth layer separately for the following sub-regions: Sea of Azov, NW shelf, near Bosporus area, and the rest of the Black Sea. However splitting the domain to such large chunks did not allow to achieve the desired result fully: the in-layer heterogeneity (and consequently variability) within sub-regions was still high, therefore many good data were discarded while the doubtful ones were retained.

For the current product 3-sigma criteria was used for global (1955-2019) monthly fields, calculation was done for 0.5x0.5° squares per layer. Automatic data rejection by 3-sigma criteria is not recommended because, for example, many good data in thermocline or halocline do not pass the criteria and should not be discarded. Therefore the residuals exceeding 3 sigma were merged with the climatology dataset and analysed in ODV by expert whether to flag the respective data with QF=7 (as out of range) or 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 about 22.3. 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.

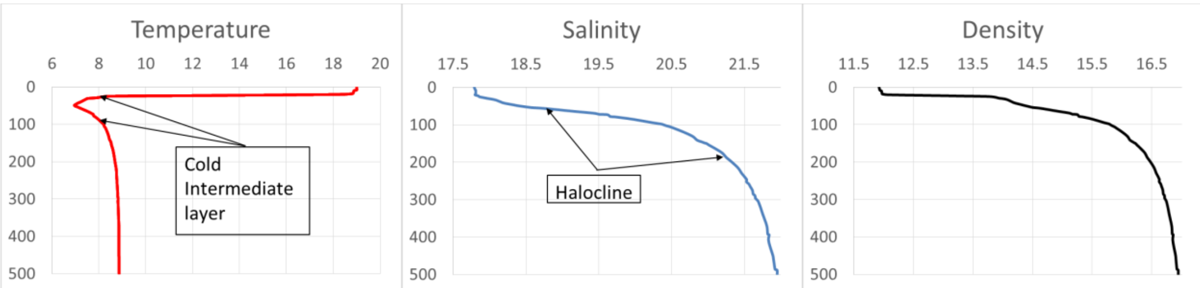


Figure 3.1 Typical Black Sea temperature, salinity, and density profiles.

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.

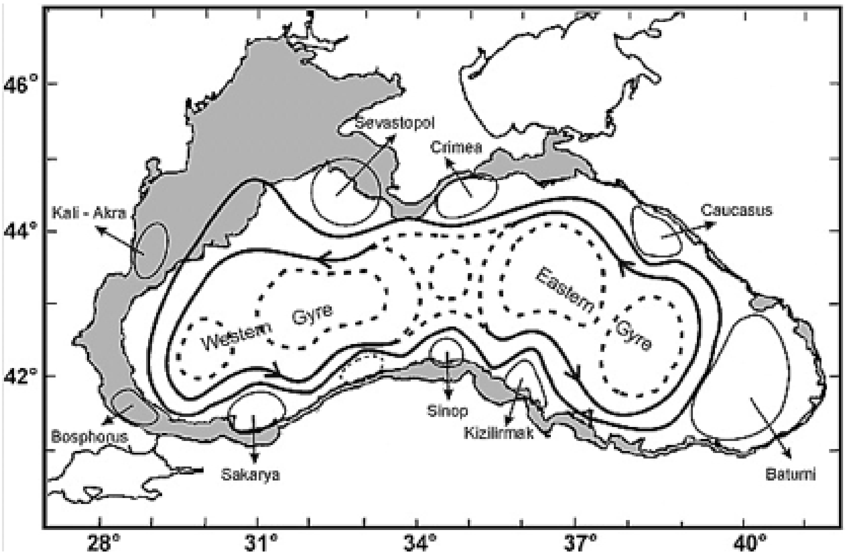


Figure 3.2 Schematic diagram for the main features of the upper layer (17).

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°.

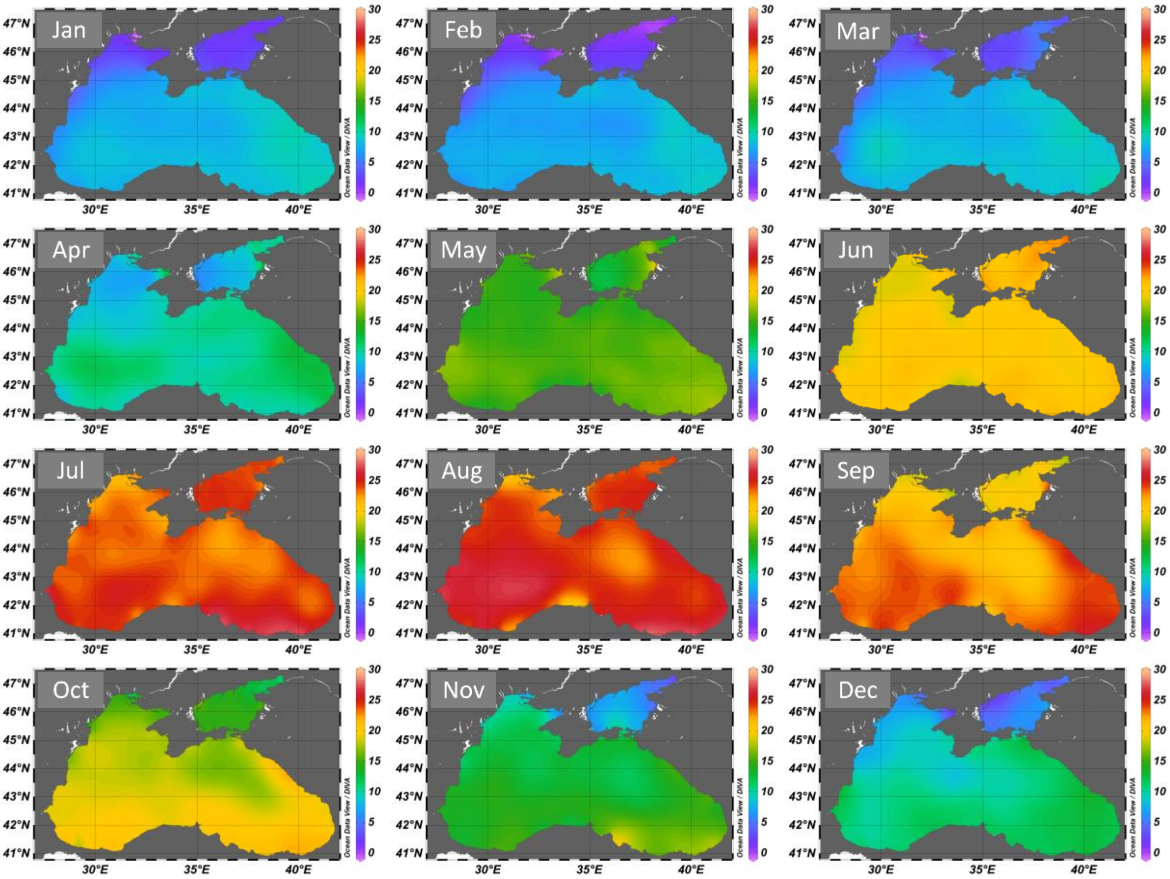


Figure 3.3 Monthly variation of Temperature at surface from DIVAnd analysis for the time period 1955-2019.

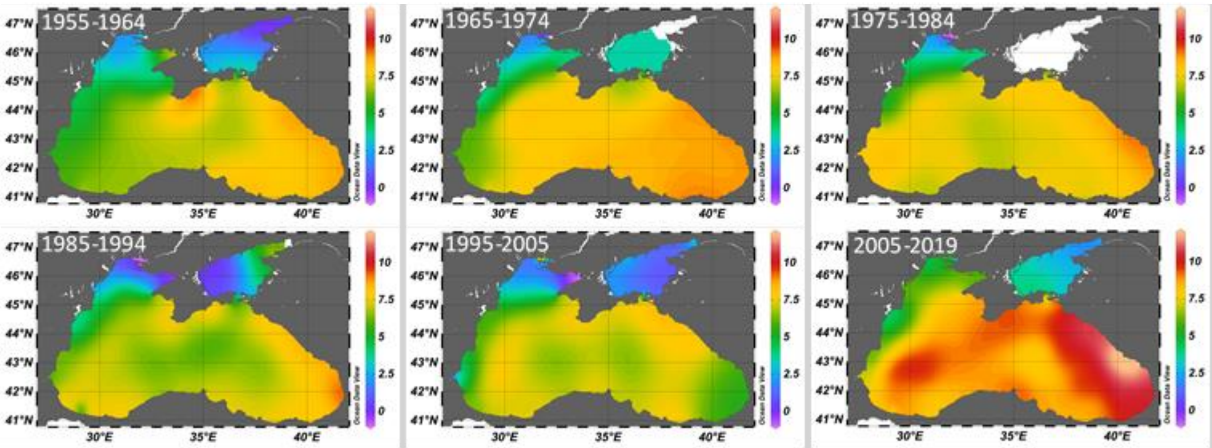


Figure 3.4 Variation of winter Temperature (Jan, Feb, Mar) at the surface in 6 decades over the period 1955-2019

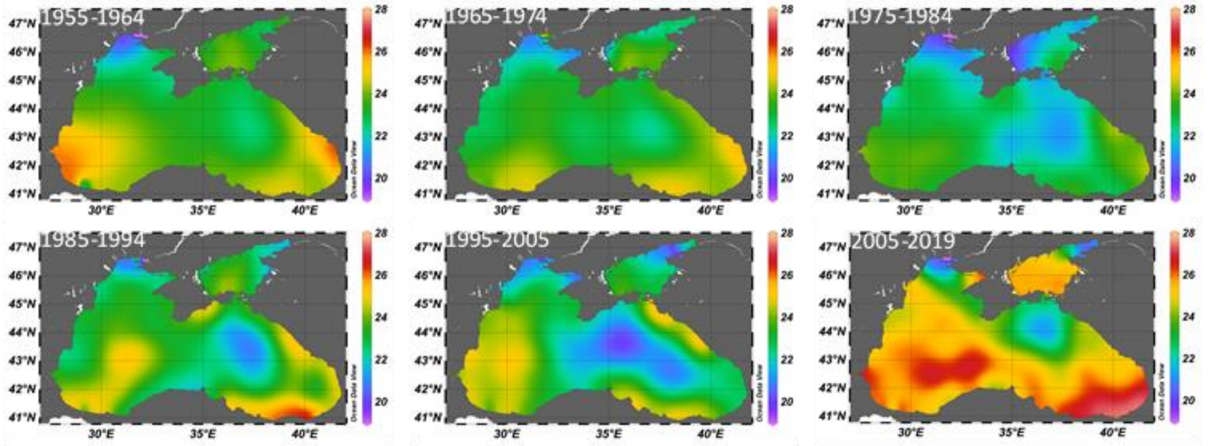


Figure 3.5 Variation of summer Temperature (Jul, Aug, Sep) at the surface in 6 decades over the period 1955-2019.

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.

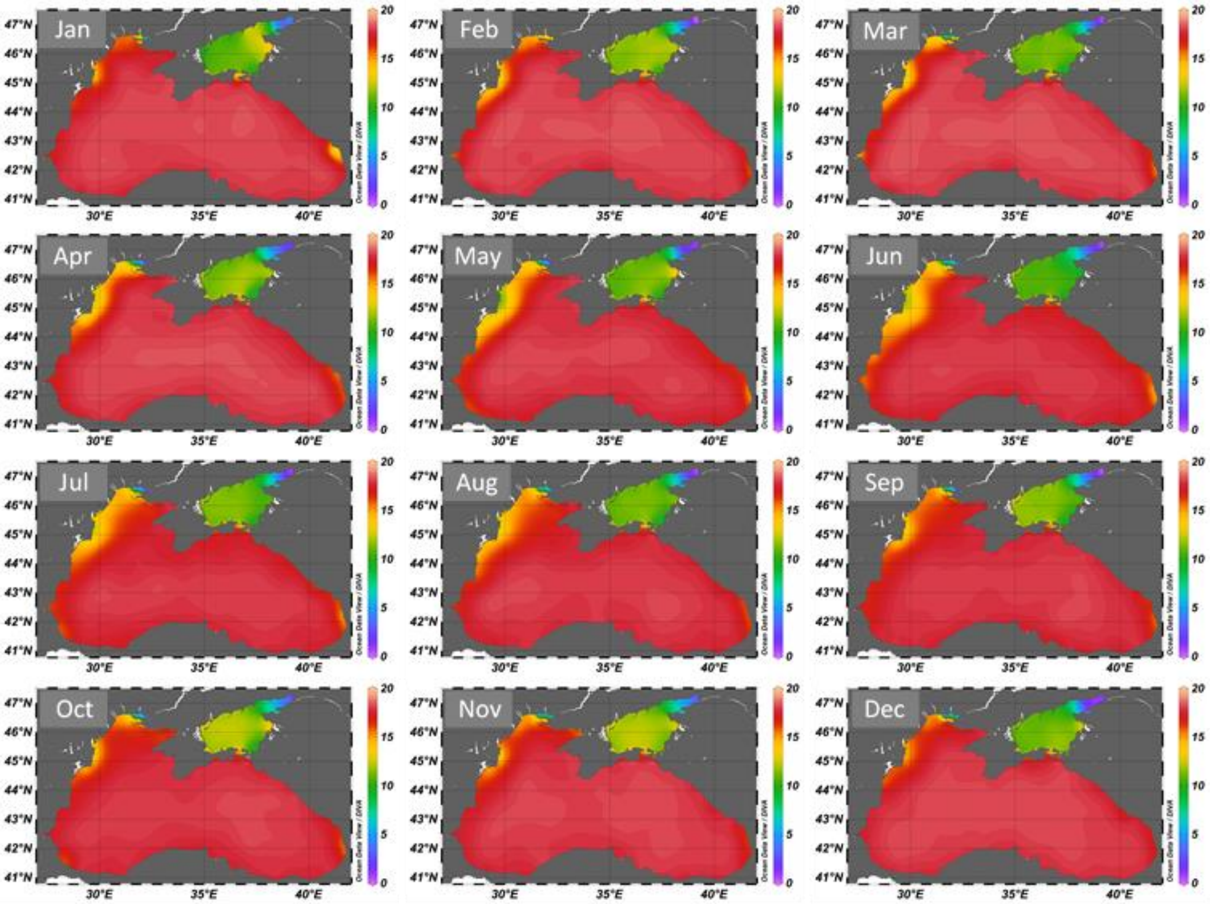


Figure 3.6 Annual variation of Salinity at the surface from DIVAnd analysis for the time period 1955-2019.

The evolution of main circulation features during the year (Rim Current, Batumi Eddy, see Figure 3.2), as well as the intrusion of saline Mediterranean waters through Bosporus strait (Figure 2.1) are well visible in the salinity maps between 70 and 130 m (see Figure 3.7).

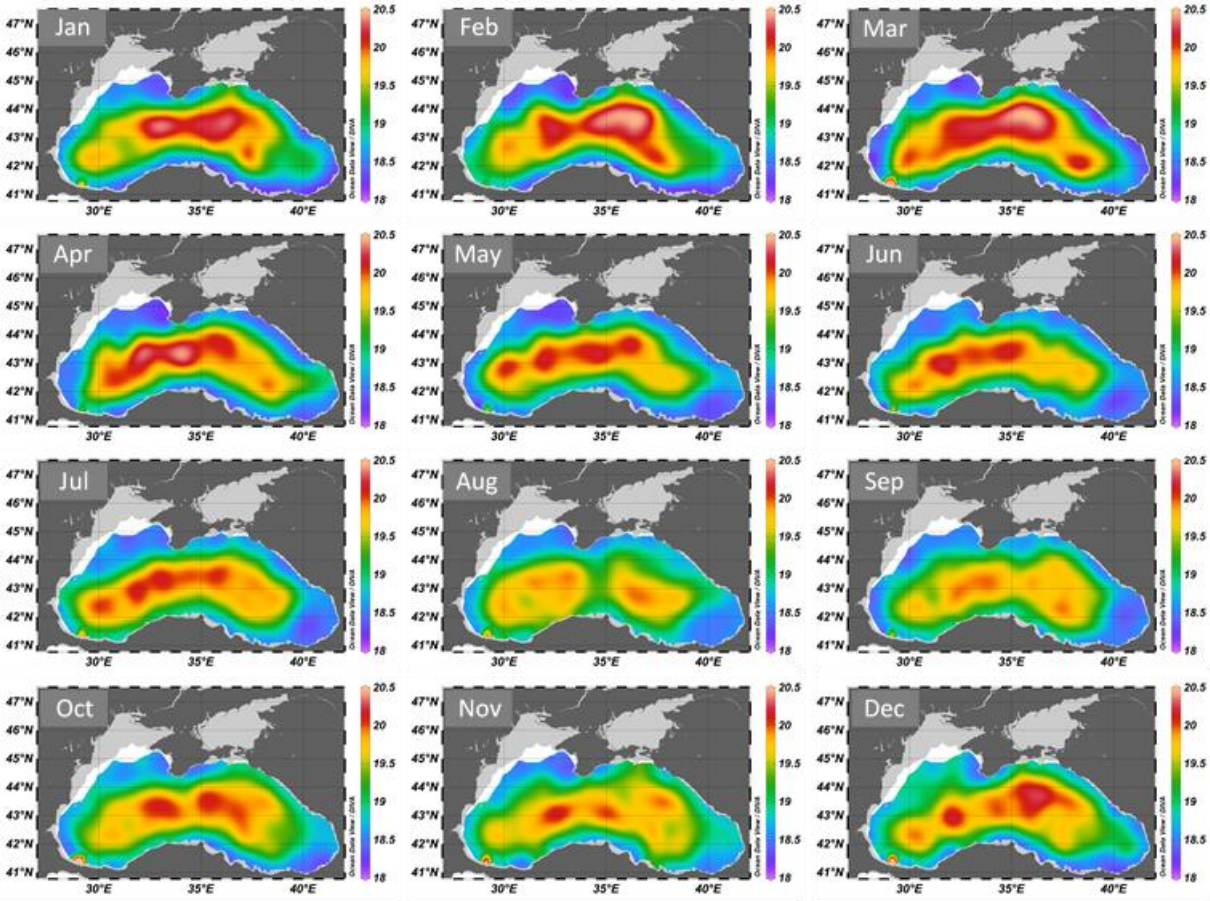


Figure 3.7 Annual variation of Salinity at 70 m from DIVAnd analysis over the time period 1955-2019.

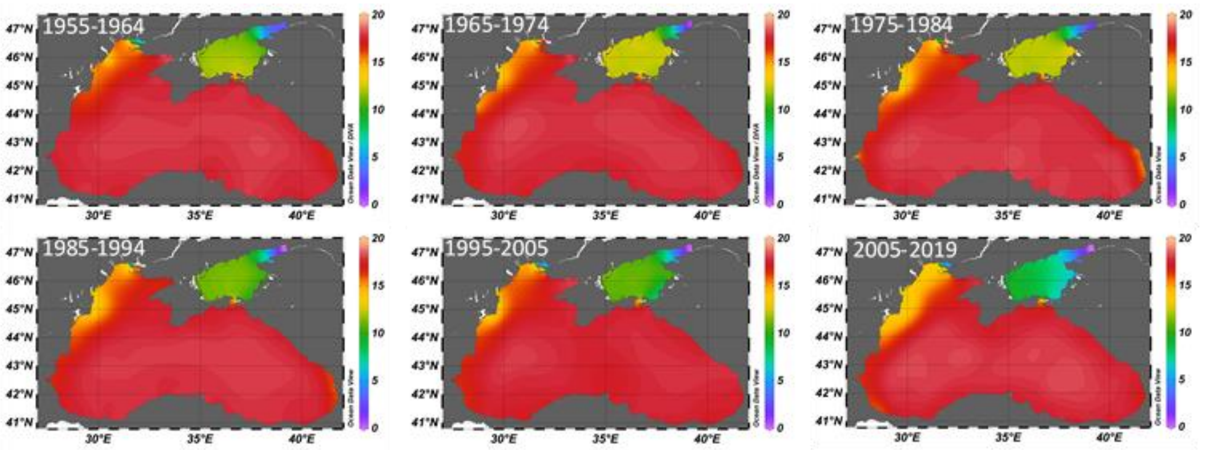


Figure 3.8 Variation of summer Salinity (Jul, Aug, Sep) at the surface in 6 decades in period 1955-2019

3.4. Error fields

DIVAnd output contains the analysed parameter field supplied with the respective relative error field and incudes two derived fields: parameter masked with error thresholds at 0.3 and parameter masked with error thresholds 0.5 fields. Relative error ranges from 0 to 1, it is lowest near the observations and tends to 1 far away from them. The threshold 0.3 was selected in assumption that it will allow masking anomalies caused by low data coverage, however it is not always the case as it is presented at Figure 3.9. The figure contains 3 maps of seasonal salinity for autumn 2005-2019. Anomaly of salinity has been highlighted by a circle area NW of Crimean peninsula (upper map) and is not masked. Analysed salinity values here reach 19.2 PSU while usual in-situ salinity at surface in this area is 18-18.3 PSU. The reason for anomaly is data gap in this area (middle map), which is reflected in the relative error field (lower map), however the relative error maximum = 0.2 is below the 0.3 threshold therefore the anomaly is not masked. The suggested threshold for masking anomaly is 0.1.

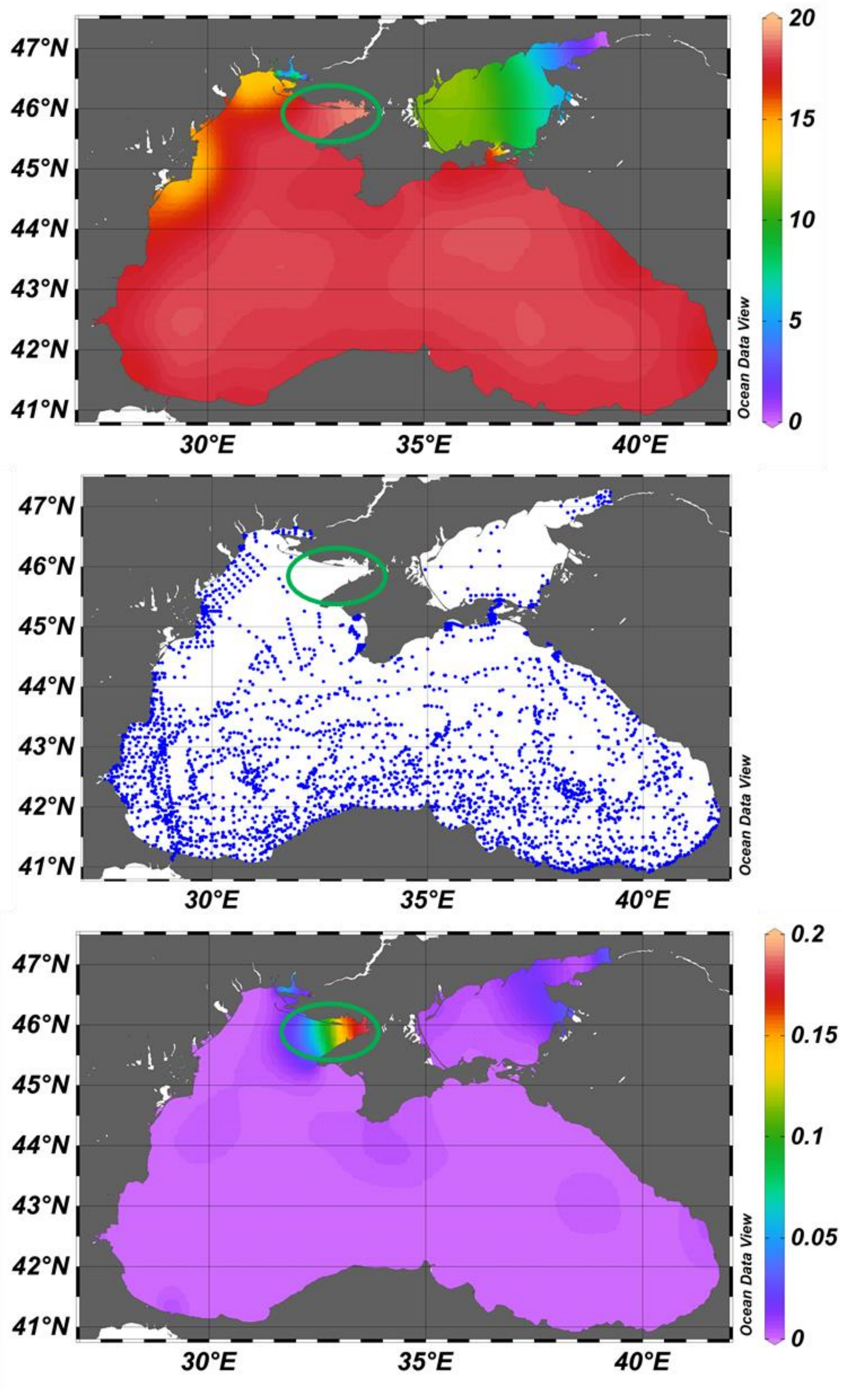


Figure 3.9 Analyzed field (upper map), observation positions (middle map), and relative error field for salinity, autumn 2005-2019

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), version WOA18 released in September 2018. Seasonal climatological fields of Temperature and Salinity (objectively analysed mean) are available at resolution 1/4° for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, and 2005-2019. 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 4.3. The maps have similarities and differences. The WOA18 maps are smoother and contain fewer 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 February is stronger; in SDC salinity map the areas of river inflows are more pronounced, the Sea of Azov has a more natural salinity distribution.

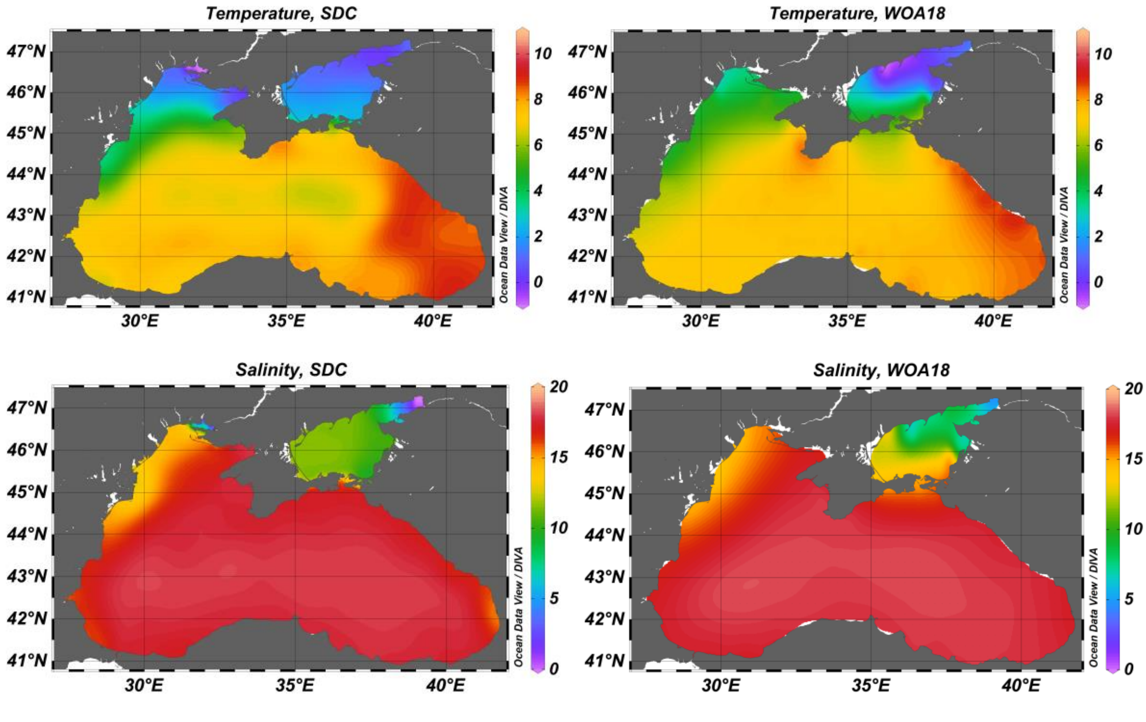


Figure 4.1 SDC and WOA18 temperature (February) and salinity (July) maps at the surface for time span 1955-2019.

Main differences between two products are observed in upper 300 m layer. For example, the well-known effect of isohalines doming at the centre of the sea due to the Rim Current is well pronounced in SDC maps, while in WOA18 ones it is not that strong probably due to its coarse resolution. Moreover, the Bosporus plume and Batumi Eddy are visible in the SDC salinity maps (Figure 4.2) in depth layer 70-130 m, while these Black Sea features are missing in WOA18 maps.

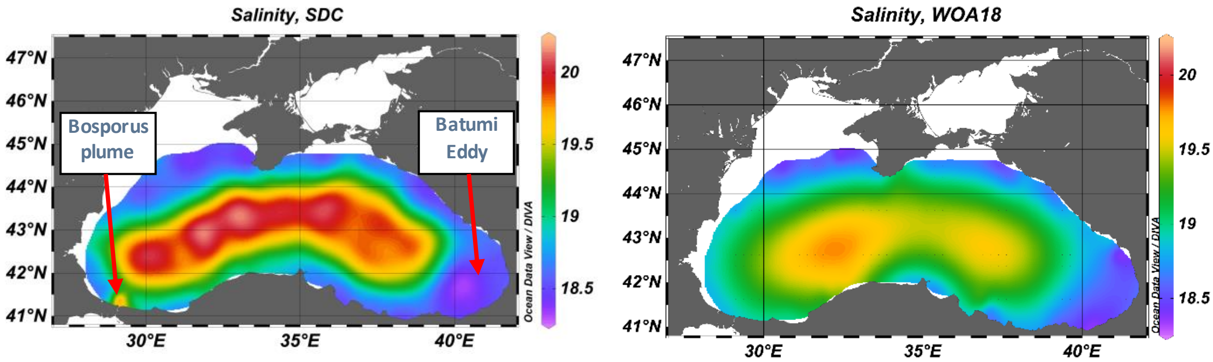


Figure 4.2 SDC and WOA18 salinity maps at 70 m in July.

To quantify the differences between WOA18 and SDC climatologies the statistical indexes BIAS and RMSE were calculated over different time periods: monthly and seasonal fields for the time span 1955-2019 and, seasonal fields for the decades. The comparison was performed for matching grid nodes at 0.125, 03.75, 0.625, and 0.875 degree for upper layer 0 – 300m. The basin averaged BIAS indexes (i.e. calculated for the 3d grid and whole time span) in Table 4.1 range from -0.16 to 0.14 for temperature and from -0.11 to 0 for salinity, suggesting an 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	0.72	0.00	0.34
Seasonal	1965 - 1974	-0.01	0.70	-0.03	0.30
Seasonal	1975 - 1984	0.14	0.56	-0.10	0.27
Seasonal	1985 - 1994	0.09	0.63	-0.05	0.28
Seasonal	1995 - 2004	-0.16	1.17	-0.11	0.40
Seasonal	2005 - 2019	-0.15	0.76	0.02	0.39
Seasonal	1955 - 2019	-0.05	0.55	-0.07	0.30
Monthly	1955 - 2019	-0.05	0.61	-0.07	0.31

More detailed analysis was performed for monthly fields. The extremes of temperature BIAS (WOA18 – SDC) up to -0.6C° are observed in summer months in the upper layer (Figure 4.3): the negative BIAS is apparent in the 0-25 m depth layer while a positive BIAS below presents its maximum at about 50 m. The RMSE values are also the highest over the same time periods and depths.

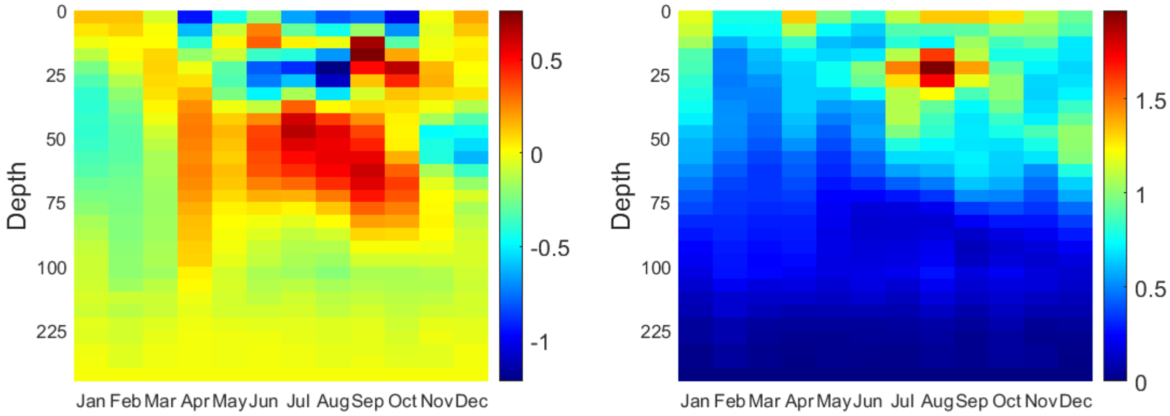


Figure 4.3 Hovmoller plots of BIAS (left) and RMSE (right) indexes of WOA18 – SDC monthly temperature fields (upper 300 m).

The maximum of positive salinity BIAS (WOA18 – SDC) up to 0.25 is observed at the surface, while the negative values up to -0.3 are observed in the 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).

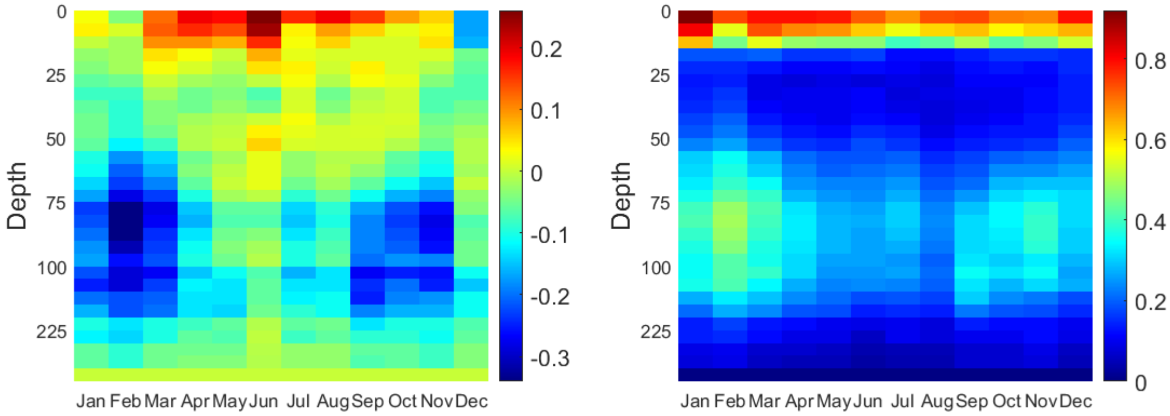


Figure 4.4 Hovmoller plots of BIAS (left) and RMSE (right) indexes of WOA18 – SDC monthly salinity fields (upper 300 m).

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

1) The dataset used for computation of SDC climatology are different, moreover, the SDC dataset used for this product contains only couples T-S profiles. Usage only coupled profile significantly decreased data coverage in 1st and 2nd decade. The difference in data leads to the difference in obtained climatic fields.
2) The horizontal resolution of WOA18 climatology is half the resolution of the SDC climatology, thus WOA18 fields are smoother with less details than SDC ones, particularly in areas characterized by pronounced horizontal gradient: areas of rivers inflow, near Kerch and Bosporus straits, along the coast. The BIAS, and particularly RMSE index in such areas are the largest.
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 regions characterized by temperature or salinity gradients, and also reflected in extremes: i.e. values of maximums (minima) should be lower (higher) in WOA18 than in SDC fields.

4) Unlike WOA18, which is based on 2-d data analysis, the SDC climatology is produced with 3-d data analysis. DIVAnd analysis works well for internal grid points which are surrounded by observation data however it may produce anomalies in case scarce data and at domain boundaries, e.g. in case of strong positive vertical gradient DIVAnd tends to overestimate boundary values and vice versa for negative gradient.
5) Flagging temperature values in thermocline as bad in WOD (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:

- First three factors are responsible for overall differences between two products but do not explain presence of extreme values in BIAS and RMSE indices.
- Large negative values of temperature BIAS at surface layer in summer are explained mainly by factor 4.
- Layer 10-30 m contains thermocline that is present in all seasons except winter. Large values of temperature BIAS in that layer are explained by factor 5. The same factor is responsible for large RMSE values in summer months when thermocline is most developed.
- Elevated values of temperature BIAS are related to lower part of CIL and explained by factors 1 to 4.
- Factor 4 is also responsible for large positive values of salinity BIAS at the surface.
- Elevated values of salinity BIAS and RMSE in halocline zone (70-150 m) are explained by factors 1 to 4.

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 because of presence anomalies in the SDC fields. Due to higher sensitivity of DIVAnd analysis 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_2019_0125_m.4Danl.nc** Temperature **m**onthly climatological fields for 3 time spans: 1955-1994, 1995-2019, and **1955-2019** at **0.125** degrees spatial resolution.
2. **SDC_BLS_CLIM_S_1955_2019_0125_m.4Danl.nc** Salinity **m**onthly climatological fields for 3 time spans: 1955-1994, 1995-2019, and **1955-2019** at **0.125** degrees spatial resolution.
3. **SDC_BLS_CLIM_T_1955_2019_0125_s.4Danl.nc** Temperature **s**easonal climatological fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2019, and 3 time spans: 1955:1994,1995:2019, and **1955-2019** at **0.125** degrees spatial resolution.
4. **SDC_BLS_CLIM_S_1955_2019_0125_s.4Danl.nc** Salinity **s**easonal climatological fields for 6 decades: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2019, and 3 time spans: 1955:1994,1995:2019, and **1955-2019** at **0.125** degrees spatial resolution.

NetCDF file also contains the set of variables with metadata of observations used for analysis:

- obsid – list of observation identifiers in form “EDMO code”_”Local CDI ID”
- obslat, obslon – corresponding list with observation coordinates
- obstime - corresponding list of time values
- obsdepth - corresponding list of depth values

NetCDF file contains the 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 may contain T-S profiles with vertical instability. In this version of the product, efforts were undertaken to achieve vertical stability. As a result the number of profiles having density inversions decreased significantly. The remaining cases of vertical instability are mainly related to winter seasons in 1st and 2nd decades in which data coverage is very low. It should be noted that magnitude of remaining density inversions also decreased significantly compared to the previous version. In the current version of the product **none** dedicated post processing was applied for correction of remaining vertical instability.

One of undertaken measures for achieving vertical stability was selection for analysis only coupled T-S profiles. The side effect of this was worsening of data coverage in some periods, particularly in the 1st and 2nd decades, which resulted in appearing anomalies.

The SDC climatology well reproduces the 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 threshold = 0.3. It is recommended to use analysed fields in conjunction with the respective error field and adjust the threshold for masking based on concrete relative error maximums.

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 2019 and available at SEXTANT Catalogue (http://sextant.ifremer.fr/en/web/seadatanet) under the name “SeaDataCloud Black Sea Temperature and Salinity Climatology V1”.

Compared to previous version (V1), the present one (V2) is based on extended data coverage up to middle of 2019. Following measures were undertaken to achieve steady vertical stability of merged T-S profiles:

- only co-located T-S profiles were included in the integrated dataset for analysis;
- the vertical correlation length was tuned to match the shape of climatology profiles with the respective mean observed profiles;
- the background field was not used in analysis because it has a negative effect in mixed layer over the winter months.

These measures resulted in significant decreasing of number of profiles with vertical instability.

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 1995-2019 **1955-2019**	monthly	SDC_BLS_CLIM_T_1955-2019_0125_m
SDC	BLS	CLIM	S	1955-1994 1995-2019 **1955-2019**	monthly	SDC_BLS_CLIM_S_1955-2019_0125_m
SDC	BLS	CLIM	T	1955-1964 1965-1974 1975-1984 1985-1994 1995-2004 2005-2019 **1955-2019**	seasonal	SDC_BLS_CLIM_T_1955-2019_0125_s
SDC	BLS	CLIM	S	1955-1964 1965-1974 1975-1984 1985-1994 1995-2004 2005-2019 **1955-2019**	seasonal	SDC_BLS_CLIM_S_1955-2019_0125_s

References

1. SeaDataCloud - Further developing the pan-European infrastructure for marine and ocean data management. Grant Agreement Number: 730960 - HBM4EU - H2020-SC1-2016-2017/ H2020-SC1-2016-RTD. *https://www.hbm4eu.eu/wp-content/uploads/2017/03/HBM4EU-Grant-Agreement.pdf*
2. Volodymyr Myroshnychenko, Dick Schaap, Reiner Schlitzer (2018). Black Sea - Temperature and salinity Historical Data Collection SeaDataCloud V1. *https://doi.org/10.12770/2287615d-1977-479f-8d5b-439960bcb21a*
3. Boyer, T.P., O. K. Baranova, C. Coleman, H. E. Garcia, A. Grodsky, R. A. Locarnini, A. V. Mishonov, T.D. O'Brien, C.R. Paver, J.R. Reagan, D. Seidov, I. V. Smolyar, K. Weathers, and M. M. Zweng, 2018: World Ocean Database 2018 (in preparation). Resource web address: *https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html*.
4. Szekely Tanguy, Gourrion Jerome, Pouliquen Sylvie, Reverdin Gilles (2016). CORA, Coriolis Ocean Dataset for Reanalysis. SEANOE. *https://doi.org/10.17882/46219*
5. Myroshnychenko Volodymyr (2020). SeaDataCloud Temperature and Salinity Historical Data Collection for the Black Sea (Version 2). Product Information Document (PIDoc). *https://doi.org/10.13155/77211*
6. Schlitzer, R., Ocean Data View, odv.awi.de, 2017
7. PRODUCT USER MANUAL For Global Delayed Mode Insitu Dataset INSITU_GLO_TS_REP_OBSERVATIONS_013_001_b called CORA. *http://marine.copernicus.eu/documents/PUM/CMEMS-INS-PUM-013-001-b.pdf*
8. Arthur Capet, Emil V. Stanev, Jean-Marie Beckers, James W. Murray, and Marilaure Grégoire. Decline of the Black Sea oxygen inventory. Biogeosciences, 13, 1287–1297, 2016, doi:10.5194/bg-13-1287-2016.
9. A. Capet, C. Troupin, J. Carstensen, M. Grégoire, J.-M. Beckers. Untangling spatial and temporal trends in the variability of the Black Sea Cold Intermediate Layer and mixed Layer Depth using the DIVA detrending procedure. Ocean Dynamics (2014) 64:315–324 DOI 10.1007/s10236-013-0683-4.
10. WORLD OCEAN ATLAS 2018 (WOA18) – prerelease *https://www.nodc.noaa.gov/OC5/woa18/*
11. L20 (SeaDataNet measurand qualifier flags) *http://seadatanet.maris2.nl/v_bodc_vocab_v2/search.asp?lib=L20*
12. Garcia, H. E., T. P. Boyer, R. A. Locarnini, O. K. Baranova, M. M. Zweng (2018). World Ocean Database 2018: User's Manual (prerelease). A.V. Mishonov, Technical Ed., NOAA, Silver Spring, MD (Available at https://www.NCEI.noaa.gov/OC5/WOD/pr_wod.html).
13. Barth, A., Beckers, J.-M., Troupin, C., Alvera-Azcárate, A., and Vandenbulcke, L.: DIVAnd-1.0: n-dimensional variational data analysis for ocean observations, Geosci. Model Dev., 7, 225-241, doi:10.5194/gmd-7-225-2014, 2014.
14. The GEBCO Digital Atlas published by the British Oceanographic Data Centre on behalf of IOC and IHO, 2003
15. Murray, J. W., Stewart, K., Kassakian, S., Krynytzky, M., and DiJulio, D. (2007). "Oxic, suboxic and anoxic conditions in the Black Sea," in The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement, eds V. Yanko-Hombach, A. S. Gilbert, N. Panin, and P. M. Dolukhanov (Amsterdam: Springer), 1–21.

16. C. Michael Hogan (2013). *Black Sea*. Encyclopedia of Earth. National Council for Science and Environment. Washington DC Retrieved from *http://editors.eol.org/eoearth/wiki/Black_Sea*
17. Oguz, T., V. S. Latun, M. A. Latif, V. V. Vladimirov, H. I. Sur, A. A. Makarov, E. Ozsoy, B. B. Kotovshchikov, V. Eremeev, and U. Unluata, Circulation in the surface and intermediate layers of the Black Sea, Deep Sea Res., Part I, 40, 1597–1612, 1993.
18. Locarnini, R.A., A.V. Mishonov, O.K. Baranova, T.P. Boyer, M.M. Zweng, H.E. Garcia, J.R. Reagan, D. Seidov, K.W. Weathers, C.R. Paver, I.V. Smolyar (2018). World Ocean Atlas 2018, Volume 1: Temperature. A. Mishonov, Technical Editor. NOAA Atlas NESDIS in preparation.
19. Zweng, M.M, J.R. Reagan, D. Seidov, T.P. Boyer, R.A. Locarnini, H.E. Garcia, A.V. Mishonov, O.K. Baranova, K.W. Weathers, C.R. Paver, I.V. Smolyar (2018). World Ocean Atlas 2018, Volume 2: Salinity. A. Mishonov, Technical Editor, NOAA Atlas NESDIS 82, 40pp.

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