Product Information Document (PIDoc)

Black Sea gridded decadal seasonal climatology for cold intermediate layer cold content at 1/8°

SDC_BLS_DP2

HORIZON **2020**

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Product Name

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Short description

Black Sea gridded decadal seasonal climatology for cold intermediate layer (CIL) cold content (CCC) (1/8°, 6 decades, 4 seasons) based on the collection of temperature and salinity profiles spanning 60 years (1955–2014).The CCC 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.

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1.0	V. Myroshnychenko	01/10/2020	First version
1.1	C. Troupin	08/02/2021	Revision
1.2	S. Simoncelli	10/02/2021	final check
1.3	V. Myroshnychenko	11/02/2021	Final version

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Abstract

The SDC_BLS_DP2 product contains the Black Sea gridded seasonal climatology for cold intermediate layer (CIL) cold content (CCC) based on the collection of temperature and salinity profiles spanning 60 years (1955–2014). The CIL cold content CCC is the value of ocean heat content within the cold intermediate layer. The CCC fields have spatial resolution 1/8° and provided for each season - winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and autumn (Oct-Dec) - in 6 decades (1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2014). The product was developed in framework of the SeaDataCloud project. The profiles for CCC computation were extracted from a merged Black Sea dataset that combines data 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

1.1. Source data set

The input dataset for the computation of the cold intermediate layer (CIL) cold content (CCC) climatological fields was extracted from the integrated dataset used for calculation of Black Sea Temperature and Salinity Climatology and combining data from the following sources:

1. SeaDataCloud (SDC (1)) Temperature and Salinity Historical Data Collection for the Black Sea (Version 1) - SDC_BLS_DATA_TS_V2 (2).
2. SeaDataCloud Restricted Temperature and Salinity Historical Data Collection for the Black Sea (Version 2) - 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.

The duplicated were excluded in the process of merging data into the integrated dataset. All source datasets underwent quality control (QC) according to the procedures used by the respective producers. Each data value in the integrated datasets is supplied with the quality flag (11).

The whole integrated dataset contains data from more than 270,000 oceanographic stations and underway measurement. From that dataset only the profiles, which contain CIL, were extracted for the current product.

1.2. Selection of data for CIL analysis

According to the classical definition, the Black Sea CIL is the layer with temperatures lower than 8°C in Black Sea subsurface waters. The CIL occurs in a depth range 10 - 200 m.

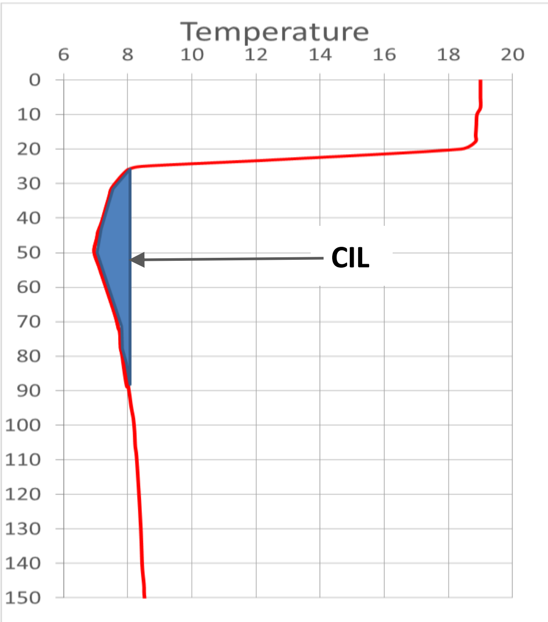

Figure 1 Temperature profile with CIL

The CCC is calculated with the formula:

$$CILcoldcontent = \rho Cp \int_{z1}^{z2} [T - Tcil] dZ, \quad (1)$$

where ρ is the potential density, *Cp* the heat capacity, T is potential temperature and *Tcil* = 8°C. The CCC should be calculated only from good observations, i.e. observations having Depth, Temperature and Salinity values flagged as "good".

The candidate profiles for CIL analysis and CCC calculations should satisfy the following conditions:

- contain both temperature (T) and salinity (S);
- contain cold subsurface layer with Tmin < 9.25°, where 9.25° is the climatic maximum for deep waters temperature in Black Sea;
- contain at least one good observation within that layer, i.e. the observation with values of Depth, Temperature and Salinity flagged as good;
- be deep enough to include the whole CIL;
- have T > 8° at upper and lower depth.

A total of 35,428 candidate profiles were identified in the integrated dataset for the period 1955-2019. From this amount 18,833 profiles were acquired with different types of CTD profilers (SeaBird, ARGO etc.) while the rest 16,595 were acquired with bottles.

In case of bottle profiles the CIL can't be caught precisely because of the low vertical resolution of measurements. Ideally the CCC should be calculated from the CTD profiles, preferably having a depth resolution of 1m. But the share of CTD data in the CIL subset is just slightly above 50%, moreover, CTD data in the Black Sea are practically not available before 1980, therefore we have to deal with bottle data too.

It is obvious that CCC calculated from low resolution bottle data is subject to underestimation/overestimation error. The following experiment was performed in order to investigate that error:

- there were 575 CTD stations selected in the period 1996-2013 for which also the bottles data were available from an independent source;
- the CCC calculated from CTD data was compared with the CCC calculated from bottle data.

The result showed that in general CCC computed from bottle data underestimates heat content in CIL, and that the difference between the two values significantly depends on the number of bottle points within the CIL (NPcil):

- if NPcil=3, 1 point within CIL and 2 intercept points, the average difference is 35%;
- if NPcil≥5 the average difference is below 10%.

It was also investigated if applying spline interpolation to bottle profiles can improve the result. Spline interpolation showed an improvement for NPcil values between 5 and 7 with average difference lower than ~2%, but at the same time it produced a number of weird outliers which could bias the further analysis, therefore spline interpolation was not applied.

The CIL was present in 28929 candidate profiles. The reason for the absence of CIL on the rest of the profiles could be the scarcity of observations in the CIL layer (in case of bottle profiles) and **climatic changes** occurred in the Black Sea environment in the last two decades (8, 9, 10): the CIL temperatures are gradually increasing, while the CIL volume is decreasing up to a total disappearance in certain areas and periods. Therefore in order to get a complete overview of CIL evolution in time and space we have to take into account also the candidate profiles without CIL and assign the CCC value for such profiles equal to 0.

Summarizing the above, the eligible profiles for CCC analysis are those which:

- contain CIL and contain at least 3 good observations within CIL plus one good observation above and one good observation below the CIL. For such profiles the CCC is calculated by formula (1); or
- contain subsurface layer with the minimum that exceeds Tcil, however are deep enough to include the whole CIL if it would be present, and are acquired with CTD-type profiler (i.e. have good depth resolution in order to exclude cases where CIL is simply not caught by low resolution bottle data). The profile maximum depth should be more than 200m for observations done before 2000, 180m for observations between 2000 and 2010 and 150m after 2010 (Figure 2). For such profiles CCC is set to 0.

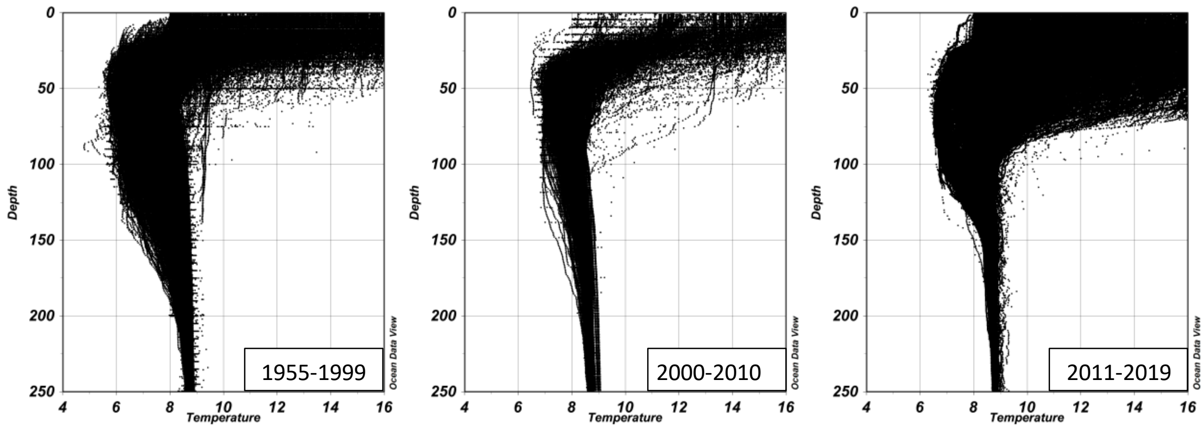

Figure 2 Scatter plot of Temperature in the up upper 0 – 250 m layer for three time periods: before 2000 (left), between 2000 and 2010 (middle) and after 2010 (right).

Upon discarding non-eligible candidate profiles, the input dataset contains 24950 profiles (19800 with CCC > 0 and 5150 with CCC set to 0). The spatial and temporal distributions of profiles in the input dataset are presented in Figure 3 and Figure 5 respectively.

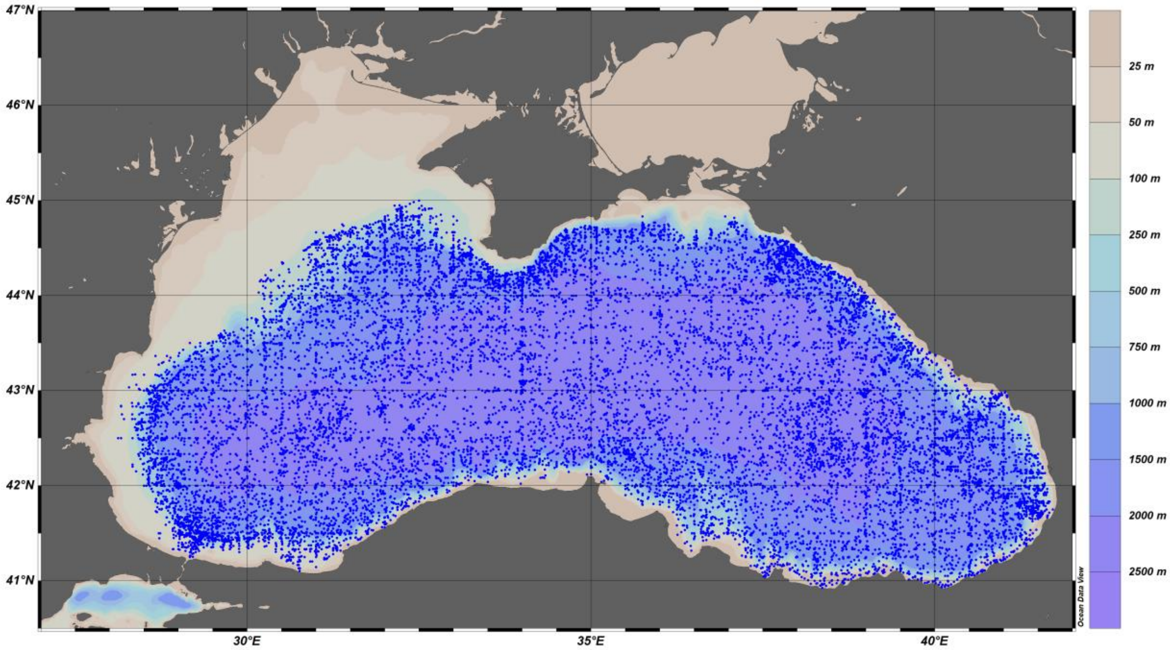

Figure 3 Spatial distribution of profiles used for CCC analysis.

The overall spatial coverage looks regular, but in some months, years and even within longer periods it can be very heterogeneous (Figure 4).

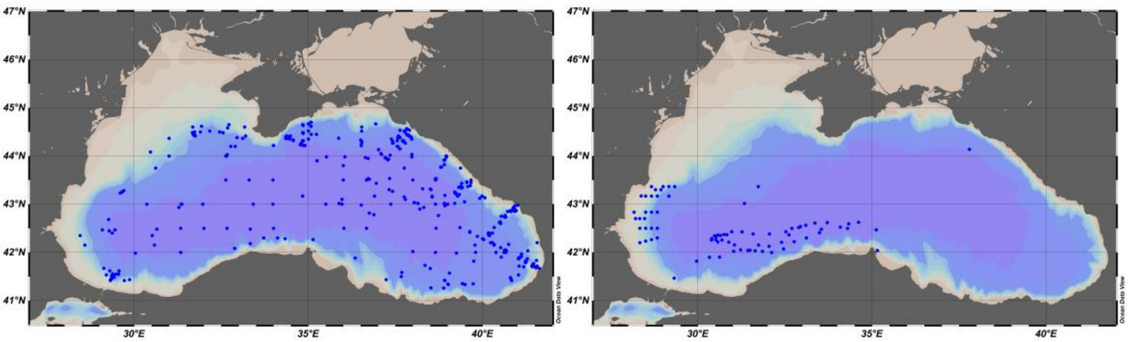

Figure 4 Examples of irregular spatial distribution of profiles: decade 1965-1974 (left) and year 2002 (right).

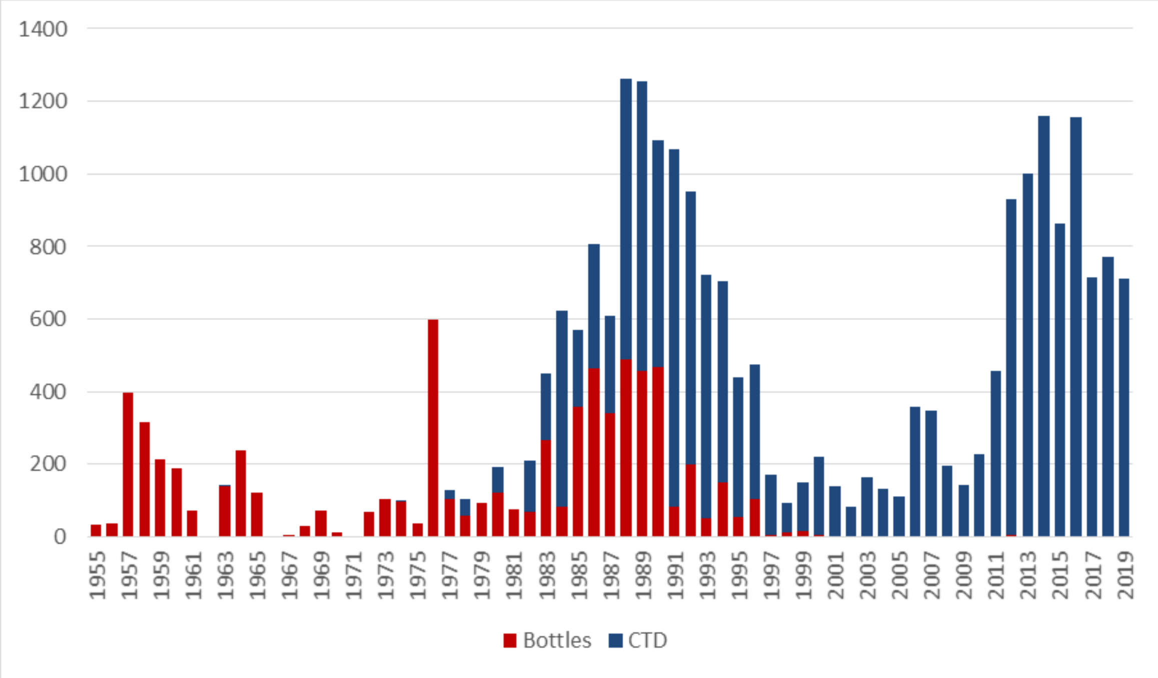

Figure 5 Time distribution of profiles

The time distribution is very irregular: data are practically missing in the decade 1965-1974, and are very scarce in the period 1997-2010, while rather good data availability is observed in the period 1983-1996 and after 2010, thanks to the intensive use of Argo floats.

The statistics per source dataset and per instrument type are provided in Table 1 and Table 2 respectively.

Table 1 Content of input dataset by data source.

	SDC	WOD	CORA	Total
Number of profiles	17364	7582	4	24950
%	70%	30%	0%	

The contribution from CORA is practically absent because the detected eligible profiles from CORA are duplicates of the profiles from SDC and WOD. The contribution of bottles data is significant up to 1995 (we have to keep in mind that CCC calculated from bottles data is less precise compared to CTD).

Table 2 Content of input dataset by instrument type

	Bottles	CTD profilers (including ARGO floats)
Number of profiles	6941	18009
%	28%	72%

The evolution of CCC with time is presented in Figure 6: the scatter plot demonstrates that in the period 1955-1999 the CCC level was more or less stable while starting from 2000 the significant negative trend of CCC is observed.

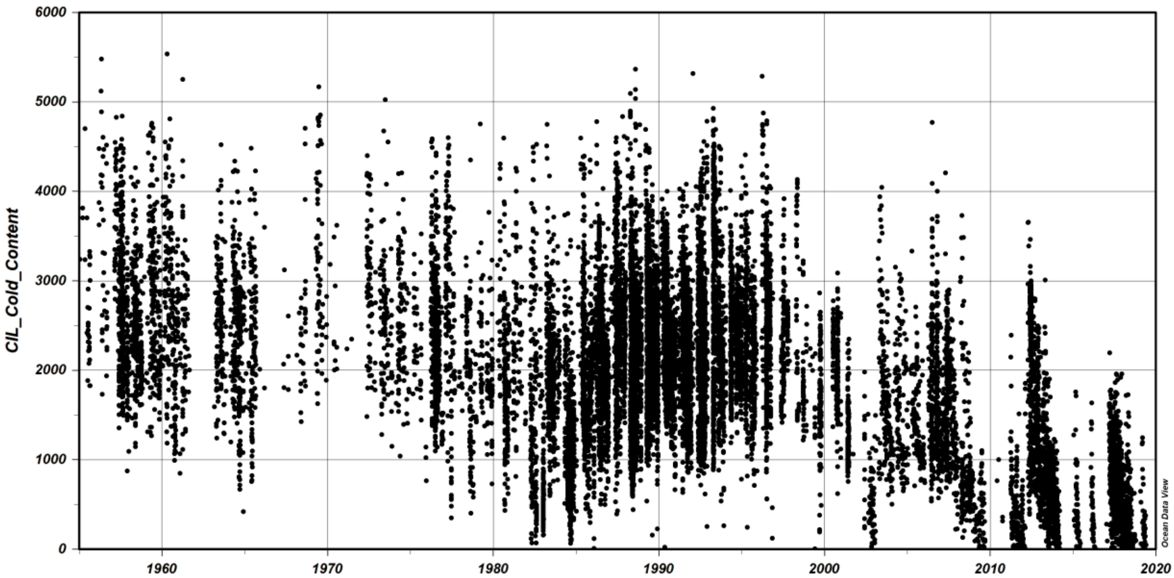

Figure 6 Scatter plot of CCC vs time

For current product the subset of **20733** profiles in period 1955-2014 was used.

2. Methodology

2.1. Data QC

As mentioned in section 1.1, all data in the input dataset underwent several stages of QC done by data originator, by data provider and by developer of the respective product. For example, the QC procedures for SDC data collection and CORA dataset are described in (5, 7). However the visual inspection of scatter plots of Temperature and Salinity from WOD and CORA subsets done in ODV (6) revealed a number of bad data flagged as good, therefore an additional QC was applied to these subsets before incorporating them into the input dataset for CCC calculations. This included:

- identification and flagging outliers and out of range values of temperature and salinity;
- identification and flagging density inversion;
- identification of bad data;
- identification and flagging profiles with wrong depth values;
- recovery of good temperature values in thermocline that were flagged as "probably bad" due to high gradient.

In the process of CCC calculation the following CIL parameters were obtained:

- minimum temperature in CIL – Tmin;
- depth of Tmin;
- CIL upper depth;
- CIL lower depth;
- CIL thickness.

Then the CCC and CIL parameters were attached to ODV collection containing the input TS dataset and following checks were performed:

- The CCC values for CIL lower depth > 200 m were discarded. Such depth is unreal and indicates presence of large gap between depth levels in a profile, therefore the respective CCC value can't be trusted.
- Profiles with CIL upper depth less than 20 m were visually analyzed to check if they do represent a winter cooling event - if so then the respective CCC values were discarded.
- Profiles with depth of Tmin > 100 m normally should not be present in interior of the sea. Such profiles were visually analyzed and CCC values for wrong or doubtful ones were discarded.

The remaining set of CCC values (20733 for this product) was taken as input dataset for DIVAnd calculations.

2.2. DIVA implementation and settings

The computation of the Black Sea CIL Cold Content monthly fields was performed with DIVAnd (12) version 2.6.2. DIVAnd is 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 tuning of parameters is much easier. For this particular product DIVAnd was used in 2D mode.

Settings for computation:

- Domain: Black Sea domain, its interior part;
- Spatial extent: 27.5 - 41.875°E, 40.875 - 45.2°N;
- Horizontal resolution: 1/8° x 1/8°;
- Horizontal grid dimensions: 116 x 35;
- Vertical resolution: No;
- Time resolution: seasonal for 6 decades (1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2014);
- Bathymetry: not needed for current 2D product however required by DIVAnd. GEBCO 30 sec bathymetry (13) subsampled with 1/4 ratio;
- Mask has the same dimensions (116x35) as the horizontal grid. The mask was produced from the spatial distribution of data;

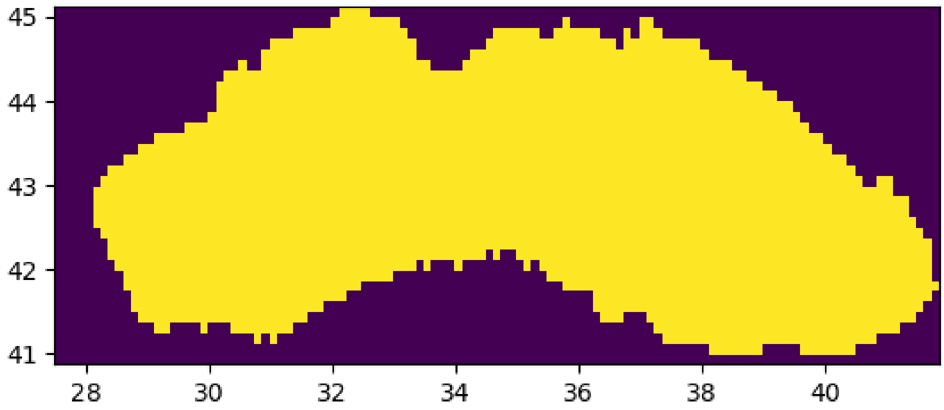

Figure 7 Mask

Table 3 DIVAnd parameters

Parameter name	Note	Value
Horizontal correlation length	km	150
Epsilon2 (noise-to-signal ratio)		0.3
epsilon2 adjustment	With weights of the observations	weight_RtimesOne (0.1,0.1, 30)
niter_e	Number of iterations (should be 1 in case of epsilon2 adjustment)	1
solver	"indirect" if not enough memory	direct
fitcorrlen	If "true" then DIVAnd will calculate correlation length	false
minfield	Minimum of parameter	0.
QCMETHOD	Method to calculate quality scores	1

DIVAnd provides several options for calculating QC scores for each observation, which then can be used to discard outliers. For the product described in this document we used QCMETHOD=1 which is based on full cross-validation calculations. With this method the QC score equal to 10 approximately corresponds to 3 standard deviations of residuals. The CCC values with QC score > 10 were discarded and DIVAnd analysis was repeated until none QC score > 10 was detected.

3. Product Description

The product is delivered in the file in netCDF format, the file contains four 3D fields (2 horizontal dimensions and time dimension):

- *CIL_Cold_Content* – climatological field of CCC calculated for 4 seasons in 6 decades (1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2014);
- *CIL_Cold_Content _L1* – CCC field masked using relative error threshold 0.3,
- *CIL_Cold_Content _L2* – CCC field masked using relative error threshold 0.5,
- *CIL_Cold_Content _relerr* – relative error of CCC.

Data availability per decades and seasons is very heterogeneous (Figure 8): the season with the best data coverage is summer, and the most covered decades are 1985-1994 and 2005-2014.

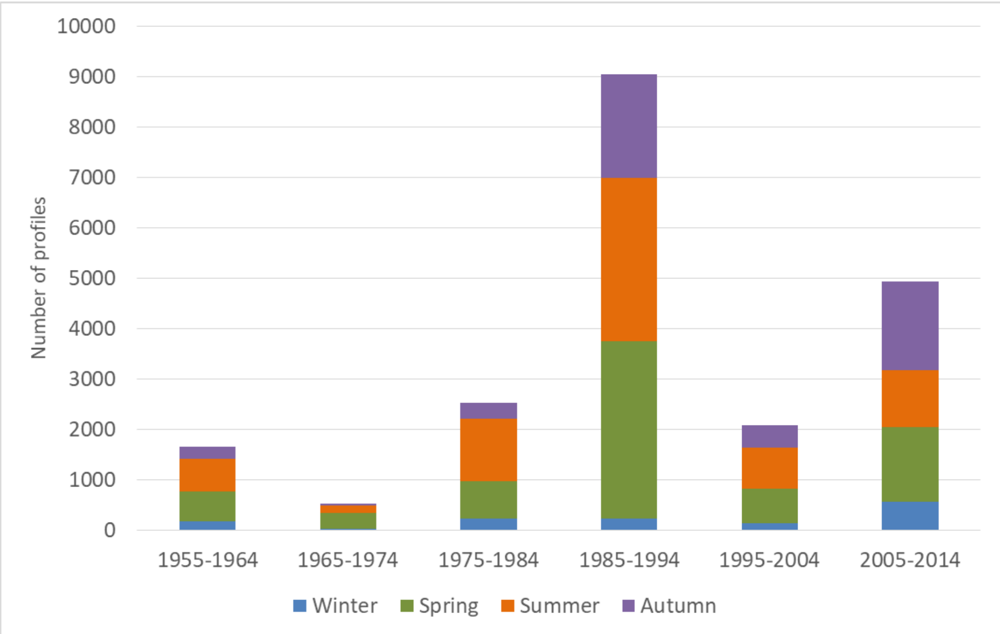

Figure 8 SDC_BLS_DP2 data availability per decade and season.

The relative error is expectedly high for most of seasonal fields because of data scarcity. In seasons with the lowest data availability, the relative error may reach 0.5 over wide areas (Figure 9).

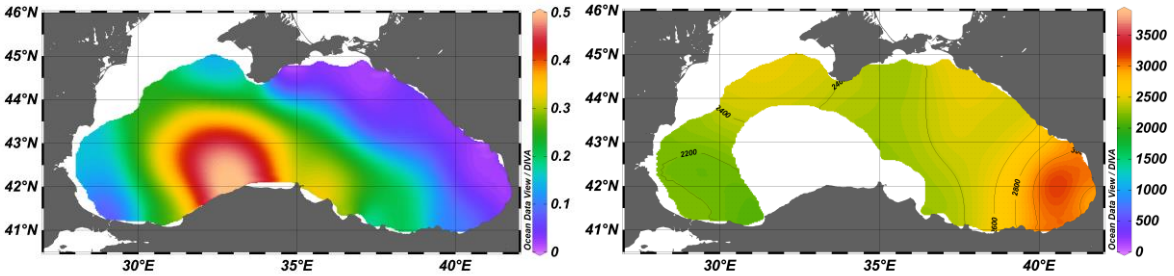

Figure 9 Relative error (left) and CCC [10^6 J/m^2] field masked using relative error threshold 0.3 in summer season of 1965-1974.

Inter-decadal changes of CCC field in summer are presented in Figure 10. The spatial structure as well as the CCC range, are similar in the first five decades from 1955 to 2004, while the field in the last decade 2005 – 2014 shows significant decrease of CCC level over the whole basin with an irregular spatial structure.

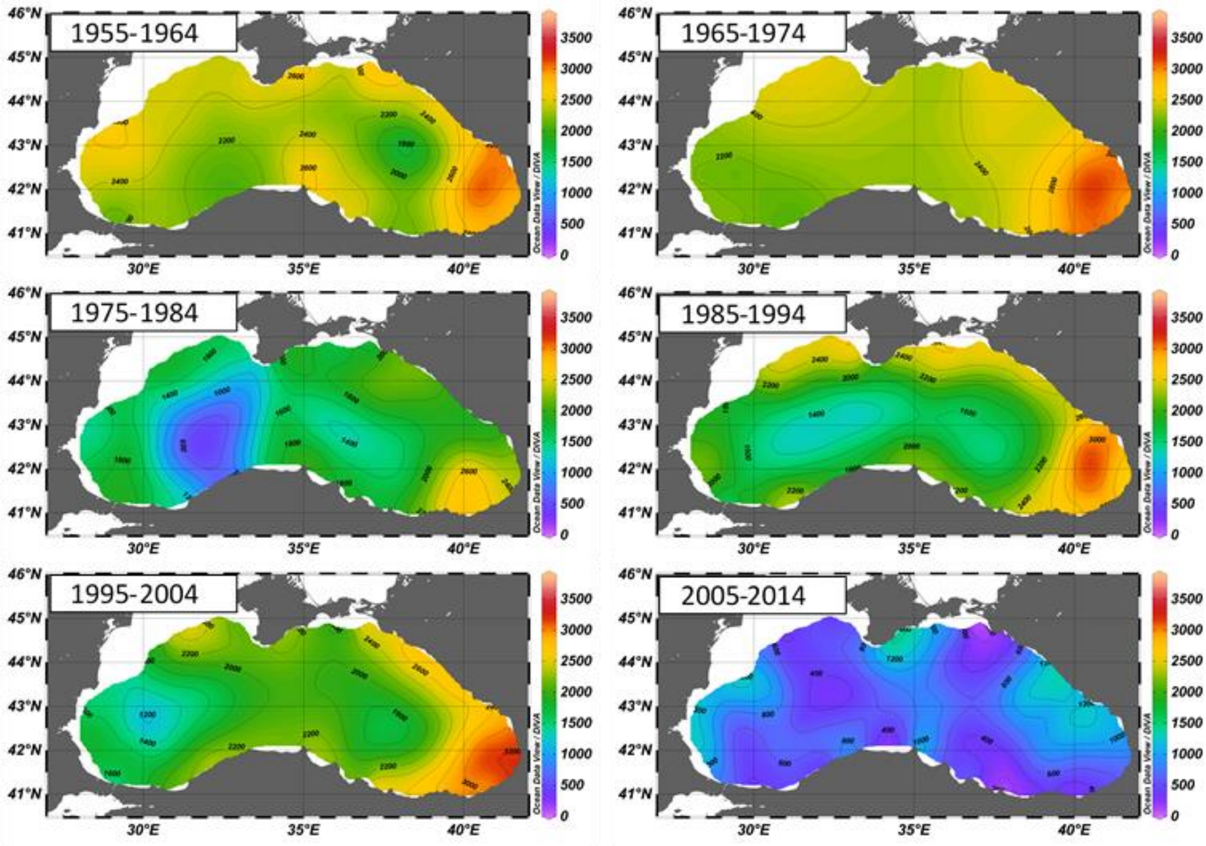

Figure 10 CCC [10^6 J/m^2] in summer season in 6 decades

Figure 11 presents a comparison of CCC for the same seasons in the two decades characterized by the best data availability: 1985-1994 and 2005-2014. The spatial structure of CCC fields in the first decade (1985-1994) in all seasons is in good agreement with the main oceanographic features of the Black Sea (14). The highest CCC values are concentrated on the periphery of the Rim Current with maxima in Batumi and Sevastopol eddies, while the lowest CCC values occupy the basin interior with minimuma in the centres of the eastern and western gyres. In the second decade, a significant decrease of CCC level is observed in all seasons, as well as a loss of spatial similarity with the earliest decade, remnants of which can be found only in the spring season – the season with the highest annual values of CCC.

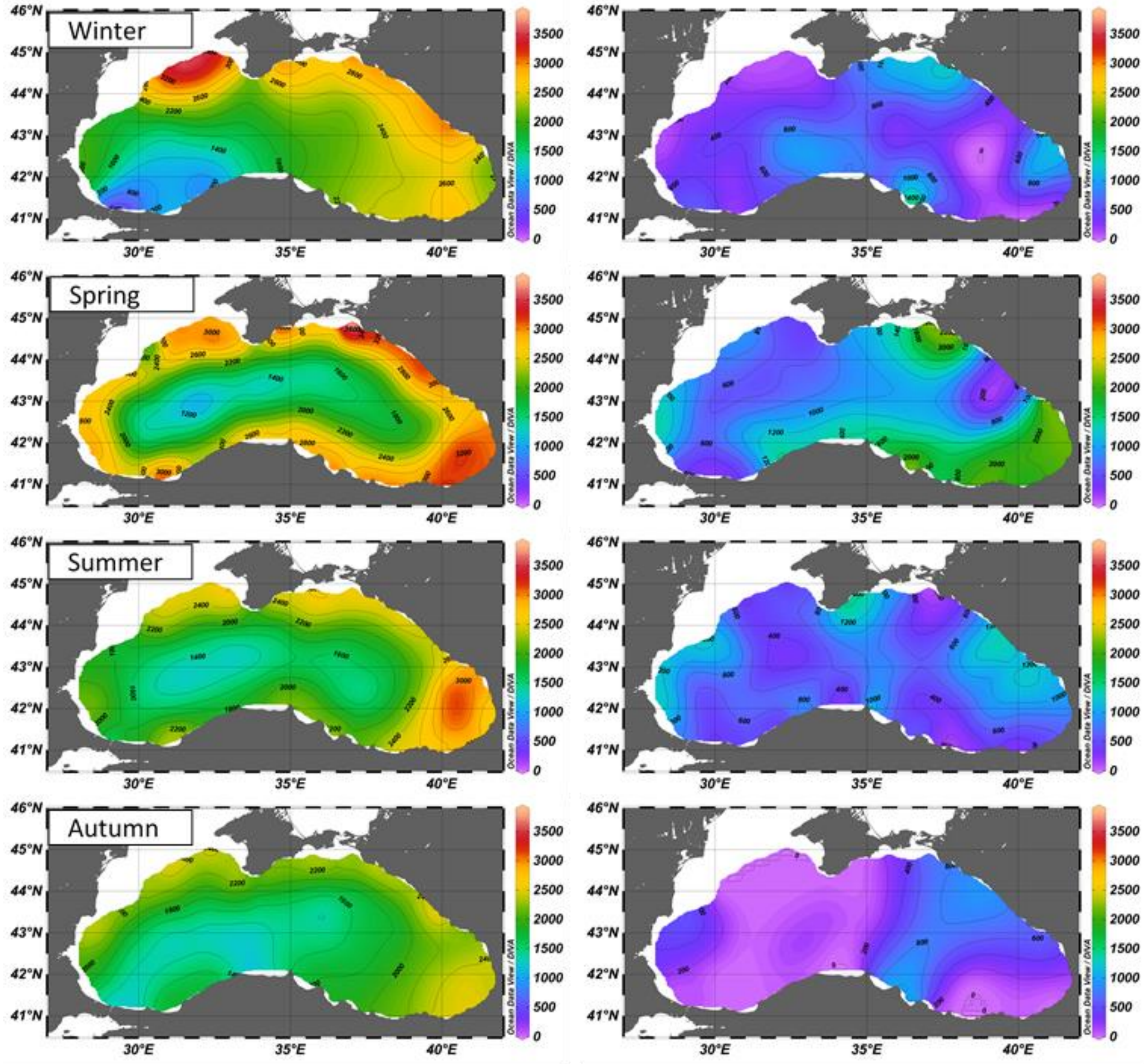

Figure 11 Seasonal distribution of CCC [10^6 J/m^2] in 1985-1994 (left) and 2005-2014 (right)

4. Technical Specifications

4.1. Product Format

The product is delivered in the file in netCDF format. The file contains four 3D fields (2 horizontal dimensions and time dimension) named according to the following rule:

- *Variable_Name* – 3d array for a parameter,
- *Variable_Name_L1* – … parameter masked using relative error threshold 0.3,
- *Variable_Name_L2* – … parameter masked using relative error threshold 0.5,
- *Variable_Name_relerr* – relative error of parameter.

For current product the *Variable_Name* is *CIL_Cold_Content.*

The netCDF file, along with the variable attributes, contains a set of global attributes describing the product:

- Product code, version and abstract,
- Name of the project,
- EDMO code of the product developer,
- Contact e-mail of developer,
- Source of observations,
- Keywords for the parameter and the area and their codes in SeaDataNet Vocabularies,
- Links to documentation, data and visualization tools (if already published at the moment of the product release).

4.2. Product Usability

The gridded decadal seasonal climatic fields of CCC can be used to support general oceanographic studies, ocean modelling and forecast, process studies, climate change studies etc. However the product has a limited usability because of the low input data availability in most of season/decade periods a number of obtained fields have rather high relative error. When working with the product it is recommended to take into account the *relerr* field and use masked arrays for seasonal fields where *relerr* is high.

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6. List of acronyms

Acronym	Definition
ARC	Arctic ocean
BAL	Baltic Sea
BLS	Black Sea
CDI	Common Data Index
DIVA	Data-Interpolating Variational Analysis (software)
DOI	Digital Object Identifier
GLO	GLobal Ocean
MED	Mediterranean Sea
NAT	North Atlantic Ocean
ODV	Ocean Data View Software
QC	Quality Checks
QF	Quality Flags
SDC	SeaDataCloud
SDN	SeaDataNet
TS	Temperature and Salinity