Time-Depth Diagrams (TDDs)

Definition

Time–Depth Diagrams (TDDs) are designed for displaying oceanographic parameters variability in space of time and depth at selected geographical locations. The parameters are shown on TDDs as anomalies (Section 5.1.4 in the Atlas technical report) representing their area-averaged monthly-mean time series.

The diagrams are based on *in situ* observations. They are included in the Atlas to demonstrate regional changes of selected oceanographic parameters in the Nordic Seas and northern North Atlantic and to provide additional visual information for consistency check of the gridded horizontal fields.

Location

Twelve areas in the Northern North Atlantic and the Nordic Seas were chosen for computing TDDs based on the long-term observational programs available at those locations. The areas' configuration and size (Table 1) were determined by available spatial and temporal distributions of the stations in the vicinities of TDDs locations.

Table 1. Specifications of areas and profiles selected for the regional time-depth diagrams

Abr.	Central point		Radius	Num. of	Period	Num. of profiles			
	Lat	Lon	(km)	stations		T	S	D	O2
I	59.0N	19.0W	100	2,605	16.09.1929 10.01.2012	2,600	1,062	1,057	140
A	62.0N	33.0W	150	2,837	17.06.1895 26.03.2012	2,831	2,724	2,720	480
FSS	61.0N	3.16W	70	4,845	31.07.1896 13.05.2011	4,840	4,758	4,753	1,492
DS	66.2N	27.0W	100	2,233	4.06.1895 30.07.2011	2,232	2,178	2,177	751
M	66.0N	2.0E	50	12,458	2.07.1935 2.09.2011	12,440	12,102	12,086	1,978
EIC	67.5N	12.4W	150	4,782	23.06.1891 23.10.2012	4,780	4,309	4,307	1,335
LB	70.0N	3.0E	100	1,390	11.08.1900 29.02.2012	1,390	1,269	1,269	409
GB	75.0N	2.0W	100	2,401	25.06.1901 15.03.2012	2,399	2,142	2,141	521
FS75	75.0N	12.0E	100	2,669	5.07.1871 18.04.2011	2,668	2,263	2,262	568
FSRA	77.0N- 79.5N	0- 10.0E	-	5,439	10.07.1871 20.10.2012	5,438	4,814	4,813	909
BSO	72.8 N	19.5 E	100	8,713	1.07.1871 24.01.2012	8,713	7,694	7,694	1,397
KS	77.0N- 79.5N	33.1E- 33.5E	-	14,492	14.07.1882 29.08.2010	14,486	12,229	12,224	2,546

I - Ocean Weather Ship India (OWSI); **A** - Ocean Weather Ship Able/Alpha (OWSA); **FSS** - Faroe Shetland Strait; **DS** – Denmark Strait; **M** – Ocean Weather Ship Mike (OWSM); **EIC** – East Icelandic Current; **LB** – Lofoten Basin; **GB** – Greenland Basin; **FS75** – Fram Strait 75^{o}N; **FSRA** – Fram Strait Recirculation Area; **BSO** – Barents Sea Opening; **KS** – Kola Section;

The diagrams were created using data from numerous field programs. Over the years, different countries, marine organizations and research projects followed diverse observational strategies. An individual subset may be dominated by profiles clustering either around single location (OWSA, OWSI, OWSM), distributed along standard sections (FSS, KS) or originated from polygon surveys (LB, GB), at least for a certain time periods. Unfortunately, location-tied observations from ocean weather ships, which provided uniform and consistent time series, had ended some time ago. Therefore, the time series of such nature have been extended using data from ships of opportunity and more recent data from Argo profiling floats (http://www.argo.ucsd.edu/).

Data and quality control

Data for TDDs were extracted from AARI oceanographic database (version: March 2012). Profiles made by three types of instruments (CTD, bottle, profiling floats) and not identified probes were all merged together. The XBT profiles were not included because of the known XBT bias problem (Gouretski & Kolterman, 2007).

Despite a relatively low number of dissolved oxygen profiles, oxygen TDDs were added to the Atlas along with temperature, salinity and density diagrams. Although scarce data availability makes oxygen diagrams not fully compatible with much better substantiated temperature and salinity diagrams, oxygen is an important tracer for horizontal and vertical advection and mixing. Inclusion of the oxygen TDDs is therefore justified.

The data have passed standard quality control described in the Section 2.3 in the Atlas technical report. Additionally, the profiles were plotted together for each of the 12 areas for visual inspection, with outliers, if any, removed from further processing. The outliers that survived the first pass of quality control were mainly caused by small scale processes (shelf processes, frontal zones) or erroneous measurements that escaped filtering out by the standard quality control procedures. Therefore, the magnitude of variability within the areas (Table 1) is most likely underestimated rather than overestimated in the TDDs. Measurements prior to 1950 often show excessive variance due to the generally lower accuracy of historical observations. Nonetheless, early observations provide an important evidence of processes, help to extend our time series and better assess anomalies' recurrence and magnitude on a longer time scale.

Computational algorithm and plots design

The diagrams were plotted after the following steps in data processing:

- For each area (Table 1), station's subsets were extracted from the database. Two area's configurations were used: (i) a circle with certain radius around a central point; and (ii) a rectangle fitting a section or area (see fig. 5.1 in the Atlas technical report). The sizes of the areas were determined by a compromise between data availability and regional features of variability (exclusion divergent processes).
- For each subset, stations' metadata were stored in database's catalog for further processing.
- An additional quality control was applied to temperature, salinity, density and oxygen profiles.
- The profiles were interpolated at standard depths by means of weighted parabolic interpolation (Reiniger and Ross, 1968).
- The mean monthly profiles were computed by averaging observed profiles.
- The mean annual cycle for each parameter and each standard depth were defined by averaging monthly values for the 1950-2000 period.

- Then, the monthly mean values at standard depths were transferred into values with annual cycle removed by subtracting the mean annual cycle.
- Finally, monthly mean values (with annual cycle removed) were reduced to anomalies by subtracting the mean values for the 1950-2000 reference period.

The algorithm is embedded as a module into ‘Ocean Shell’ software (Section 4.1 in the Atlas technical report). The TDDs in the atlas represent monthly anomalies (with the annual cycle removed) relative to the 1950 – 2000 period. The program module allows for computing diagrams with variable temporal averaging, reference periods, with or without the annual cycle. We compared several variants and concluded that basic anomalies remain quite similar while details can vary. Accounting of the annual cycle gives slightly suppressed variability in the upper ocean that highlights the large-scale anomalies. The diagrams were plotted using ‘Surfer 11’ (Golden Software Inc.) with Surfer’s automation functions integrated into ‘Ocean Shell’ code.

There are two types of diagrams: the first type shows the anomalies in the upper 500 m; while the second covers the depth range from the surface to the last standard interpolated depth level. The depth range depends on the bottom depth at a site’s location and on data availability in the deeper layers. Identical horizontal and vertical scales in all diagrams makes TDDs at different locations easier to compare, whereas the full depth plots reveal anomalies’ vertical extent and show the connection between deep and upper ocean processes.

All TDDs are accompanied with plots showing the data node positions used for mapping.
A node color signifies a number of observations available for computing the monthly mean value from in situ observations at a given position. As an additional condition on TDDs, periods with more than two years gaps in data were masked (white vertical bands in TDDs). Close to the surface, a narrow white horizontal band can be seen, which is more pronounced in the plots for upper 500 m. This is the result of applied filtering that clips area at plots’ boundaries.

Focus on regional variability

The TDDs are intended to demonstrate variability at key locations affected by different hydrographic processes. Specifically, they help to trace anomalies or climatic signals advected by ocean currents and redistributed by vertical processes. To avoid the impact of divergent processes and to obtain a clear regional signal, an area, where profiles are selected, has to be as small as possible. Ideally, the size of the area should not exceed the correlation radius for the specific sea region. According to DIVA (Section 3.2 in the Atlas technical report), an averaged correlation radius for the region is between 2 and 4 latitude degrees. Therefore, in most cases our TDDs satisfy the condition.

References

Reiniger, R.F., and C.K. Ross (1968), A method of interpolation with application to oceanographic data. *Deep Sea Research*, **15**, 185-193.

Gouretski, V., and K. P. Koltermann (2007), How much is the ocean really warming?, *Geophys. Res. Lett.*, 34, L01610, doi:10.1029/2006GL027834.