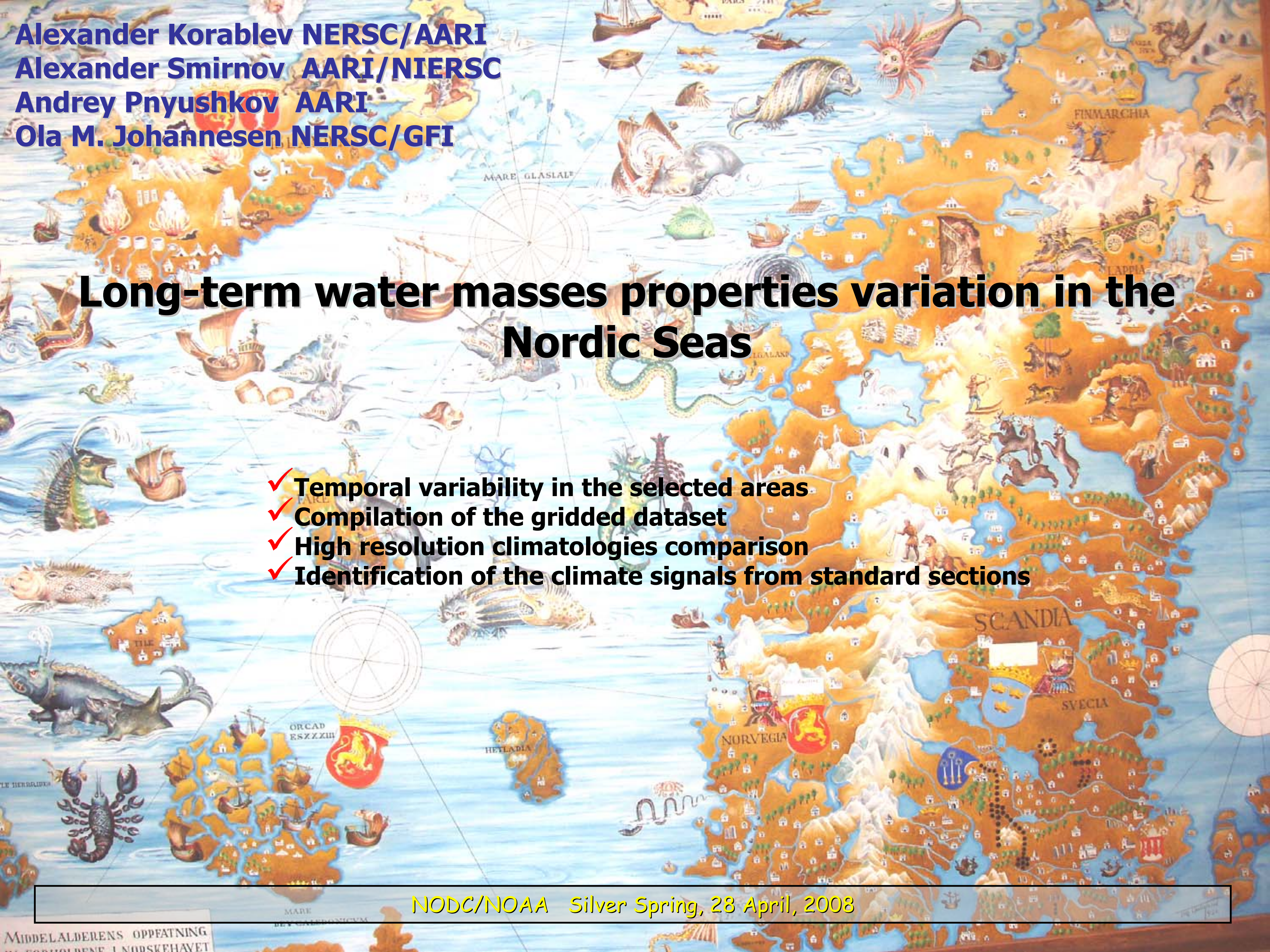
Alexander Korablev NERSC/AARI
Alexander Smirnov AARI/NIERSC
Andrey Pnyushkov AARI
Ola M. Johannesen NERSC/GFI

Long-term water masses properties variation in the Nordic Seas

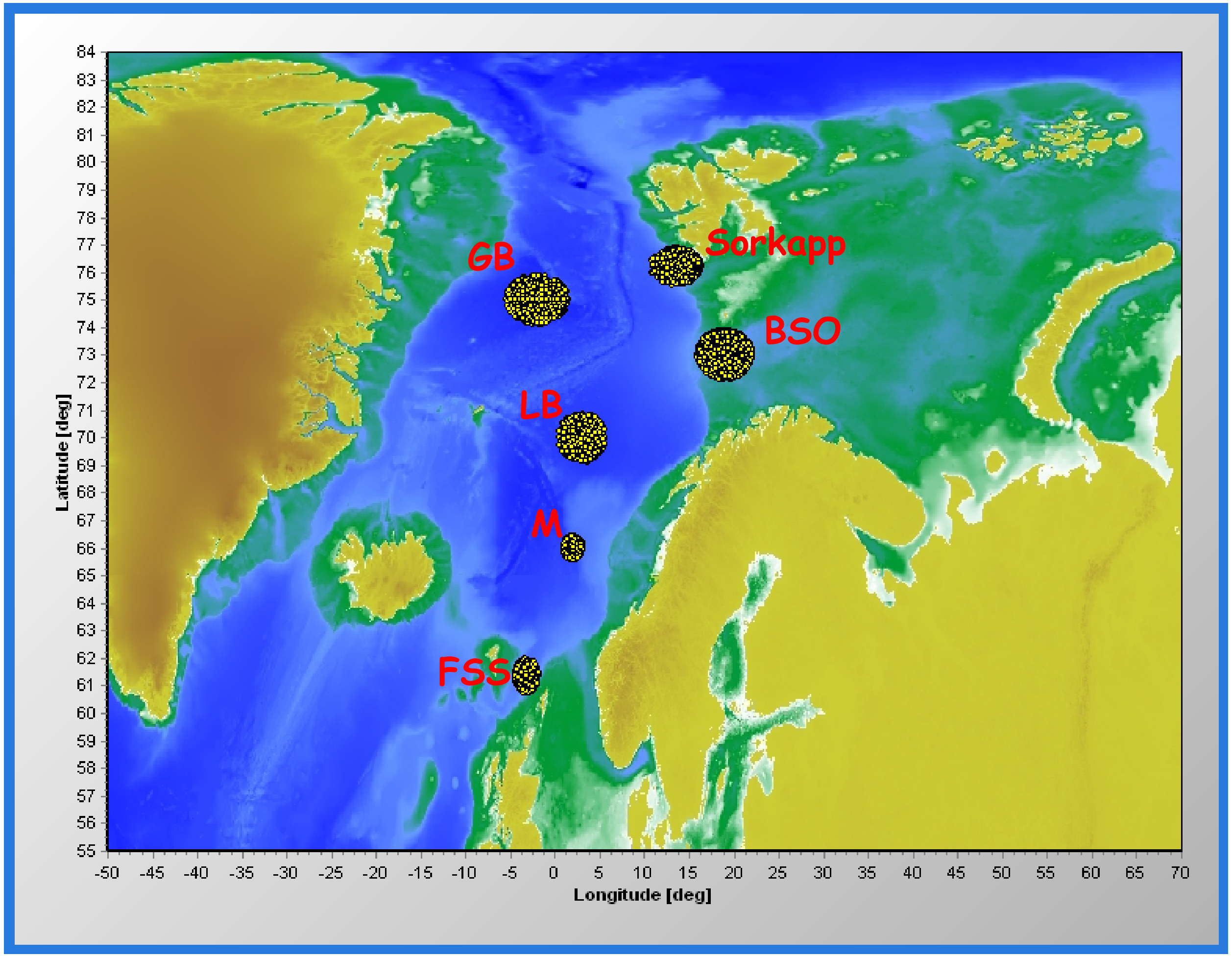
- ✓ Temporal variability in the selected areas
- ✓ Compilation of the gridded dataset
- ✓ High resolution climatologies comparison
- ✓ Identification of the climate signals from standard sections



NODC/NOAA Silver Spring, 28 April, 2008

Temporal-spatial pattern of the variability in the Nordic Seas

Selected sites for time-depth diagrams computing



FSS
Faroe-Shetland Strait
61.35ºN, 3.16ºW, 70 km

M
OWS Mike
66oN,2ºE, 50 km

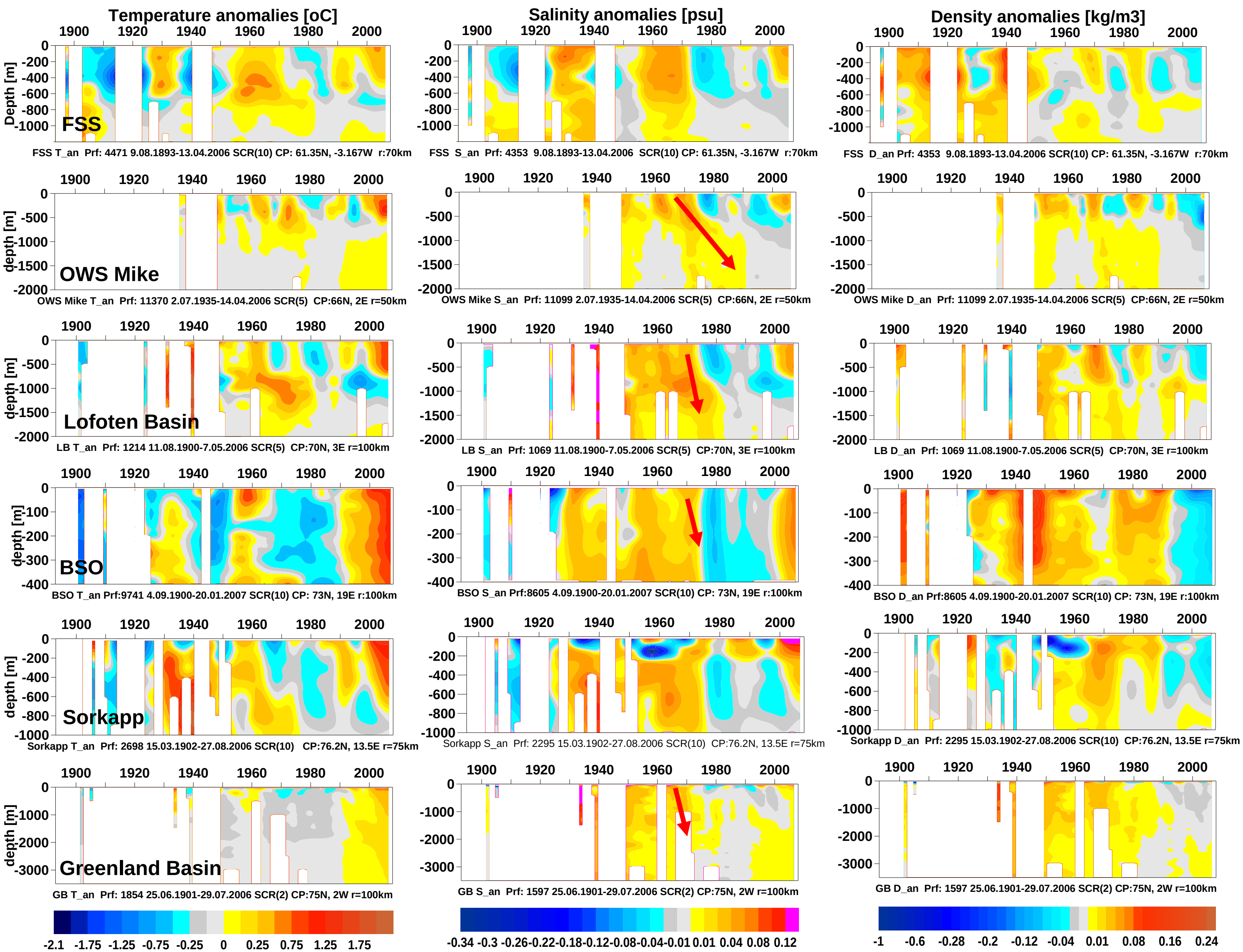
LB
Lofoten Basin
70ºN,3ºE, 100 km

GB
Greenland Basin
75ºN,2ºW, 100 km

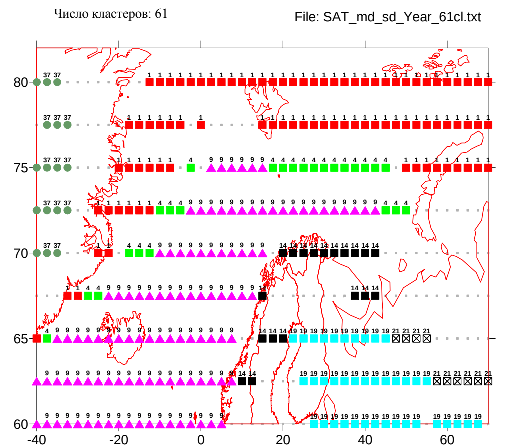
BSO
Barents Sea Openning
73ºN, 19ºE, 100 km

Sorkapp
Sorkapp section
73.6ºN, 13.5ºE, 75km

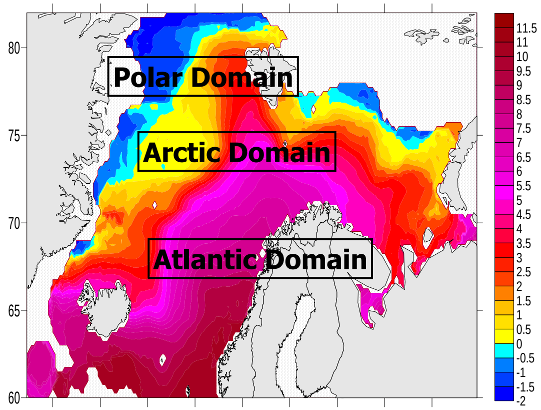
Time-depth diagrams for selected areas



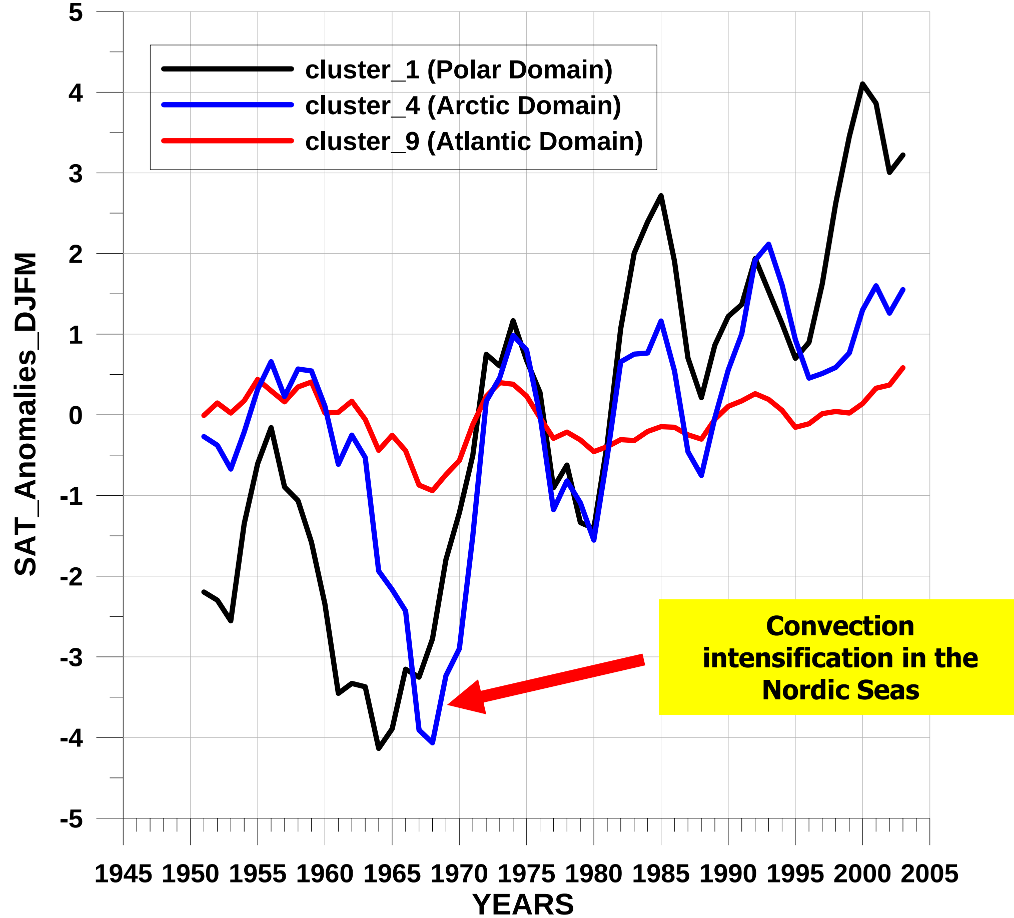
SAT anomalies time series over Atlantic, Arctic and Polar Domains



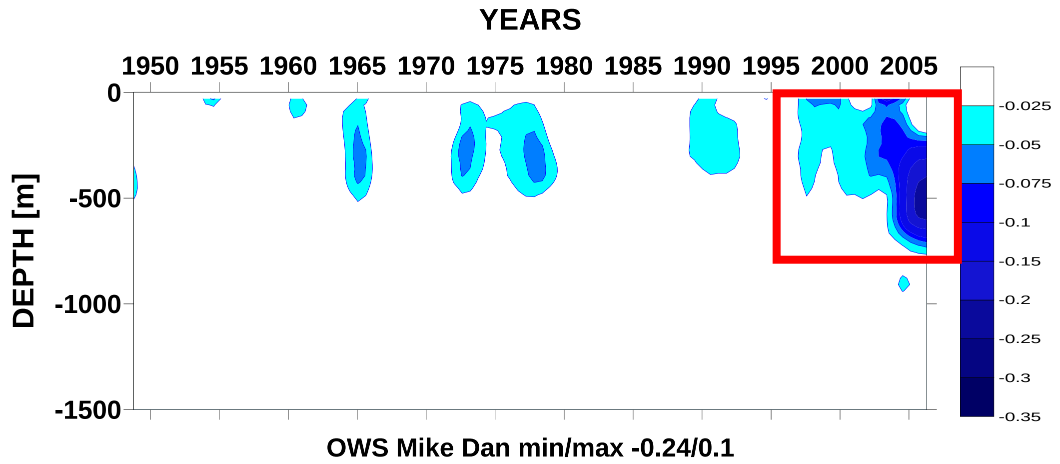
Results of the cluster analysis (SAT, SAT_SD from NCEP/NCAR reanalysis for 1948-2004

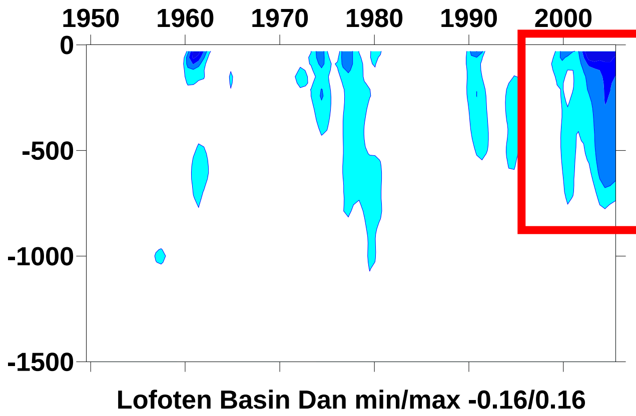


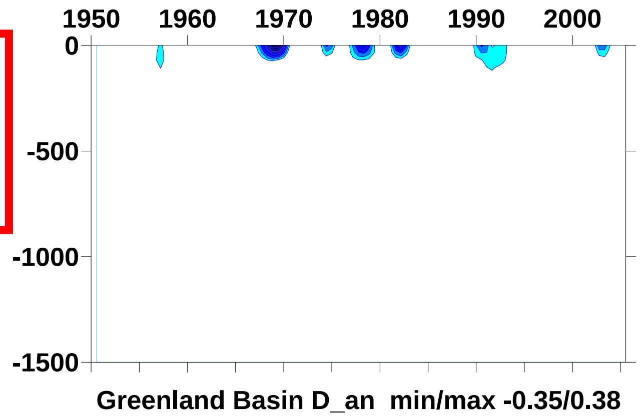
Mean 1957-90 SST (1957-90) in June with domain definition according Swift, 1981



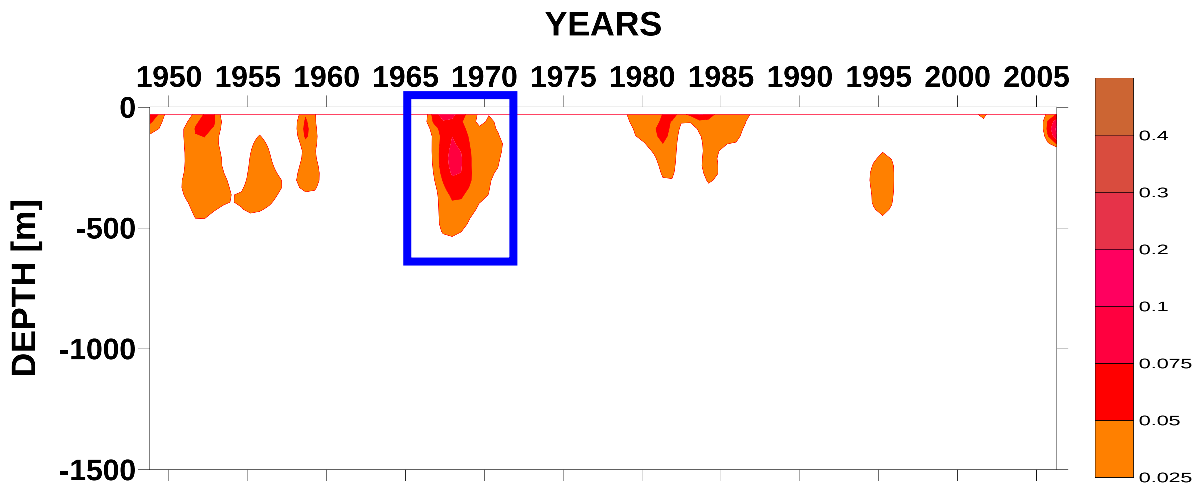
Negative density anomalies OWS Mike, LB, GB



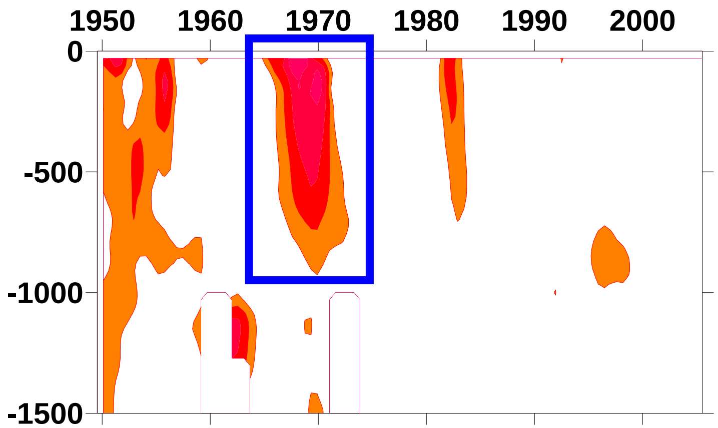




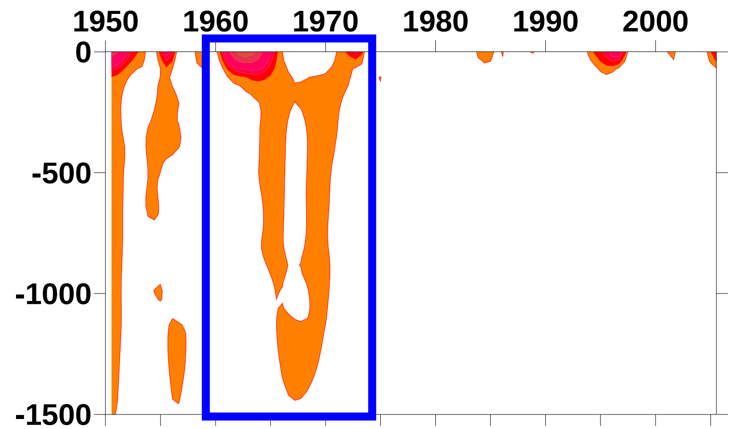
Positive density anomalies OWS Mike, LB, GB



OWS Mike Dan min/max -0.24/0.1



Lofoten Basin Dan min/max -0.16/0.16



Greenland Basin D_an min/max -0.35/0.38

Conclusions (temporal variability)

✓**Thermohaline anomalies propagated through the NS show event like behavior and linked to advection and atmospheric forcing changes**

✓**High to low upper salinity regime transition after the GSA propagation with reduction of the downward salt flux**

✓**Anomalies penetration depth depends on the regional stratification**

✓**Strong positive upper layer density anomaly and vertical exchange intensification in the late 1960s**

✓**Low density present regime due to considerable water temperature increase**

Compilation of the gridded fields from observed data

Objective analysis

To quantify spatial/temporal variability in randomly distributed initial data appropriate methods are needed to produce regular (in space and time) datasets

Geostatistics (‘geo’ stress the spatial aspect of the problem) provides methodology (kriging is the standard geostatistical technique) to interpolate data and to quantify spatial uncertainty
Mapping or estimating (linear least squares estimation algorithms with error minimization: simple, ordinary, universal, …….)
Quantification of uncertainty

Structural analysis questionnaire
What does the observation in he point tell as about the values at neighbouring points?
Can we expect continuity?
What is signal-to-noise ratio?
Are variations similar in all directions (anisotropy)?
Do the data exhibit any spatial trend (drift->special theory, intrinsic random functions)?

Key tool is structural function or variogram.
Main idea that points close in space should be likely close in values
Geostatistics focuses on modelling phenomenon itself by means of consistent probabilistic model
Search a structure of spatial correlation

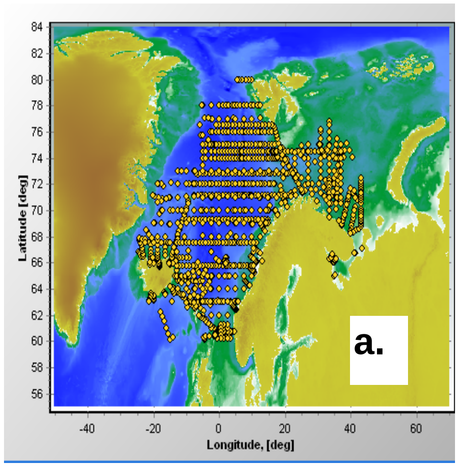
Software for objective interpolation

Original (INTAS-4620)
Oceanographic database (ODB3A) ->
embedded realization of the ordinary type of kriging (point and block)

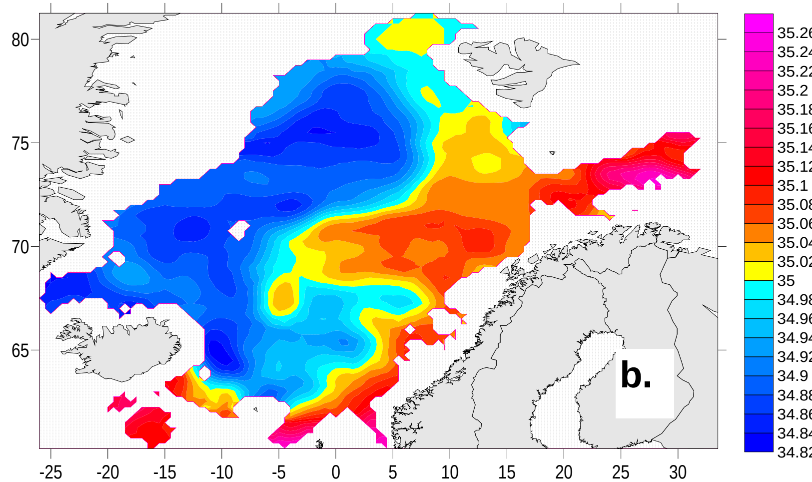
Commercial
SURFER 8 (www.goldensoftware.com) ->
ordinary and universal kriging (point and block)
•Variogram modelling subsystem

ISATIS 7 (www.geovariances.com) ->
Exploratory data analysis
Fitting a variogram model
Kriging

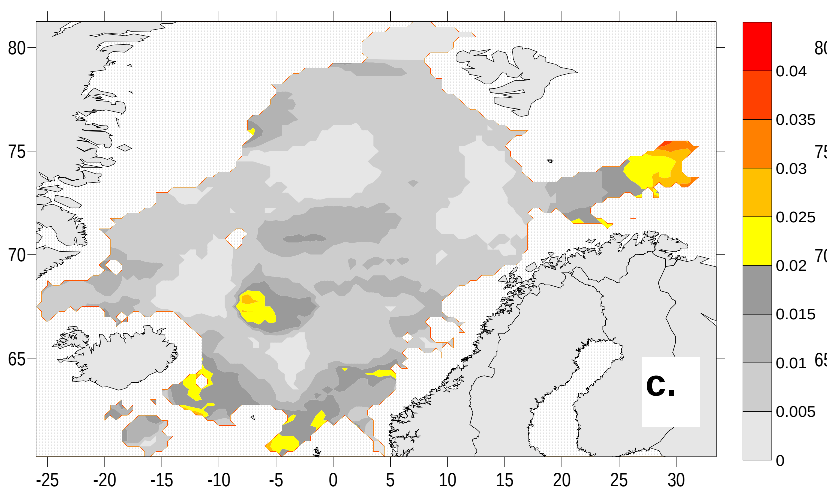
OA monthly fields and interpolation errors



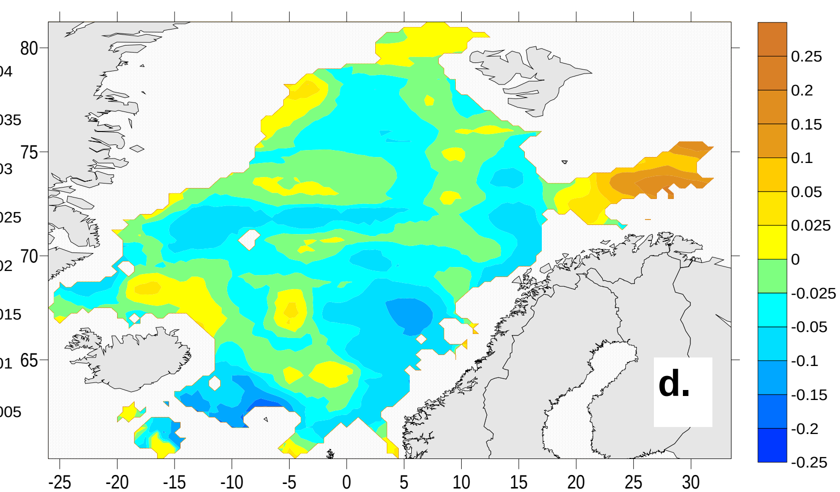
Available stations in June 1976



Objectively analyzed salinity field at 300m (0.25ºx0.5º grid)



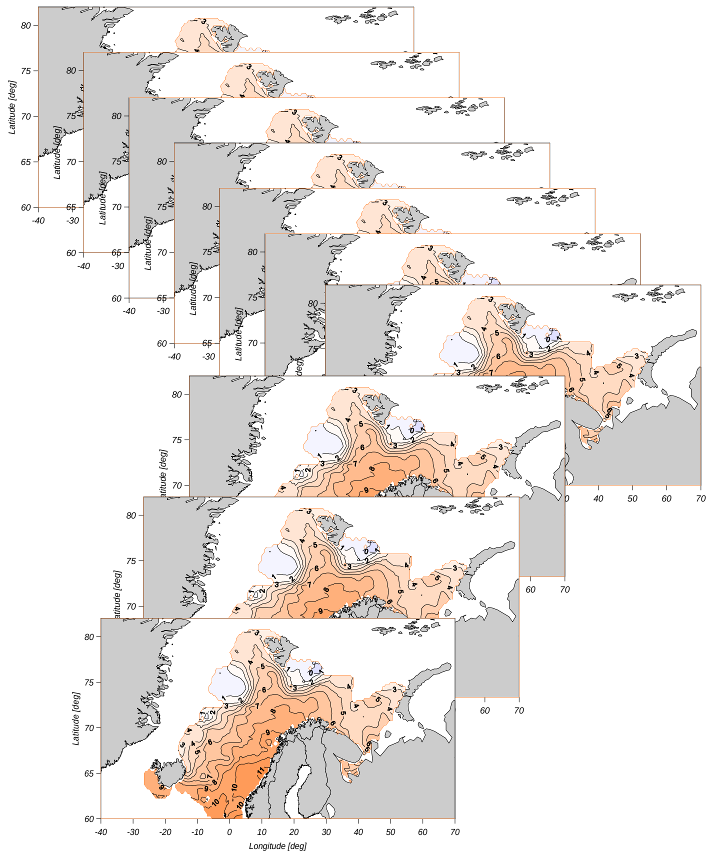
Kriging error estimates



Anomalies relative to mean for 1957-1990

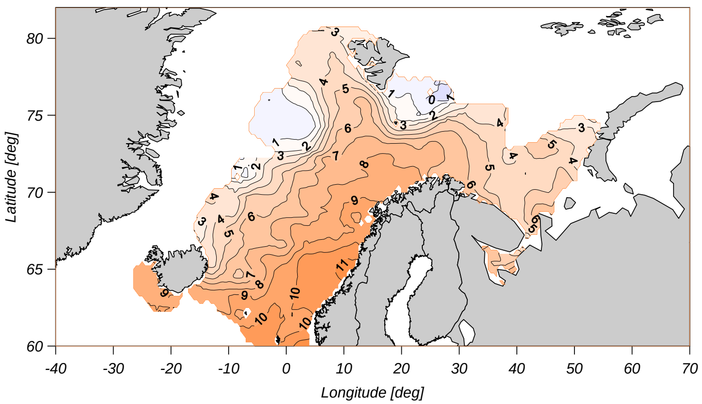
Mean fields computing from OA monthly fields

OA monthly fields for different years



averaging

Mean field for selected period



Climatologies realizes

First realize

Characteristics

- Resolution: 0.25º for latitude and 0.5º for longitude
- Period: 1900-2004
- Number of standard depth levels: 33
- Time of compiling: 2005
- Region: Nordic Seas
- Number of initial profiles: >400,000 (temperature)
- Gridding technique: block variant of kriging
- Parameters: temperature, salinity, oxygen
- All values supplied by interpolation error estimation

Limitations

- Only the high quality profiles with more than 2 measured depth levels
- Values estimated in grid if more than 7 measurements available in the interpolation radii (180-220 km)

Second realize

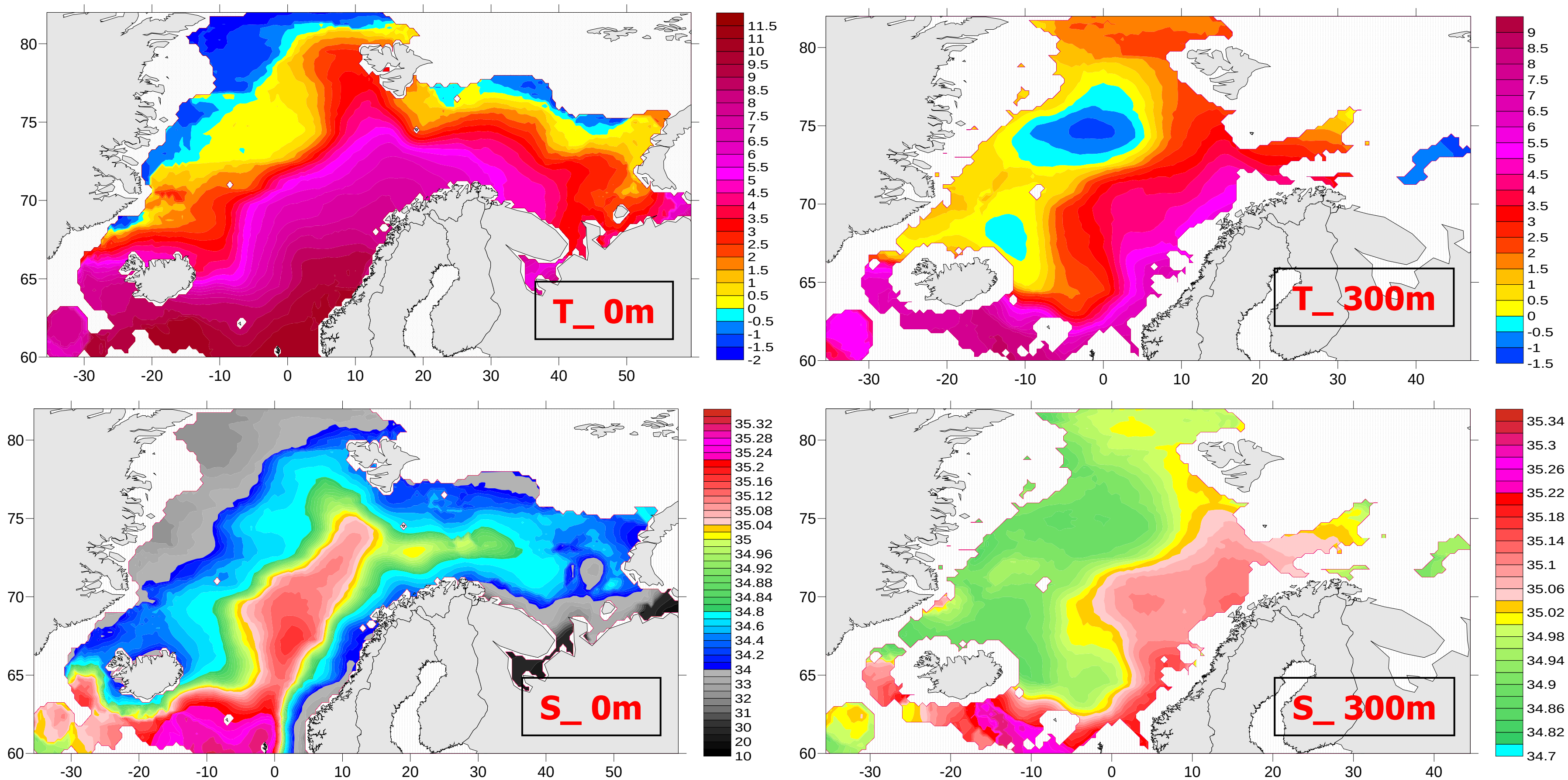
Characteristics

- Resolution: 0.25º for latitude and 0.5º for longitude
- Period: 1900-2004
- Number of standard depth levels: 33
- Time of compiling: 2006
- Region: Nordic Seas
- Number of initial profiles: >400,000 (temperature)
- Gridding technique: block variant of kriging
- Parameters: temperature, salinity, oxygen
- All values supplied by interpolation error estimation

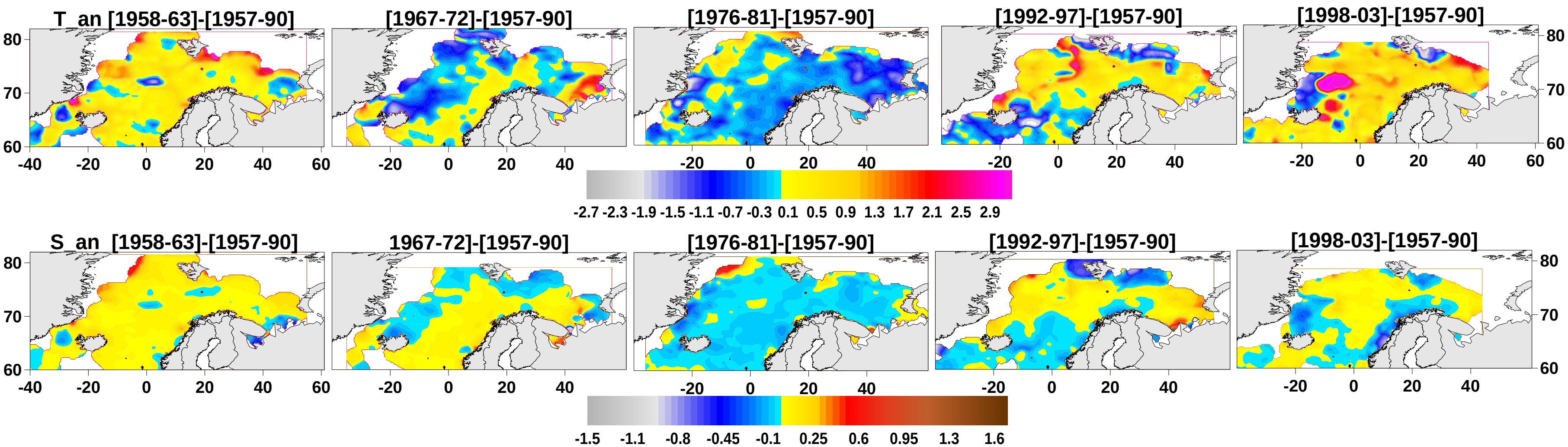
Limitations

- Only the high quality profiles with more than 2 measured depth levels

Mean temperature and salinity OA fields for 1957-1990 in June on 0.25x0.5 latitude-longitude grid

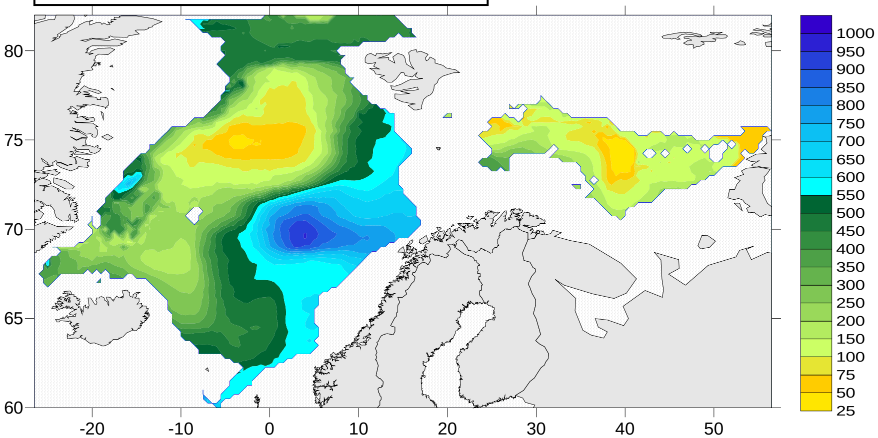


Temperature anomalies in June at 50m for different periods

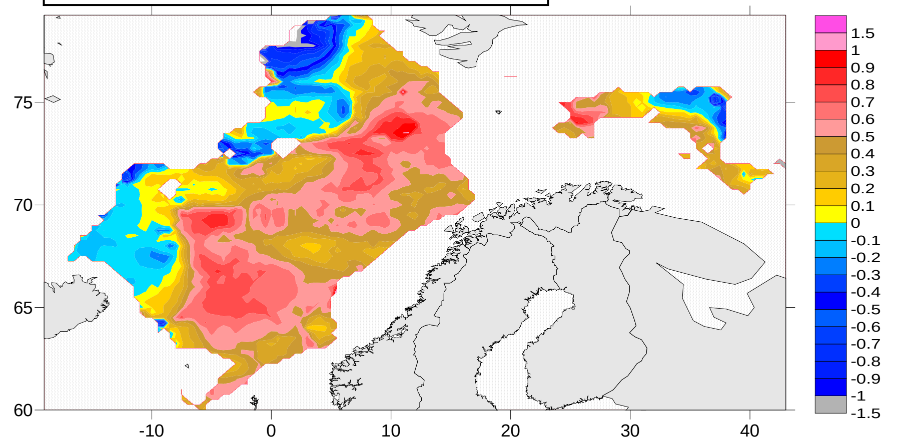


Anomalies on the σθ= 28.0 isopycnal surface (1967-72) – (1957-90) in June

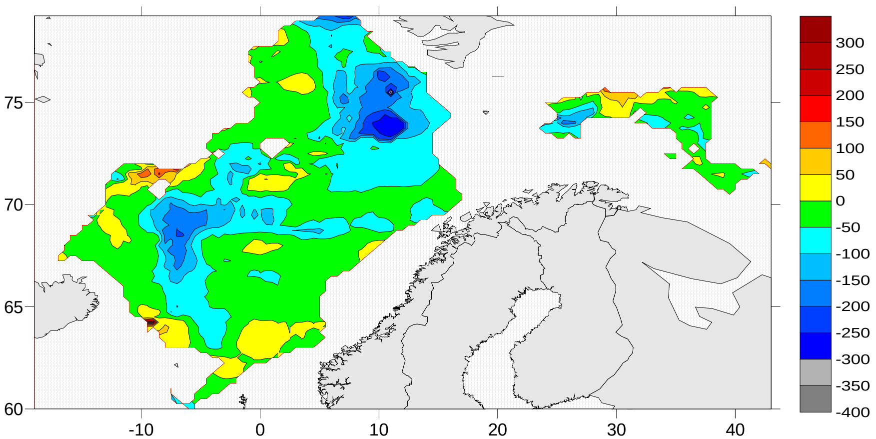
Mean depth 1957-90 [m]



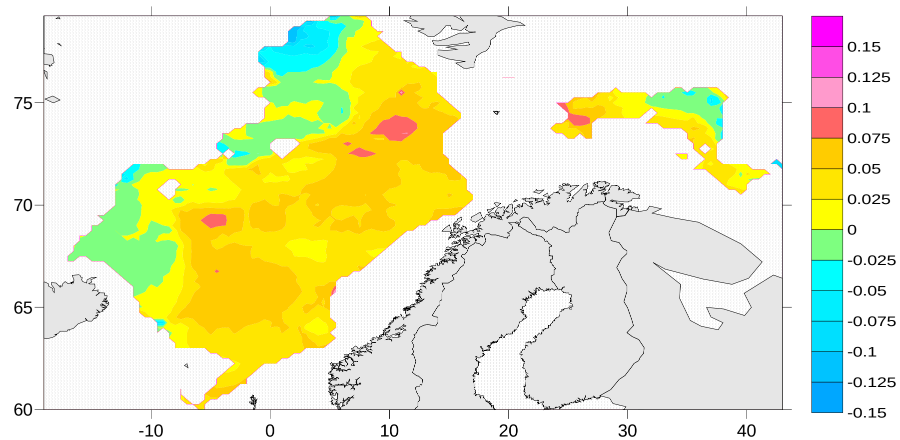
Temperature anomalies [ºC]



Depth anomalies [m]



Salinity anomalies [psu]



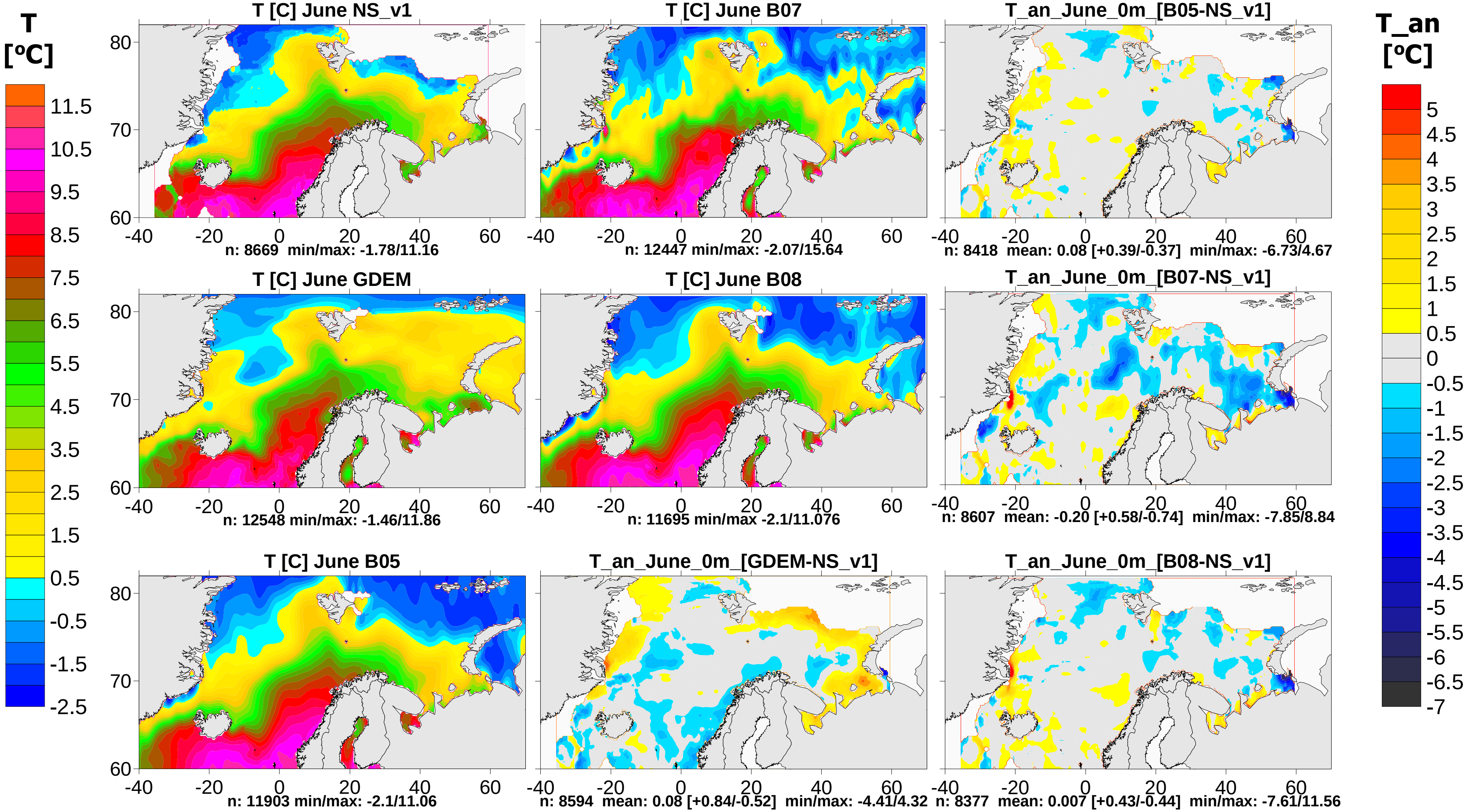
High-resolution climatologies comparison for the Nordic Seas

Available NS climatologies with high spatial resolution

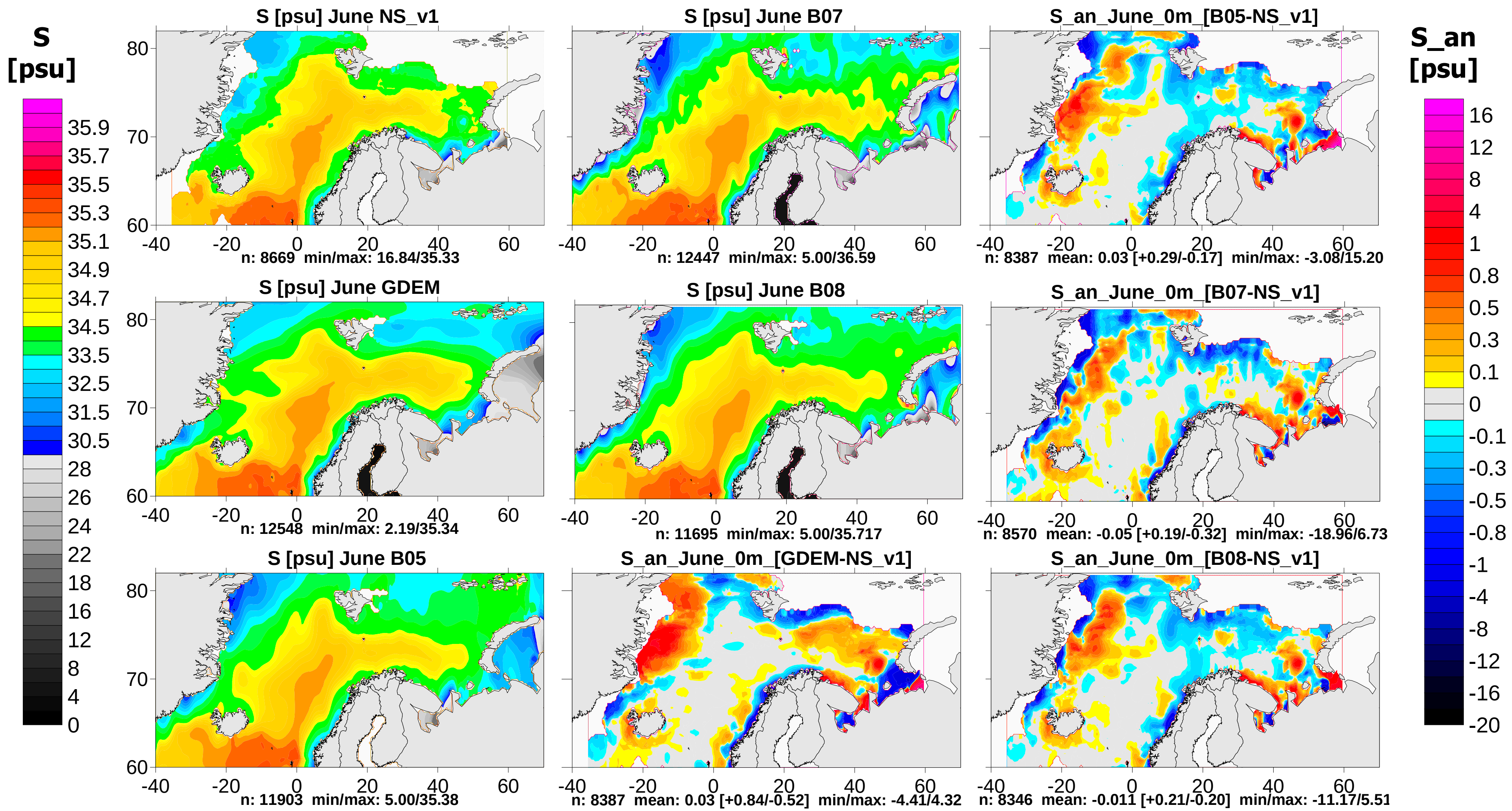
	data				Climatology					reference
Title/ year	source	period	Stations in NS region	Instru-ments	method	Spatial Resolution lat/lon	Vertical resolution	Temporal resolution	Averag-ing period	
NSv1 2007	The Nordic Seas database	1900-2004	404,808	Bottle, CTD	Block type of ordinary kriging	0.25°/0.5°	35 standard levels {WOASL* +two additional 5, 2200m)	Monthly for all standard levels	1957-1990	INTAS -4620 Final Report Korablev et al., 2005,2007 Article in preparation
GDEM 1995	Master Oceanographic Observational Data Set (MOODS) with 2.7 million profiles for the World Ocean	unknown	unknown	All	Modified minimum curvature technique	0.25°/0.25°	78 levels (27 coincide with WASL)	Monthly <1000m (Three month centered on analysis month) Annual >1000m	unknown	Data base description for the Generalized Digital Environmental Model-Variable resolution (GDEM-V) (U)/ Noval Oceanographic Office, Oceanographic Data Bases Division, Unclassified, July 2002
B05 2005	World Ocean database 2001 (WOD01)	1885-1999	191,026	All	Objective analysis procedure based on cumulative weighted difference between the means and firtst-guess fields within a given 'radius of influence' repeated three times with diminishing radius (321, 267, 214 km) with smoothing	0.25°/0.25°	33 WASL	Monthly <=1500m Seasonal 0-1500m Annual 0-1500m	1885-1999	Boyer et al., 2005 http://www.nodc.noaa.gov/OC5/WOA01/qd_ts01.html
B07 2007	World Ocean database 2005 (WOD05)	1885-2005	307,565	All	Like BO5	0.25°/0.25°	78 levels (coincide with GDEM levels)	Monthly	1885-2005	Personal communication with Timothy Boyer, 2007
B08 2008	World Ocean database 2005 (WOD05)	1885-2005	307,565	All	Like BO5	0.25°/0.25°	33 WASL	Monthly <=1500m Seasonal 0-1500m Annual 0-1500m	1885-2005	Personal communication with Timothy Boyer, 2008

*WOASL- World ocean atlas standard levels

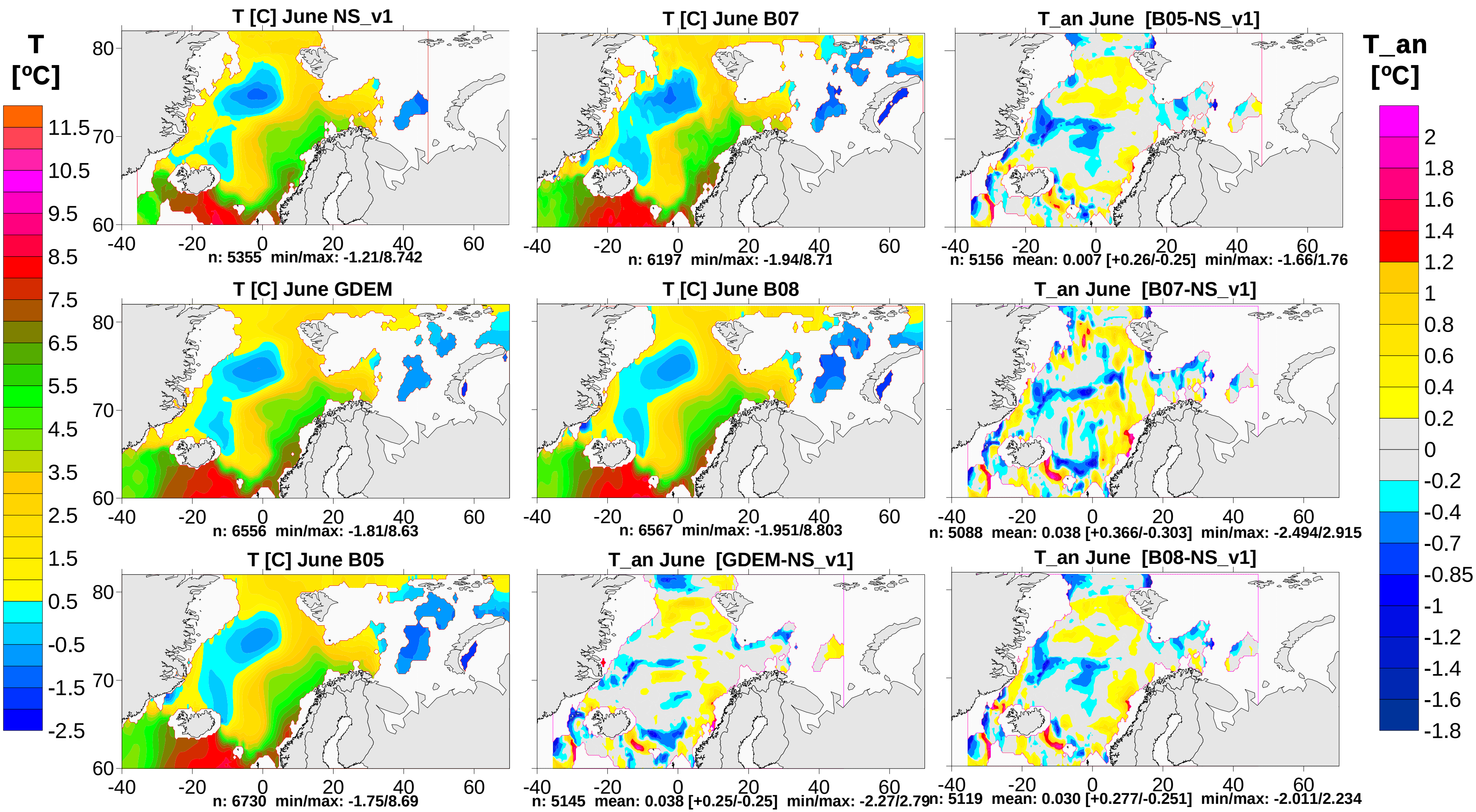
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean temperature in June on the surface and deviations from NS_v1.



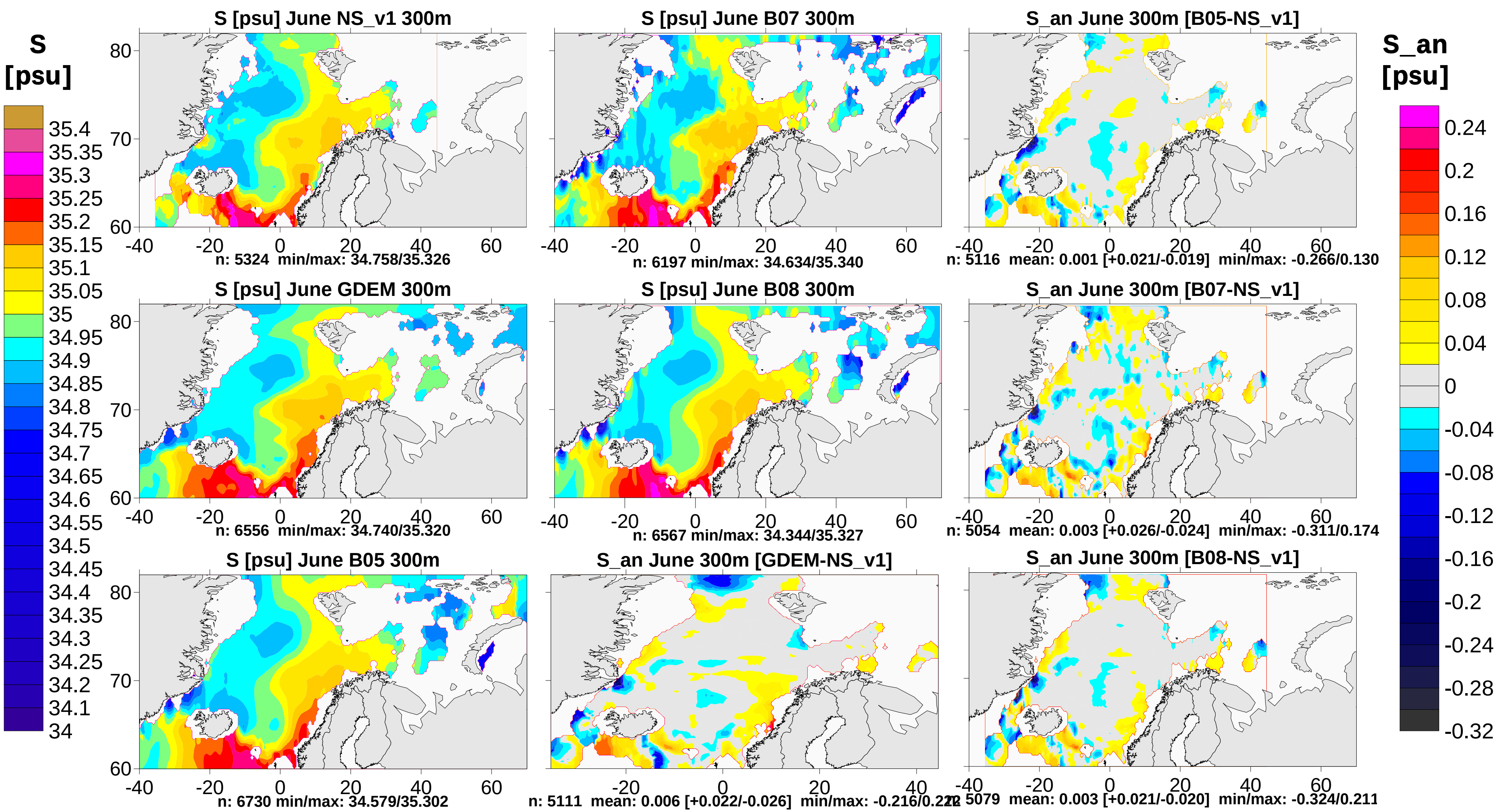
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean salinity in June on the surface and deviations from NS_v1.



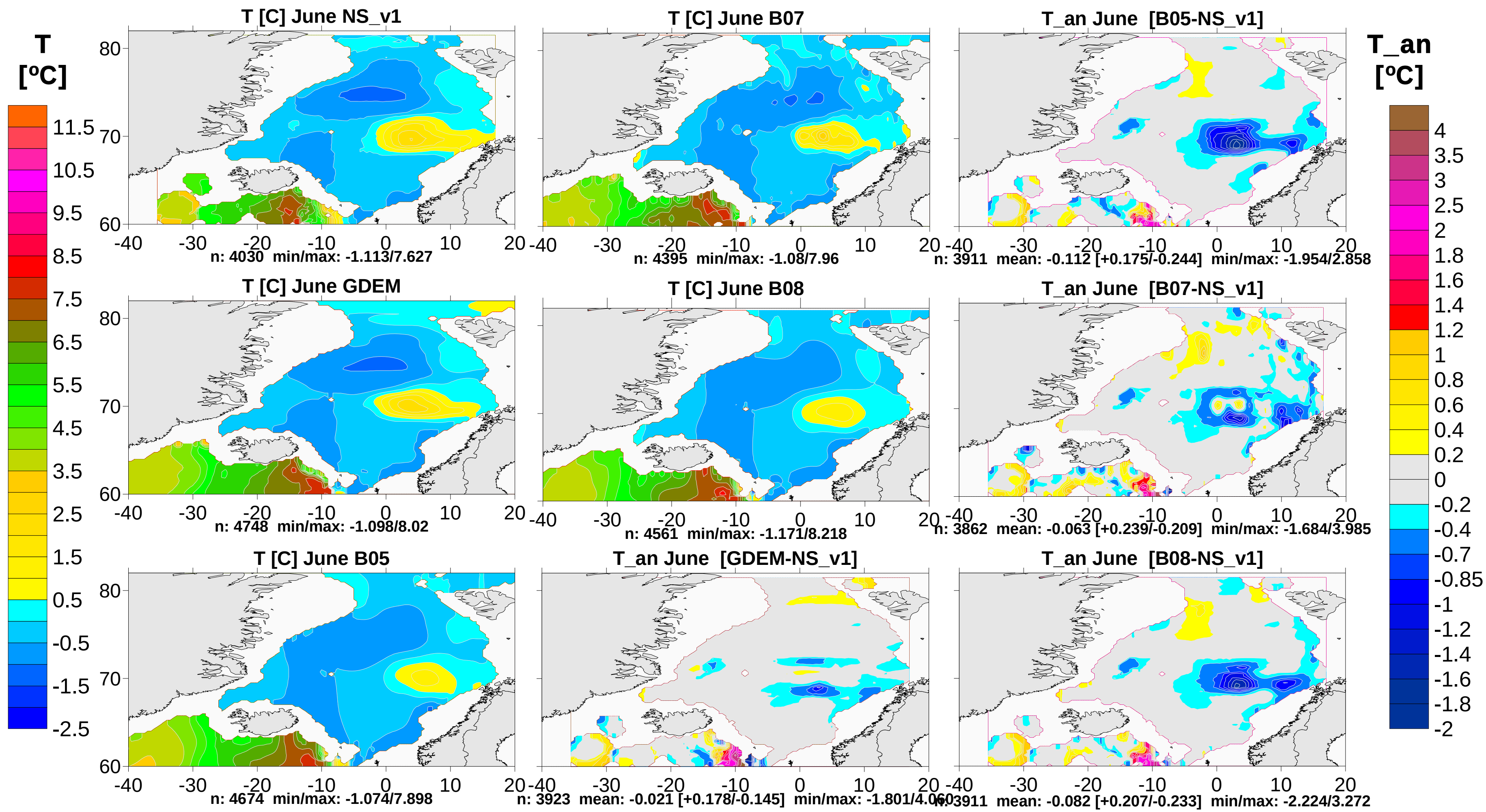
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean temperature in June at 300m depth level and deviations from NS_v1.



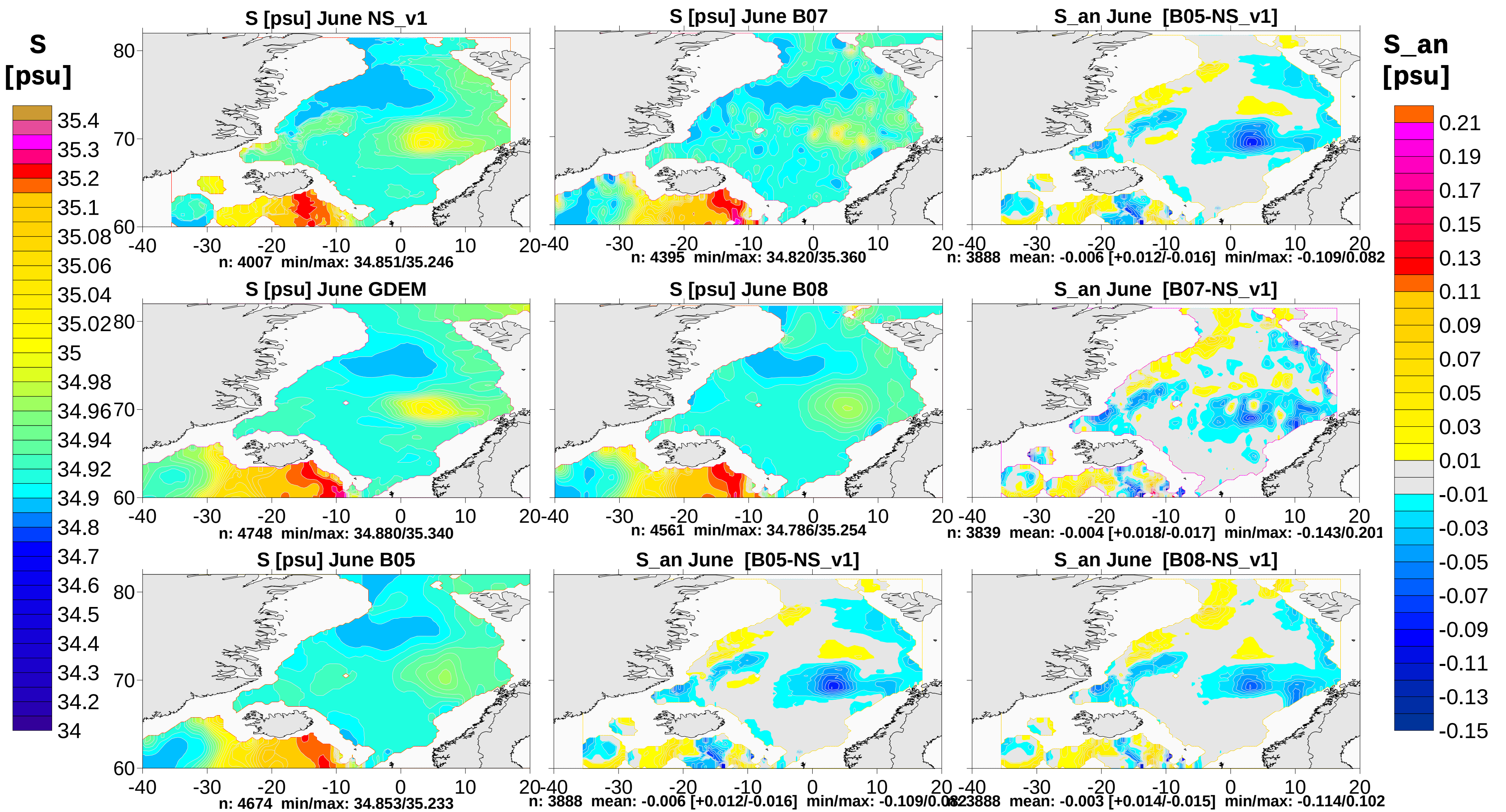
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean salinity in June at 300m depth level and deviations from NS_v1.



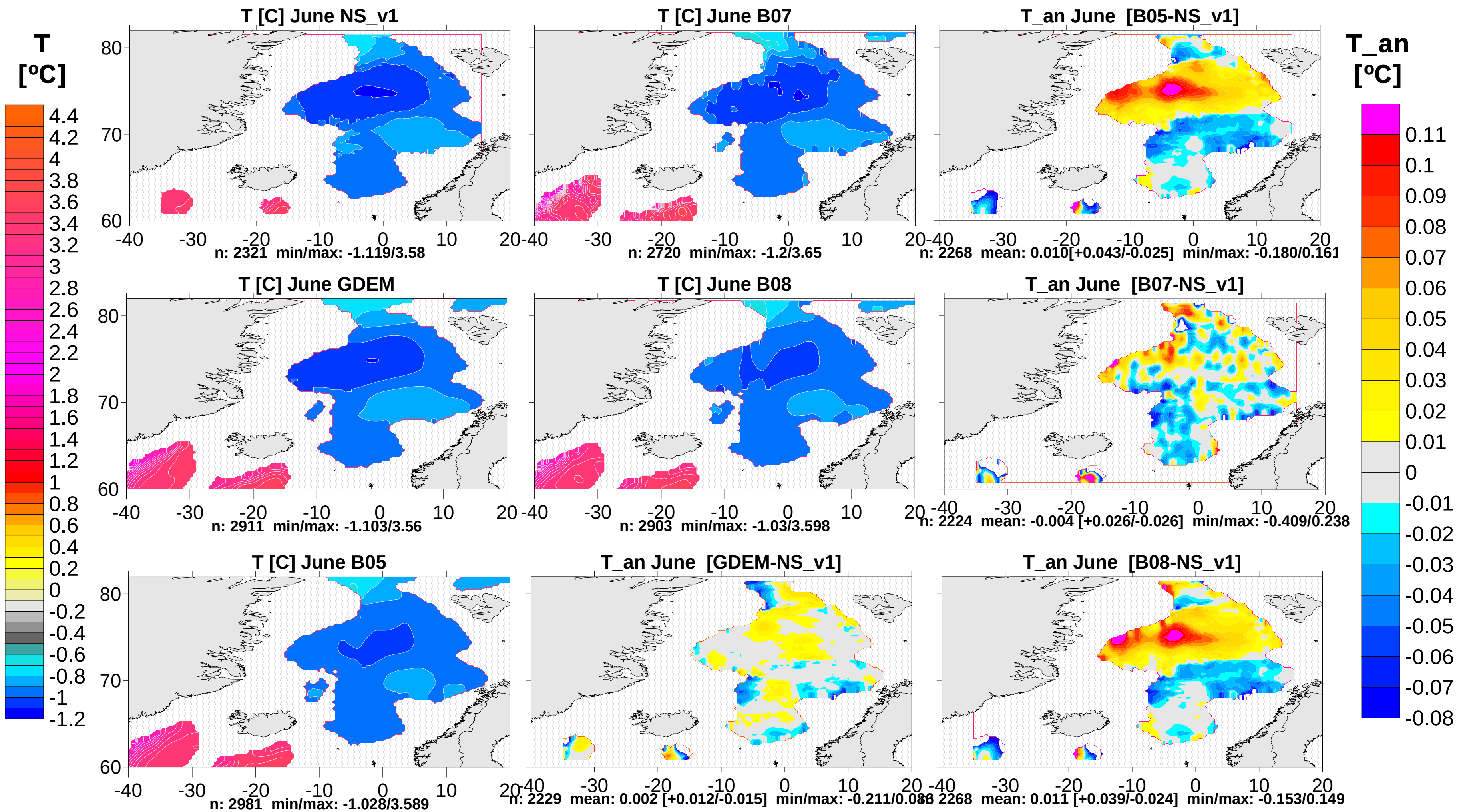
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean temperature in June at 800m depth level and deviations from NS_v1.



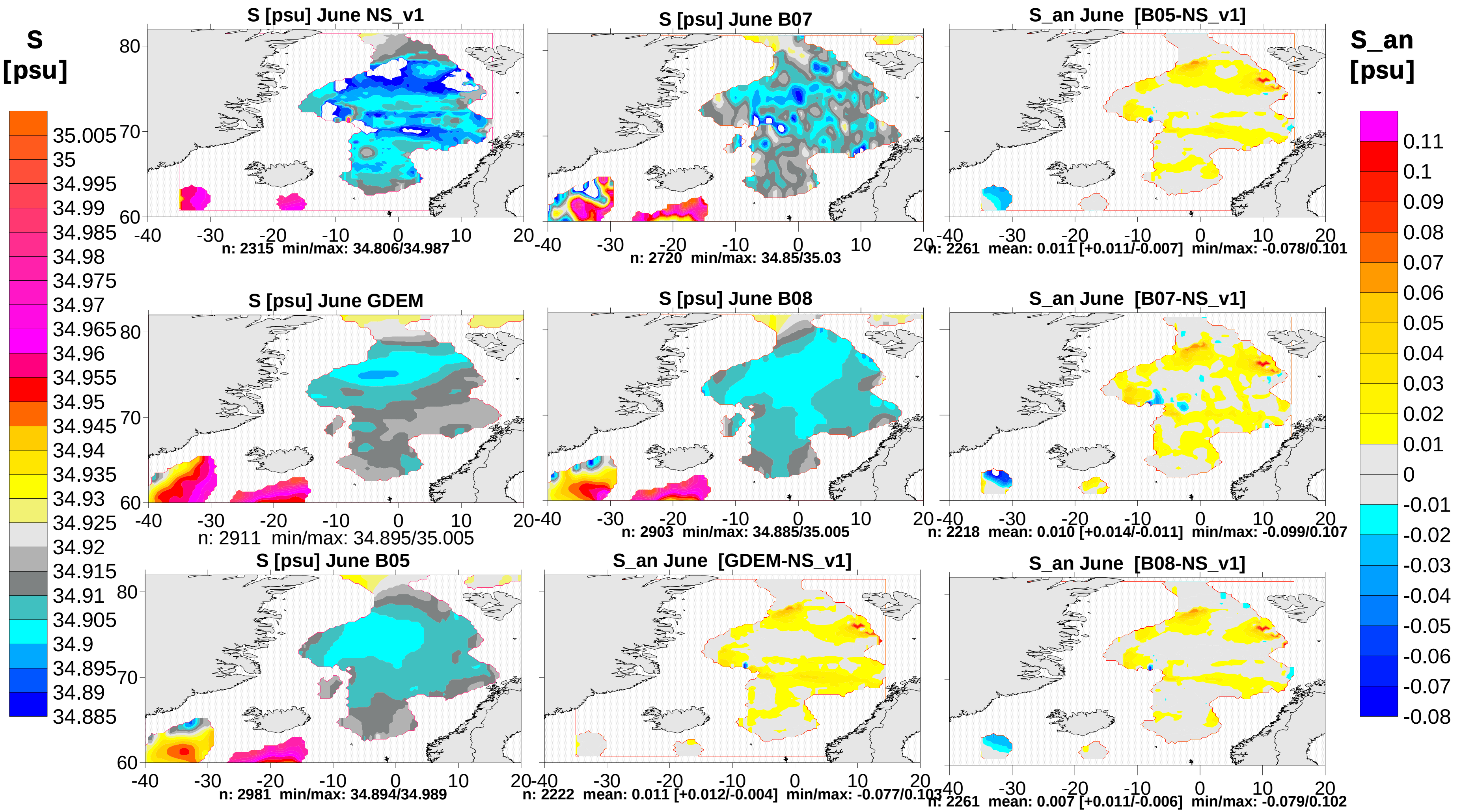
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean salinity in June at 800m depth level and deviations from NS_v1.



Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean temperature in June at 2000m depth level and deviations from NS_v1.



Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Mean salinity in June at 2000m depth level and deviations from NS_v1.



Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08). Statistics for temperature and salinity in June.

Depth:	0m						300m						800m					
Par:	T[ºC]			S[psu]			T[ºC]			S[psu]			T[ºC]			S[psu]		
Data-set	n	min	max	n	min	max	n	min	max	n	min	max	N	Min	max	n	min	max
NS_v1	8669	-1.78	11.16	8621	16.84	35.33	5355	-1.21	7.42	5324	34.76	35.33	4030	-1.11	7.63	4007	34.85	35.25
NS_v2	10127	-1.76	10.67	9751	9.20	35.31	5877	-1.68	8.48	5909	34.78	35.30	4548	-1.10	7.38	4548	34.82	35.20
GDEM	12548	-1.46	11.86	12548	2.19	35.34	6556	-1.81	8.63	6556	34.74	35.32	4748	-1.10	8.02	4748	34.88	35.34
B05i*	25290	-2.10	11.77	25290	5.00	35.40	14831	-1.75	8.86	14831	34.55	35.33	10138	-1.88	8.08	10.14	34.71	35.24
B05	11903	-2.10	11.06	11903	5.00	35.38	6730	-1.75	8.69	6730	34.58	35.30	4674	-1.07	7.90	4674	34.85	35.23
B07i*	26412	-2.10	21.97	26412	5.00	37.58	14106	-2.10	9.07	14106	34.54	35.37	9520	-1.52	8.63	9520	34.79	35.45
B07	12447	-2.07	15.64	12447	5.00	36.59	6197	-1.94	8.71	6197	34.63	35.34	4395	-1.08	7.96	4395	34.82	35.36
B08i*	24877	-2.10	14.96	24877	5.00	36.29	14493	-2.10	9.44	14493	34.52	35.36	9864	-1.63	8.35	9864	34.77	35.27
B08	11695	-2.10	13.389	11695	5.00	35.72	6567	-1.95	8.80	6567	34.34	35.33	4561	-1.17	8.22	4561	34.79	35.25

* ‘i’, following the specification means dataset in original grid, without ‘i’ dataset converted into NS_v1 grid

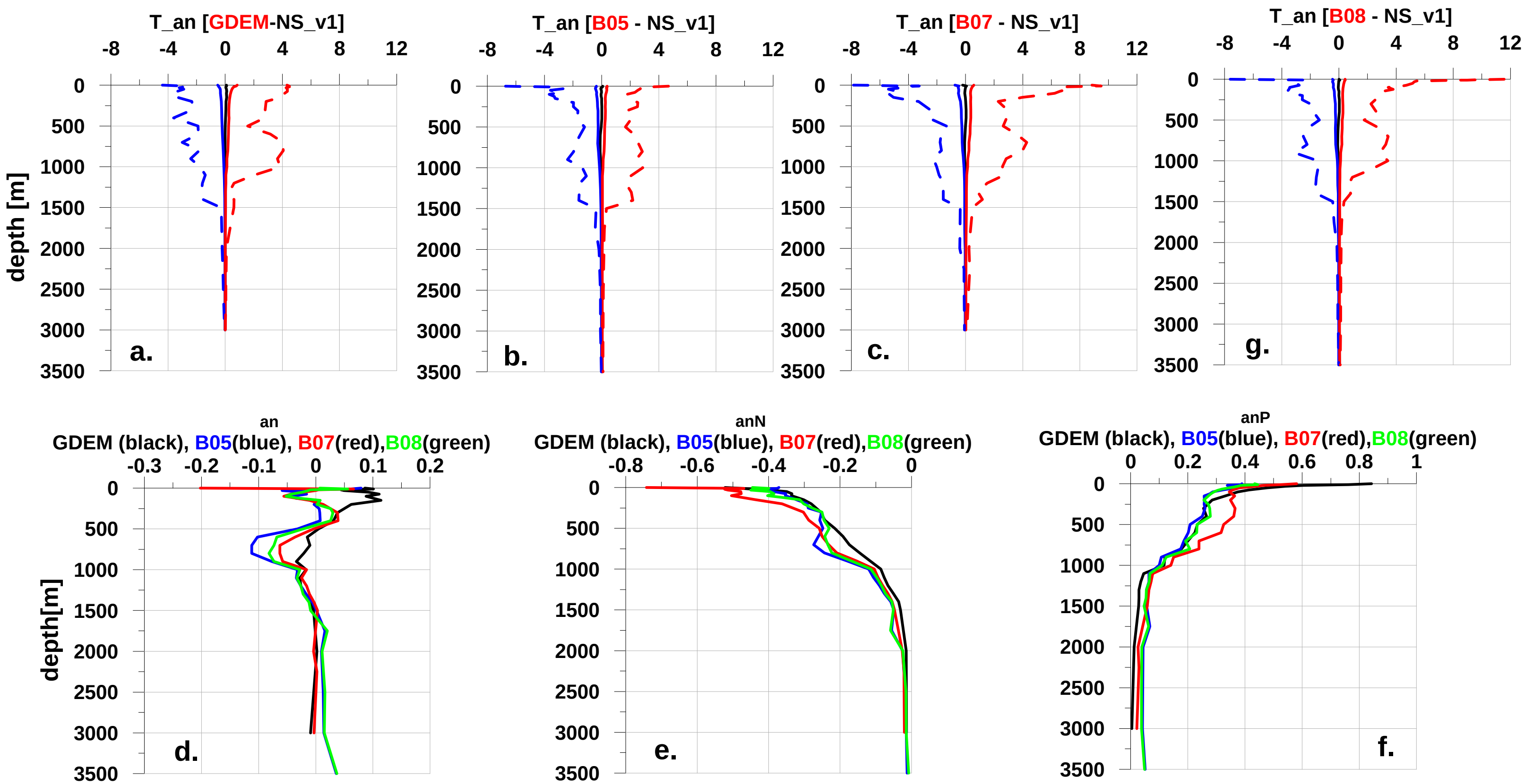
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Statistics for temperature and salinity anomalies in June relative to NS_v1.

Depth:	0m						300m						800m					
Par	n*	md	md+	md-	min	max	n*	md	md+	md-	min	max	n*	md	md+	md-	min	max
[DGEM – NS_v1]																		
T [ºC]	8594	0.08	+0.84	-0.52	-4.41	4.32	5145	0.04	+0.25	-0.25	-2.27	2.79	3923	-0.02	+0.18	-0.14	-1.80	4.06
S [psu]	8560	0.07	+0.27	-0.32	-7.42	10.72	5111	0.006	+0.02	-0.03	-0.22	0.22	3900	-0.003	+0.02	-0.01	-0.11	0.08
[B05 – NS_v1]																		
T [ºC]	8418	0.08	+0.39	-0.37	-6.73	4.67	5156	0.01	+0.26	-0.25	-1.66	1.75	3911	-0.11	+0.17	-0.24	-1.95	2.86
S [psu]	8387	0.03	+0.29	-0.17	-3.08	15.20	5116	0.001	+0.02	-0.02	-0.27	0.13	3888	-0.006	+0.01	-0.01	-0.11	0.08
[B07 – NS_v1]																		
T [ºC]	8607	-0.20	+0.58	-0.74	-7.58	8.84	5088	0.04	+0.37	-0.30	-2.49	2.91	3862	-0.06	+0.24	-0.21	-1.68	3.98
S [psu]	8570	-0.05	+0.19	-0.22	-18.96	6.73	5054	0.003	+0.03	-0.02	-0.31	0.17	3839	-0.004	+0.018	-0.017	-0.14	0.20
[B08 – NS_v1]																		
T [ºC]	8377	0.01	+0.43	-0.44	-7.61	11.56	5119	0.03	+0.27	-0.25	-2.01	2.23	3911	-0.08	0.21	-0.23	-2.22	3.72
S [psu]	8346	-0.01	+0.21	-0.20	-11.17	5.51	5079	0.003	+0.02	-0.02	-0.32	0.21	3888	-0.003	0.014	-0.015	-0.114	0.102

n* – number of coincident nodes for two fields from different climatologies

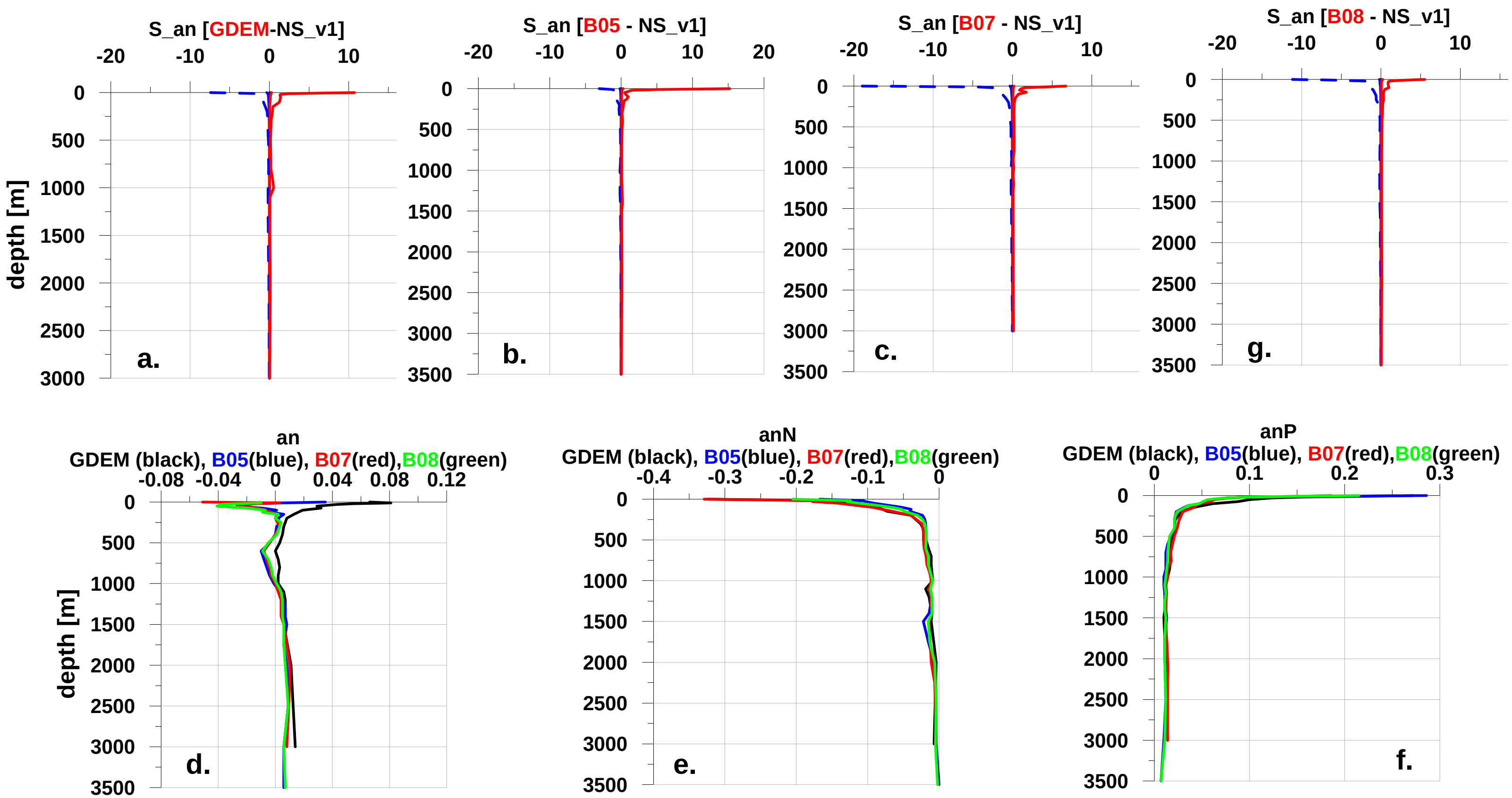
Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).

Temperature anomalies [^{o}C] profiles relative to NS_v1 for coincident nodes at statndard levels.



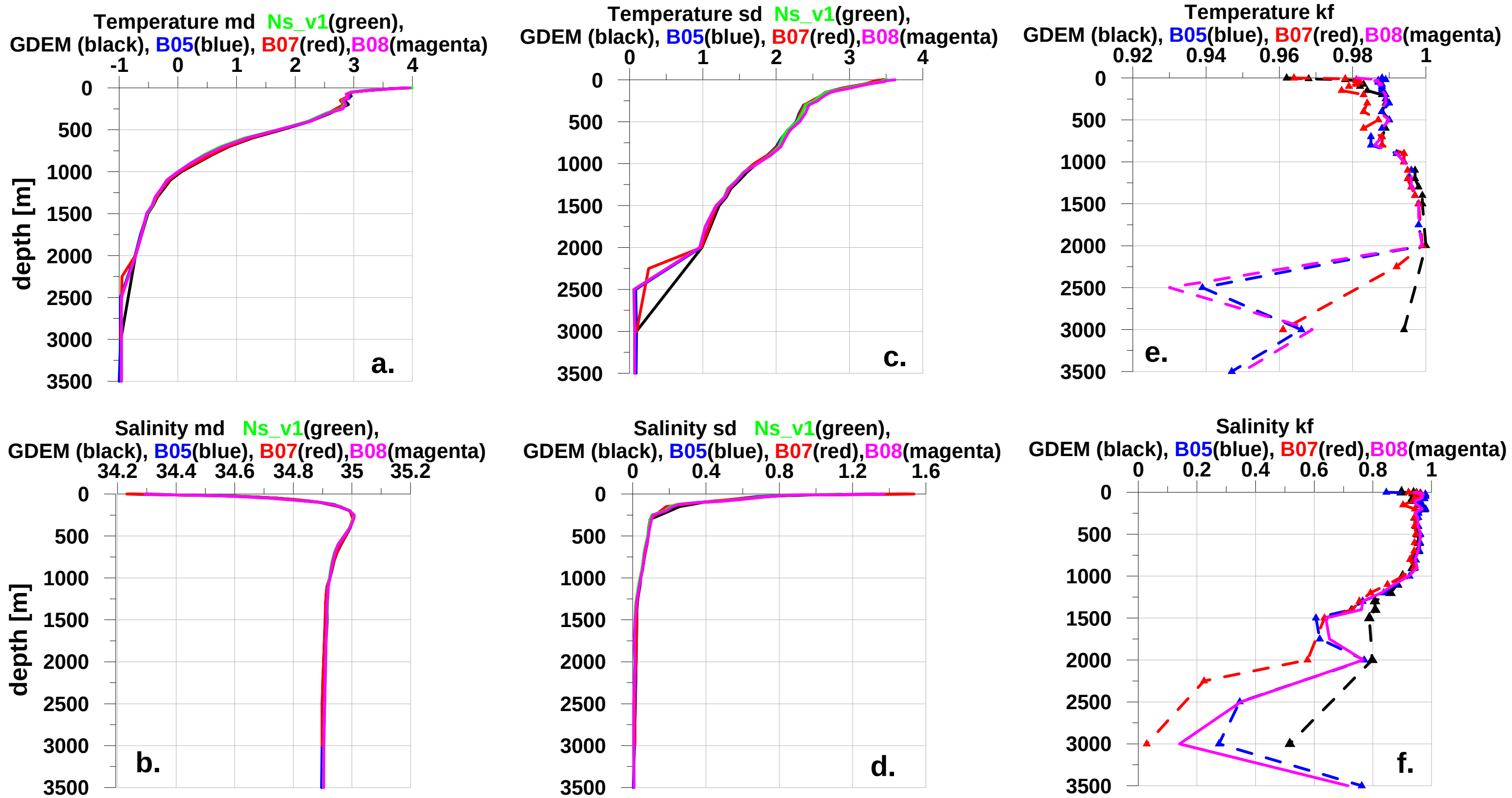
GDEM (a), B05 (b), B07 (c), B08(g) show mean anomaly (black), mean negative (blue), maximum negative (blue, dashed), mean positive (red), maximum positive (red, dashed). Low pannel represents combined mean (d), mean negative (e) and mean positive (f) anomalies vertical distributions for GDEM, B05,B07 and B08.

Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08).
Salinity anomalies [psu] profiles relative to NS_v1 for coincident nodes at statndard levels.



GDEM (a), B05 (b), B07 (c), B08(g) show mean anomaly (black), mean negative (blue), maximum negative (blue, dashed), mean positive (red), maximum positive (red, dashed). Low pannel represents combined mean (d), mean negative (e) and mean positive (f) anomalies vertical distributions for GDEM, B05,B07 and B08.

Climatologies comparison (NS_v1, GDEM, Boyer05, Boyer07, Boyer08). Vertical distributions of mean temperature, salinity and correlation coefficients relative to NS_v1 for coincident nodes at statndard levels.

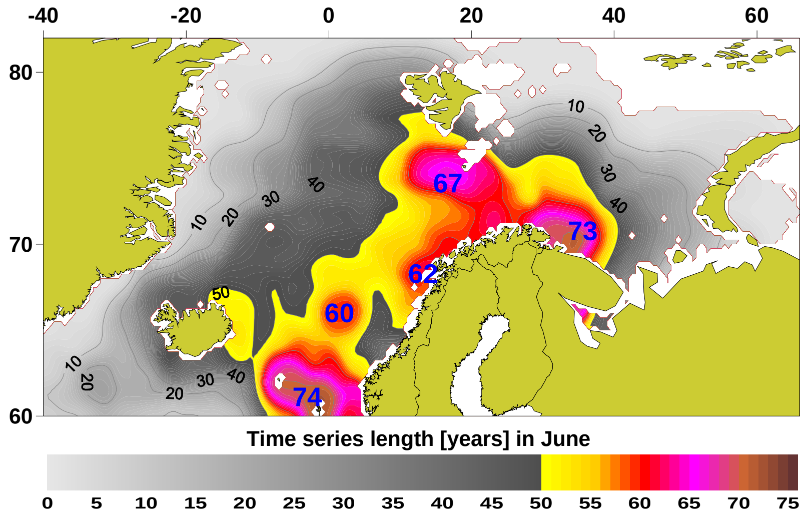


Vertical profiles of mean temperature [ºC] (a), salinitu [psu] (b), their standard deviations (c,d) and spatial correlation coefficients (e,f) between GDEM, B05, B07, B08 and NS_v1 for coincident nodes at standard depth levels.

Conclusions (climatologies comparison)

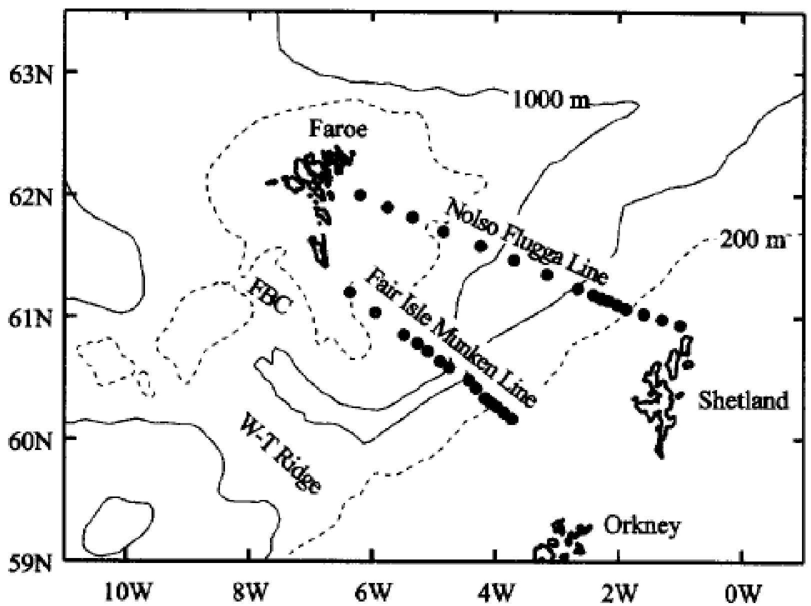
- ✓ All climatologies reproduce the mean structure of the water masses in the Nordic Seas relatively well
- ✓ T/S deviations in certain nodes can reach considerable values
- ✓ GDEM based on limited initial data collection but shows reasonable but strongly smoothed mean fields. Contrary to GDEM 2.6, methodology of the last version 3.0 does not documented in open literature
- ✓ T/S deviations from NS_v1 do not show distinct connection with physical properties of the water masses and depend mainly from data availability and processing
- ✓ Lack of spatial correlations below 2000m shows insufficient representation of true fields including NS_v1
- ✓ B07, B08 contain very low temperatures below -2.0ºC
- ✓ Insufficient information about initial data amount and interpolation errors
- ✓ After main updates of the initial database a new version of NS climatology is planned

Identification of climate signals from standard measurements



Nolso Flugga Line Section

W.R. Turrell et al. / Deep-Sea Research I 46 (1999) 1–25



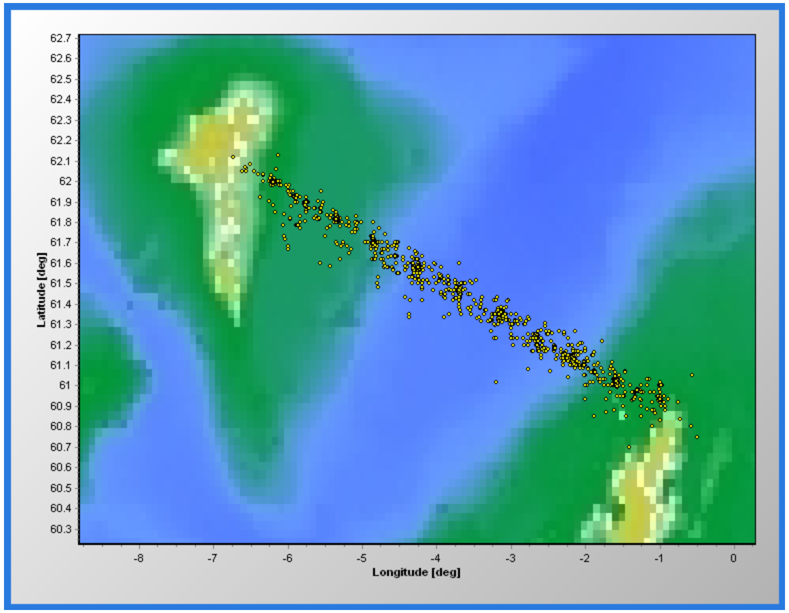
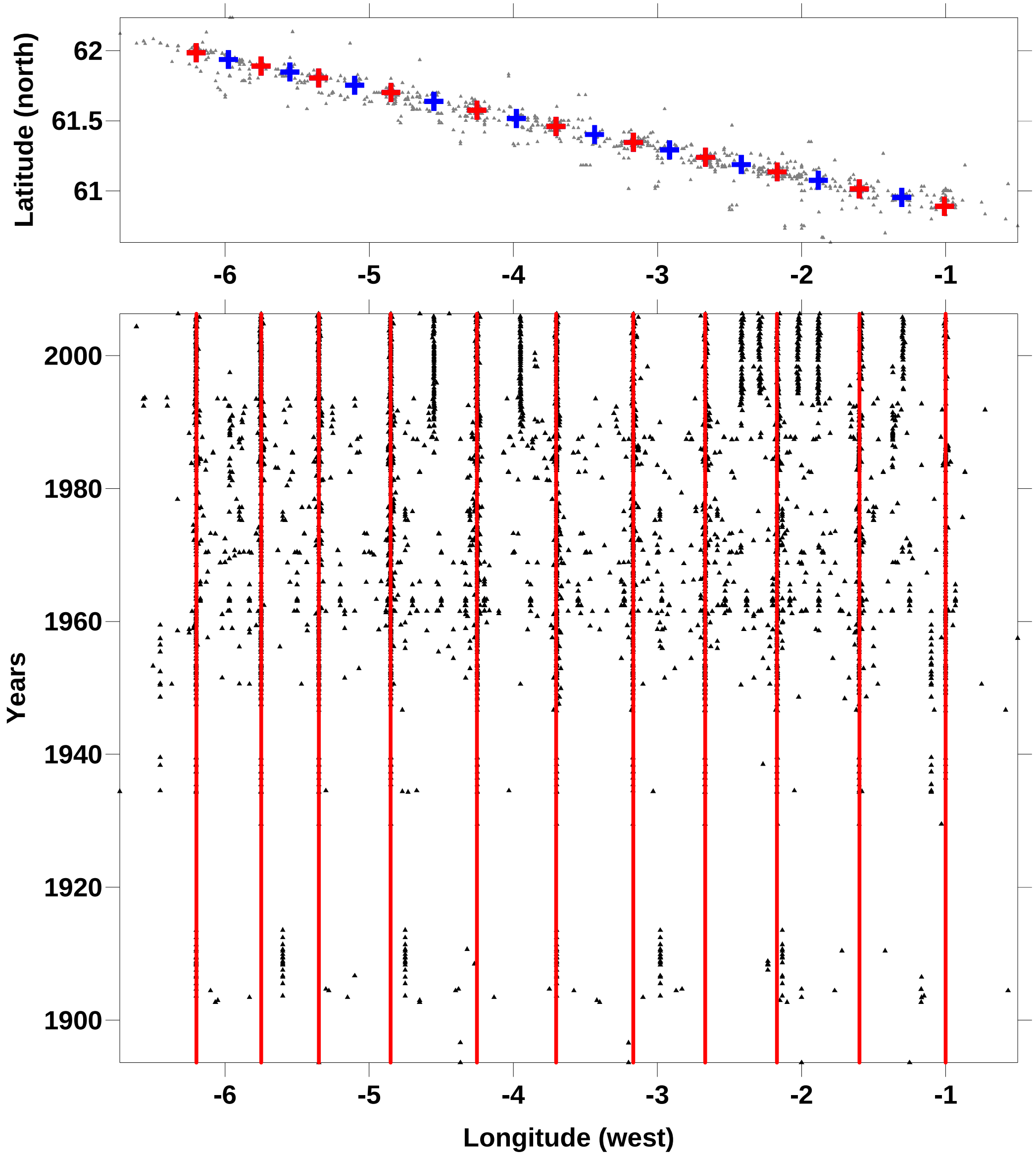


Fig.1 Map showing the Faroe Shetland Channel and the location of the two standard hydrographic sections across the Channel, which have been surveyed for over one century.
FBC - Faroe Bank Channel
W-T - Wyvill-Thomson Ridge

NFLupd.ib content
Sections: 539
Stations : 5078
Period : 1893-2006

Country	St.	%
United Kingdom	1628	32
USSR/Russia	1413	28
Denmark	771	15
Norway	622	12
Netherlands	29	
Belgium	22	
USA	7	
Unknown	586	11

Nolso Flugga Line Section
Definition of the standard stations positions



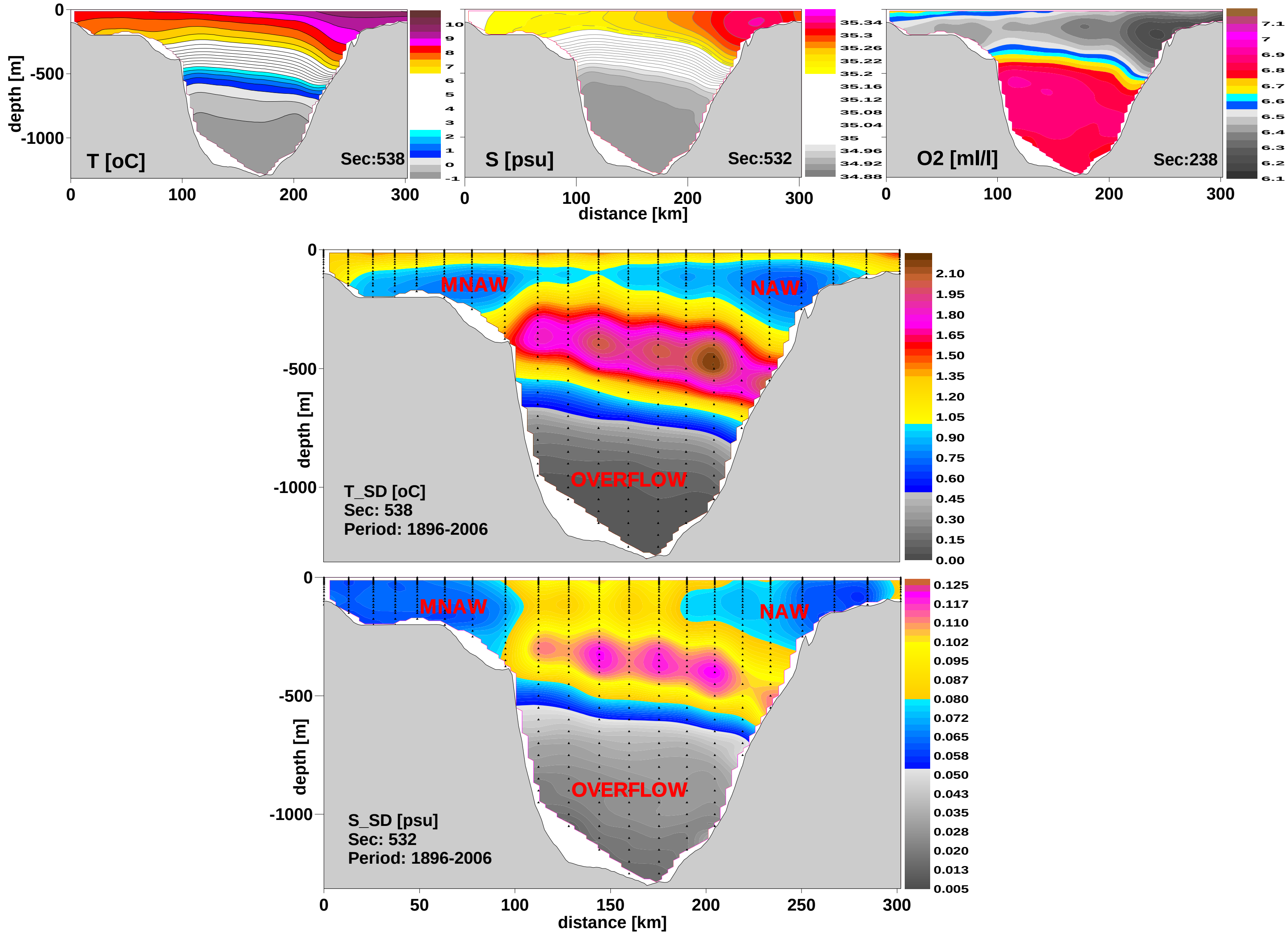
Purpose

Definition of the long-term variability of the characteristics of different water masses

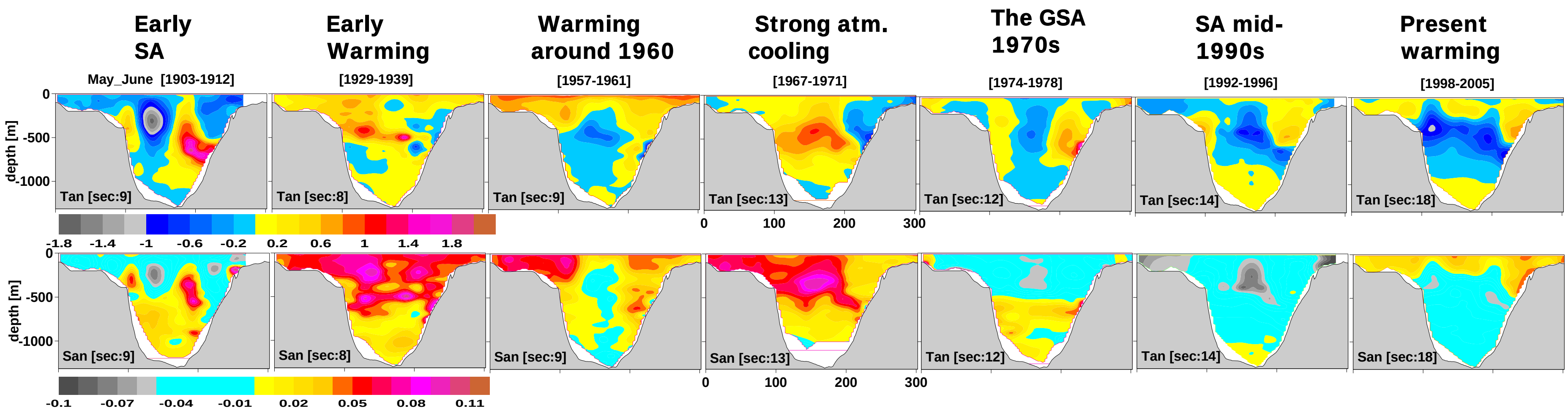
Methods

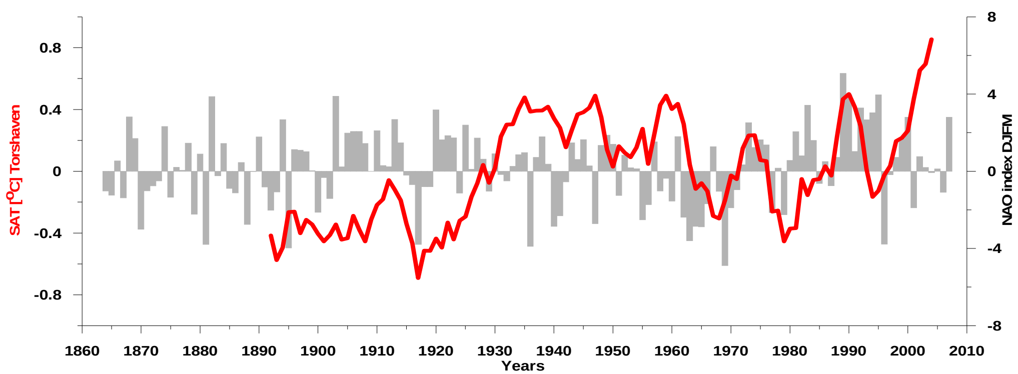
- **Collection of the complete dataset**
- **Detection of standard station position (cluster analysis)**
- **Specifying of optimal regular grid**
- **Objective analysis of the variables (t,s,o2) for each individual section**
- **Generation of objectively analyzed dataset**
- **Determination of stable water mass and mixing zones pattern by means of cluster analysis**
- **Evolution of spatial-temporal pattern of variability across the FSC**

Nolso Flugga Line Section
Mean distributions for 1896-2006

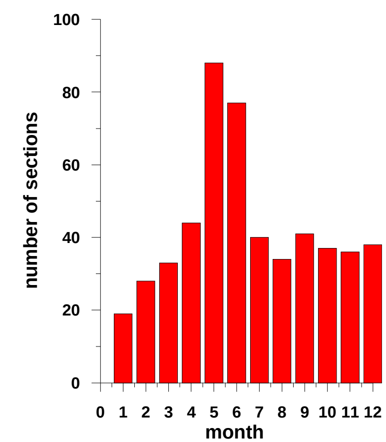


Nolso Flugga Line Section
T/S anomalies composites for May-June



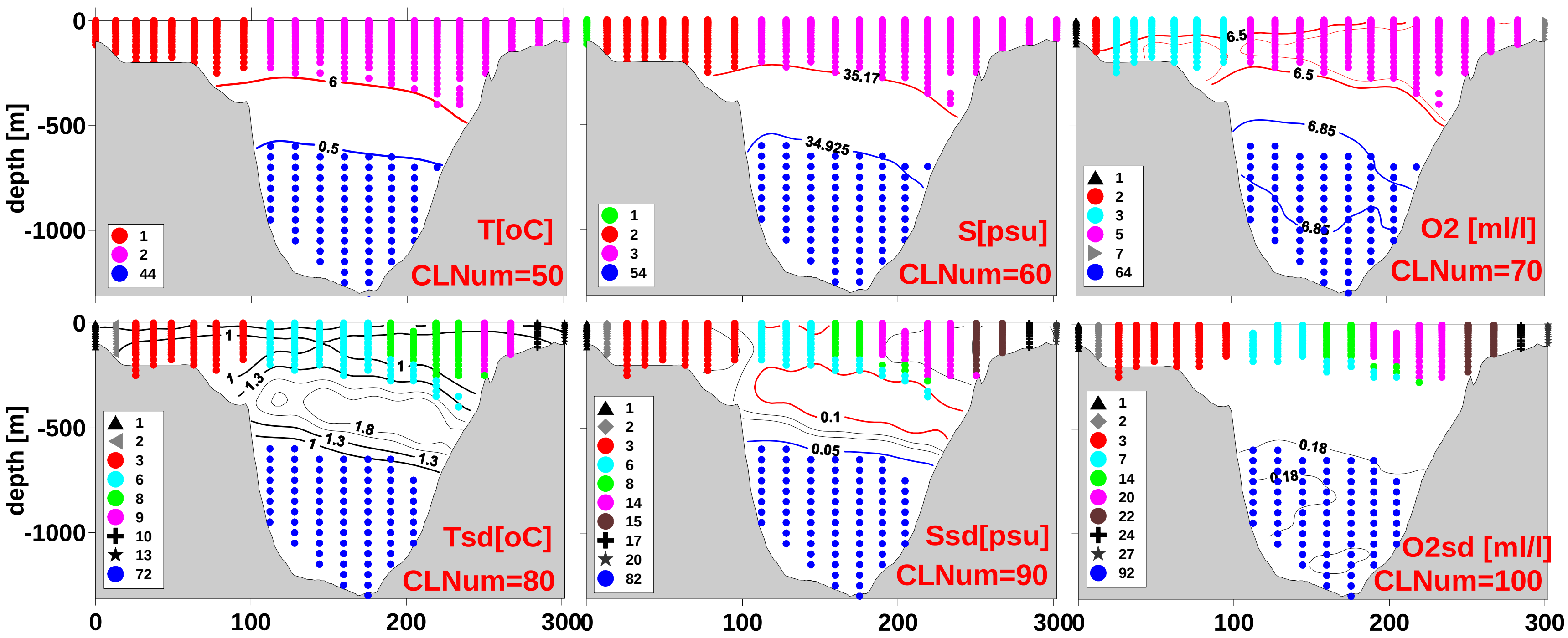


SAT, Torshaven (Faroe Island) 1890-2006 / winter NAO Index 1864-2007

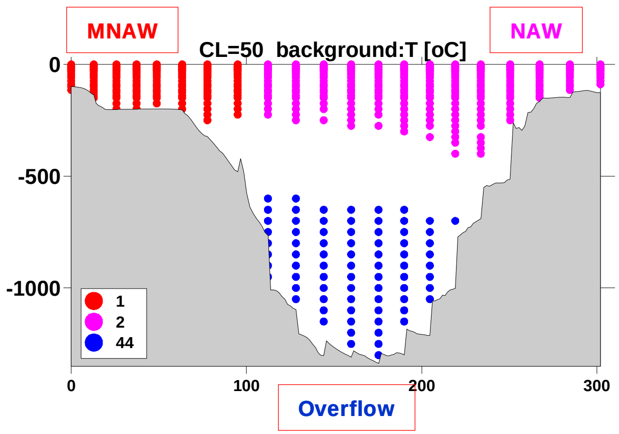


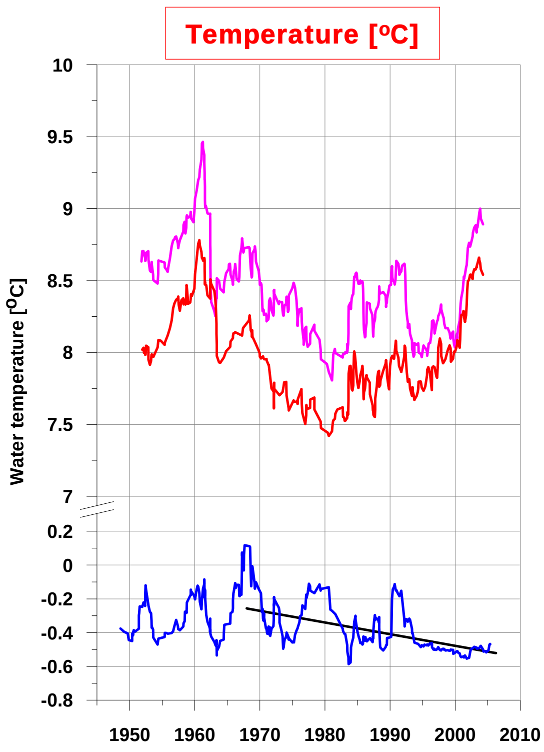
Monthly sections number distribution

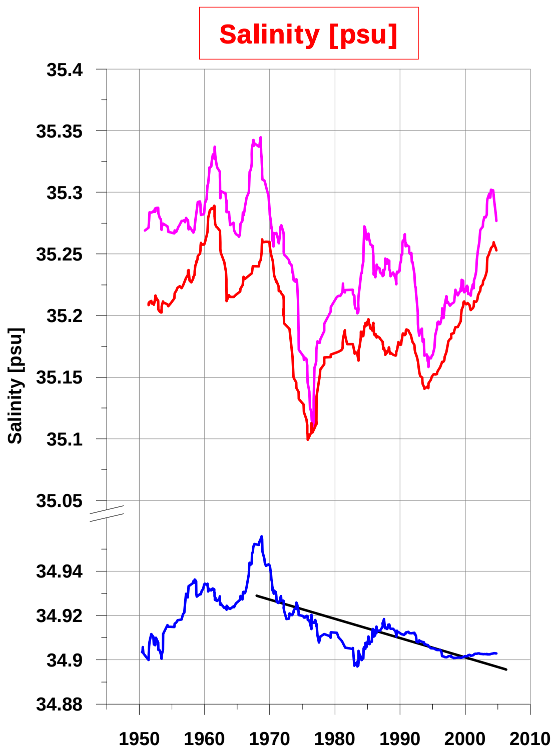
Water masses classification [t,tsd,s,ssd] with different specification. Background t,s,o2,tsd,ssd,o2sd selected isolines



Water masses classification [t,tsd,s,ssd] with different specification. Time series.

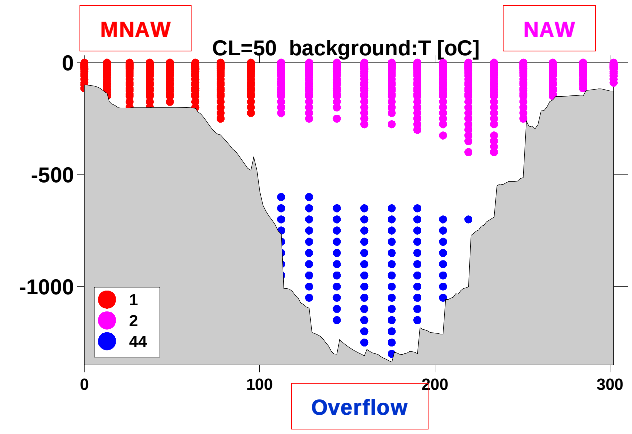


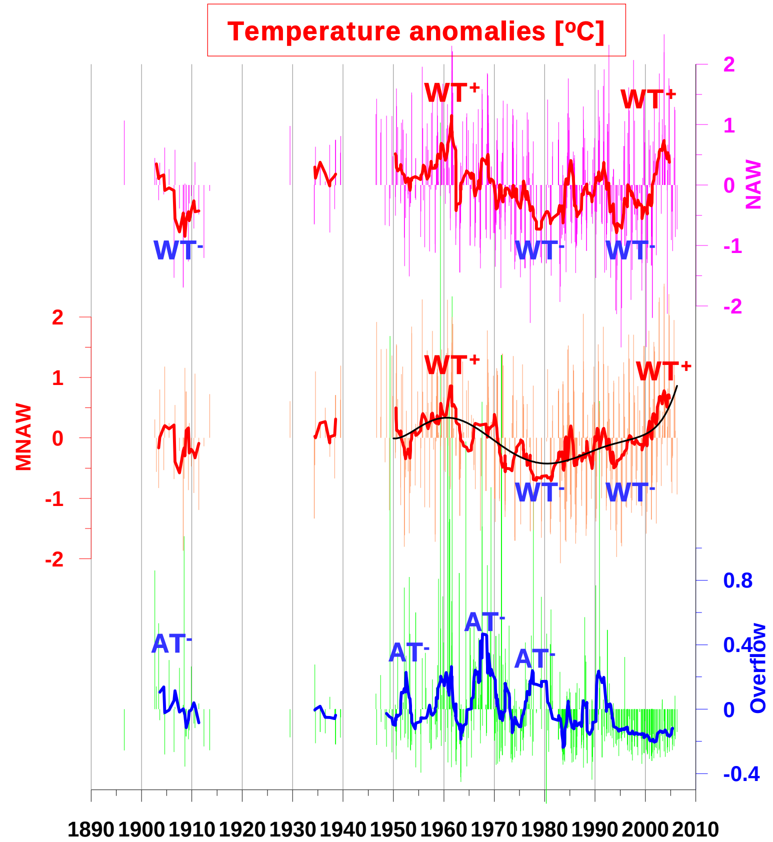


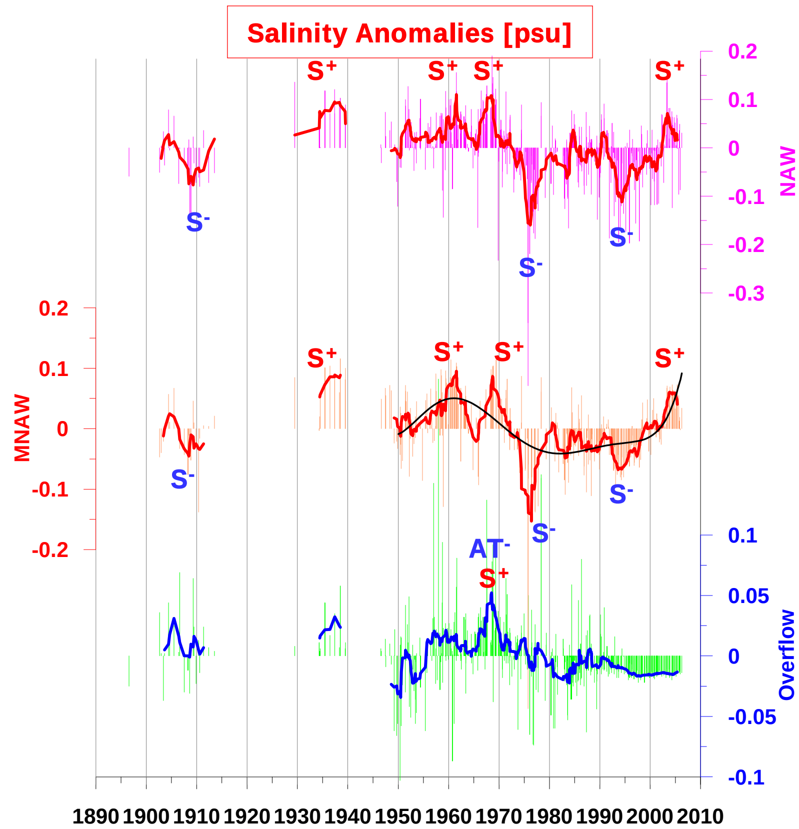


Water masses classification [t,tsd,s,ssd] with different specification. Time series.

Water temperature warm anomalies [WT+], cold anomalies [WT-]
Salinity positive anomalies [S+], salinity negative anomalies [S-]
Atmosphere warming events [AT+], cooling events [AT-]







Atlantic water -> overflow feedback

1. Overflow water temperature and salinity increase (the late 1960s- early 1970s)
Preconditioning: large amount of salty AW inflow into the NS
Forcing: strong atmospheric cooling
Mechanism:
- ✓ **upper layer density increase**
- ✓ **stratification weakening**
- ✓ **enhanced vertical fluxes**
- ✓ **AW sinking to the greater depth due to higher density**
- ✓ **Winter mixing layer depth increase due to weakened stratification**

2.Overflow water temperature and salinity reduction (since mid 1970s)
Preconditioning: upper layer density decrease
Forcing: low salinity anomalies propagation, upper layer warming
Mechanism:
- ✓ **stratification strengthening**
- ✓ **reduction in vertical fluxes**
- ✓ **horizontal transport dominate**

Conclusions (climatic signals from standard sections)

- **Analysis lead to detailed view of the water mass variability in the areas with long historical time series**

- **Thermohaline properties along NFL for the ‘early’ and ‘present’ warming events reveal significant difference**

- **Warming event during the late 1950s and 1960s is highly pronounced and in some aspects close to ‘early’ warming event**

- **Detailed cluster analysis is needed to distinguish spatial and temporal components of variability and to get meaningful estimates**

- **Salinity reduction in the overflow waters during last 30 years (reduction of AW ratio)**