Horizontal thermohaline variability at sub-mesoscale to basin scale in the North-Eastern Baltic Sea

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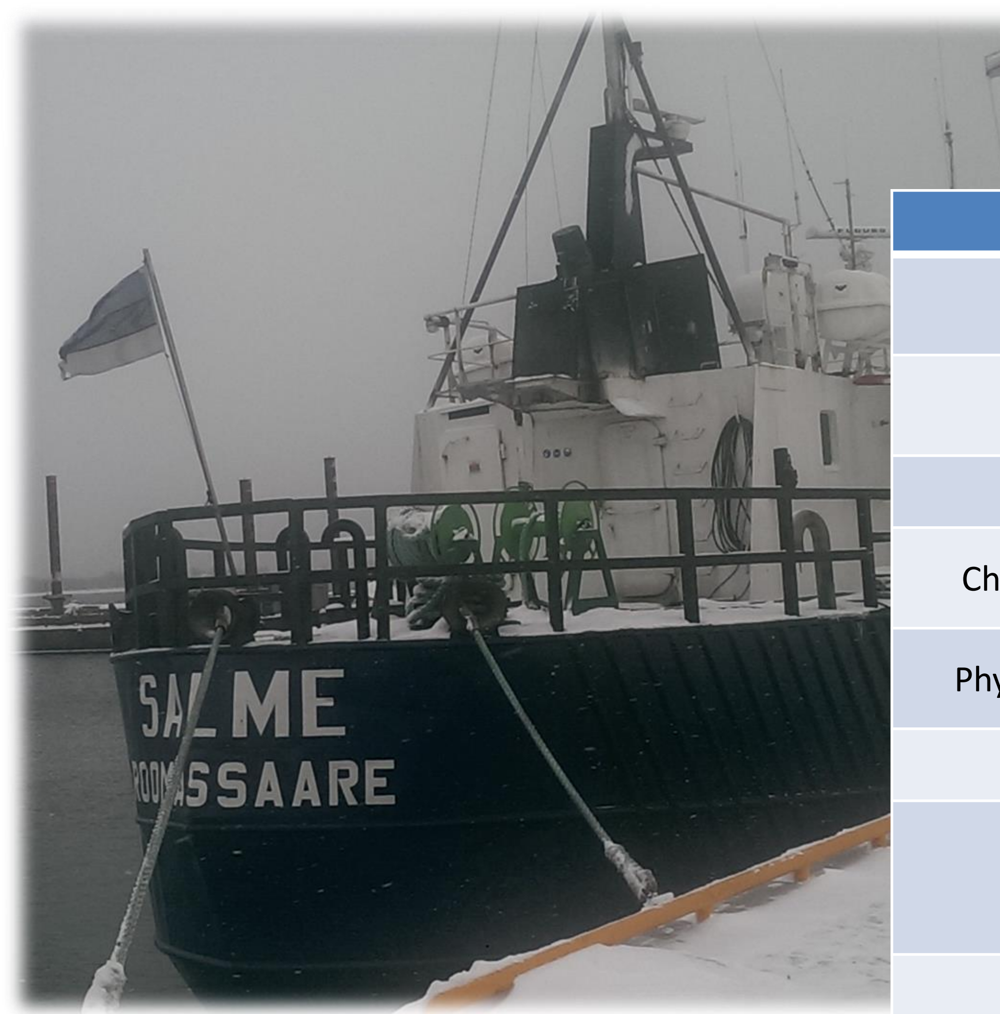
R/V Salme Ferrybox sensors



Ferrybox by Go-systemelektronik

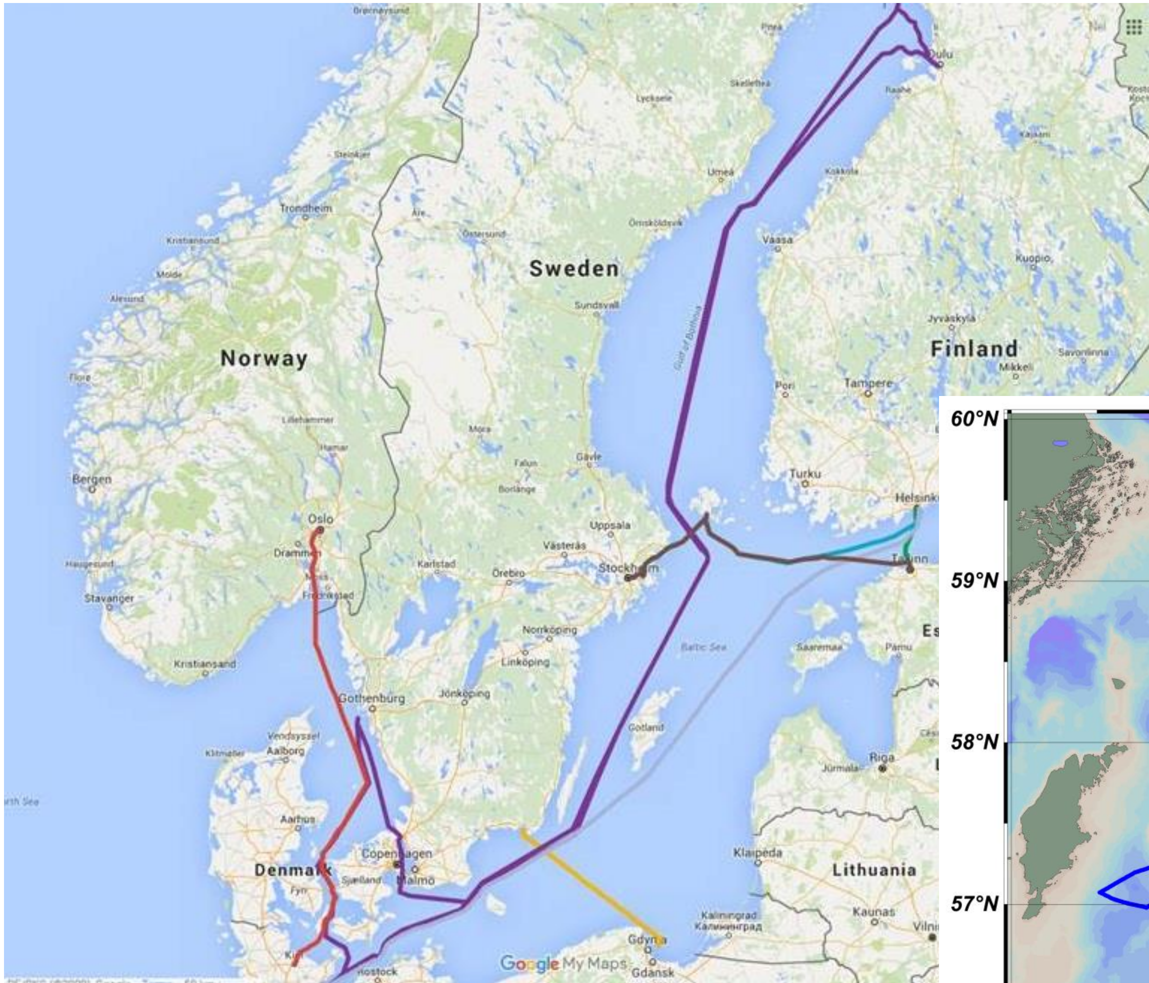
Parameter	Sensor
Temperature	SBE38
Temperature	SBE45 MicroTSG
Conductivity	SBE45 MicroTSG
Chlorophyll fluorescence	WetLabs *ECO* FL
Phycocyanin fluorescence	WetLabs *ECO* FLPC
Turbidity	WetLabs *ECO* FLNTU
Oxygen	Digital OPTOD (OPTICAL DISSOLVED OXYGEN) by PONSEL
~~pCO2~~	~~OceanPack MK2 Stand-Alone pCO2 Analyzer~~
Chlorophyll *a* fluorescence	Turner Design Cyclops-7

Ferrybox measurements

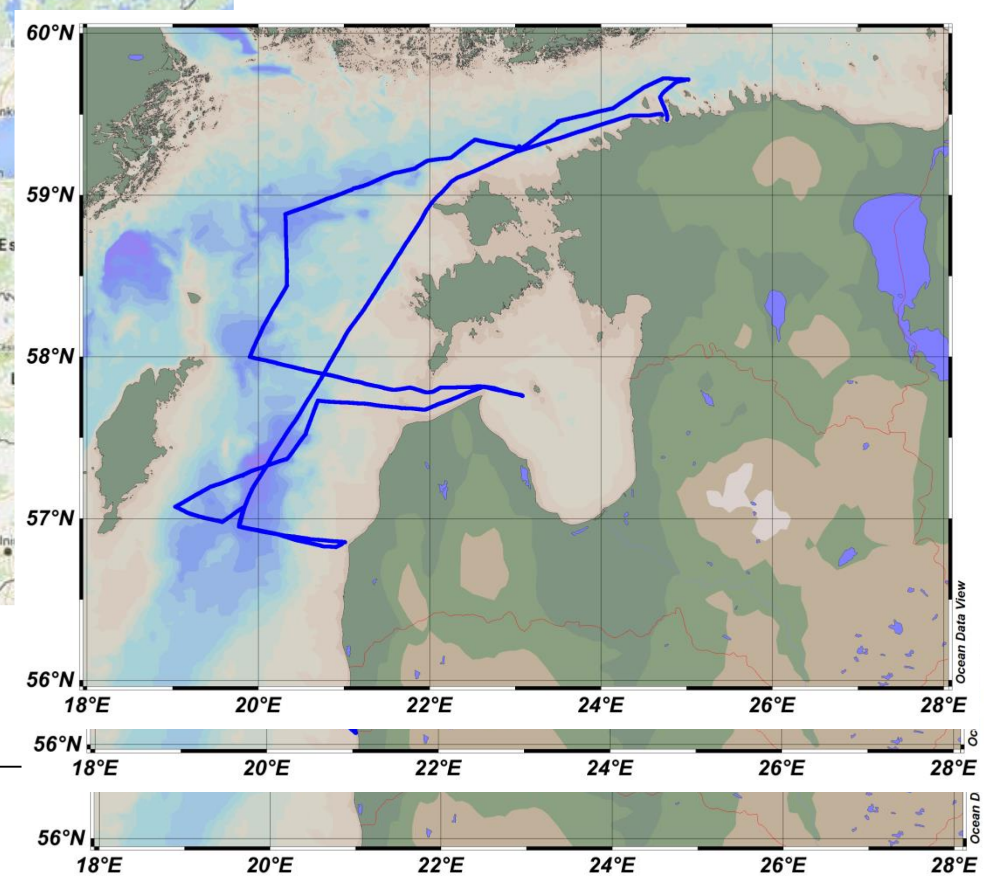
- Water intake at 2 m depth
- Sampling interval of 50 s results in nominal spatial resolution about 250 m

Year	Number of cruises	Days
2013 Sept. – Dec.	8	25
2014	36	88
2015	37	99
2016 Jan. – Apr.	4	9

Motivation



- Uncovered:
  - Eastern Gulf of Finland
  - Gulf of Riga
  - Eastern Baltic Proper

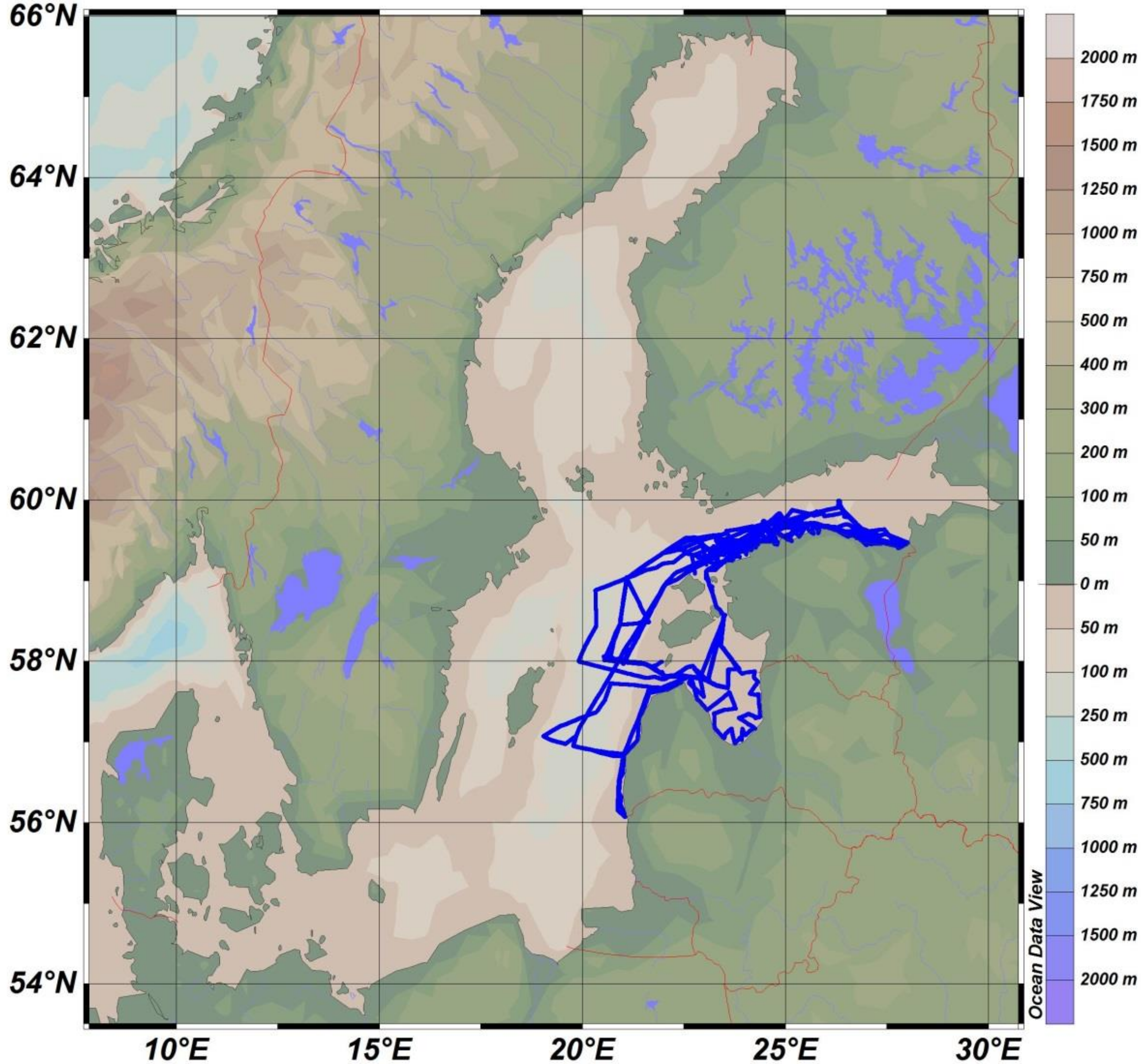


Source: http://www.ferrybox.com/

Salmebox cruises in 2015

37 cruises, out of which:

- 6x Estonian monitoring cruise
- 2x Latvian monitoring cruise



1.01.2015-31.12.2015

Source: http://on-line.msi.ttu.ee/gmaplaev2/

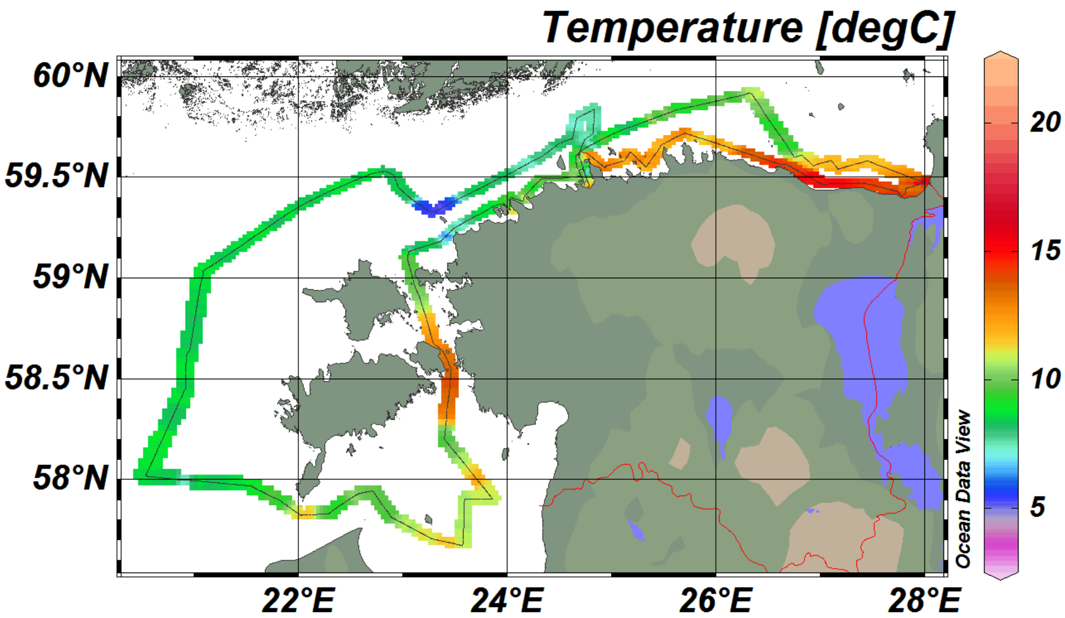
Data and methods

- To investigate the variability of sea surface horizontal thermohaline structure
- The area investigated is Northern Baltic Proper, Gulf of Finland and Gulf of Riga
- Data is analysed at the spatial scales from 1 to 100 km
- The temperature and salinity data from the surface layer (2 m) is gathered by a flow-through system
- Data from 15 monitoring cruises from September 2013 to January 2016
- The data series contain temperature and salinity data with the spatial resolution of 250 m along the cruise tracks with a length of about 1000 km each, covering all sub-basins of the Baltic Sea around Estonia

Data

Cruise	date	distance (m)
1	2013.09.09-13	1118500
2	2013.10.21-23	387500
3	2013.11.13-16	486250
4	2014.01.14-18	849250
5	2014.05.26-06.01	1082000
6	2014.07.14-17	887250
7	2014.08.25-29	1047500
8	2014.11.04-08	954750
9	2015.01.21-24	1020000
10	2015.04.14-23	994000
11	2015.05.25-29	950250
12	2015.07.13-17	1009500
13	2015.08.24-28	1020000
14	2015.10.12-16	1174000
15-16	2016.01.19-22	1339500

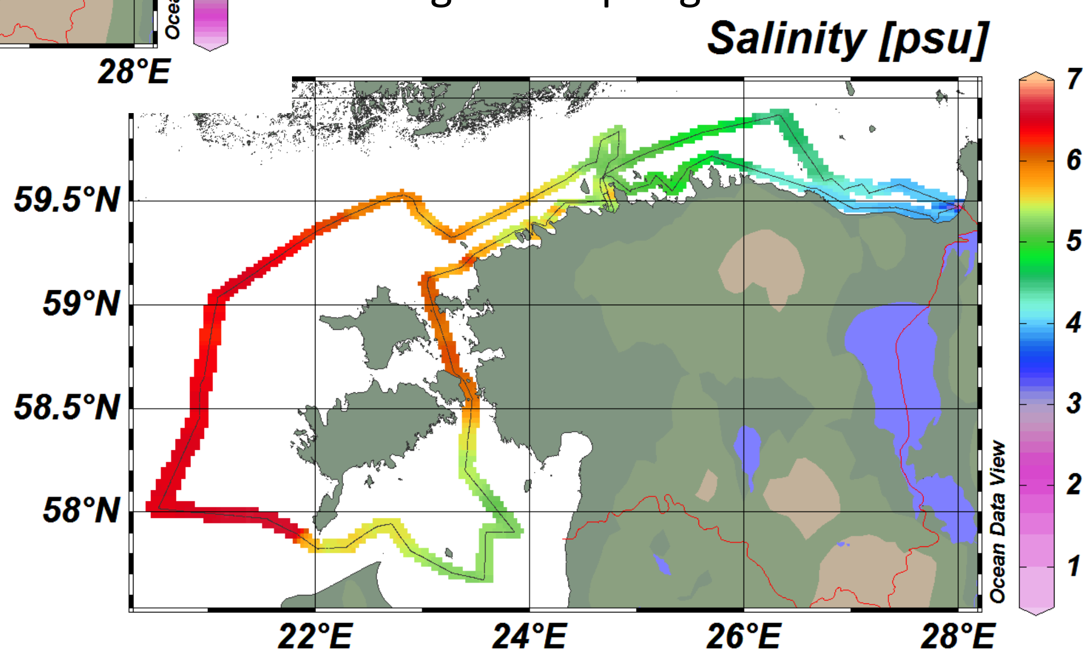
Example of horizontal variability of surface layer temperature and salinity in spring



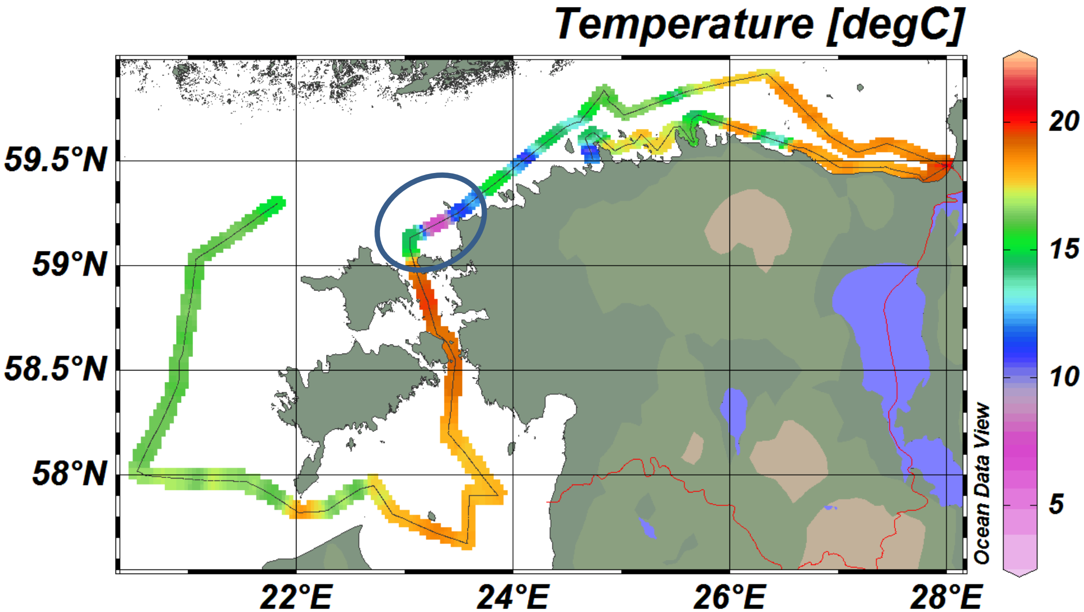
26 May – 1 June 2014

In spring, temperature is higher in the shallow coastal areas than in the open sea.
The maximum variability ranges of 16.4 °C and 5.9 g kg^{-1} were found during a late spring cruise.

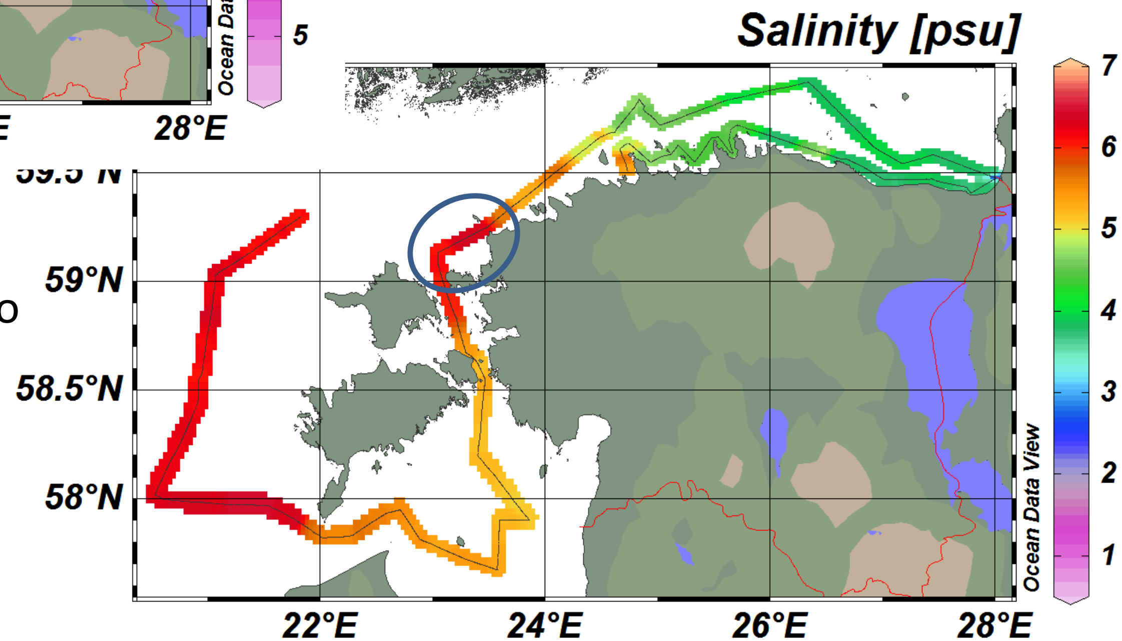
Low salinity waters are related to the regions of freshwater influence (from rivers) in the eastern part of the Gulf of Finland and Gulf of Riga



Example of horizontal variability of surface layer temperature and salinity in summer



14-17 July 2014



In summer, temperature is still higher in the shallow coastal areas, but due to upwelling events, cold waters can be upwelled in the coastal areas

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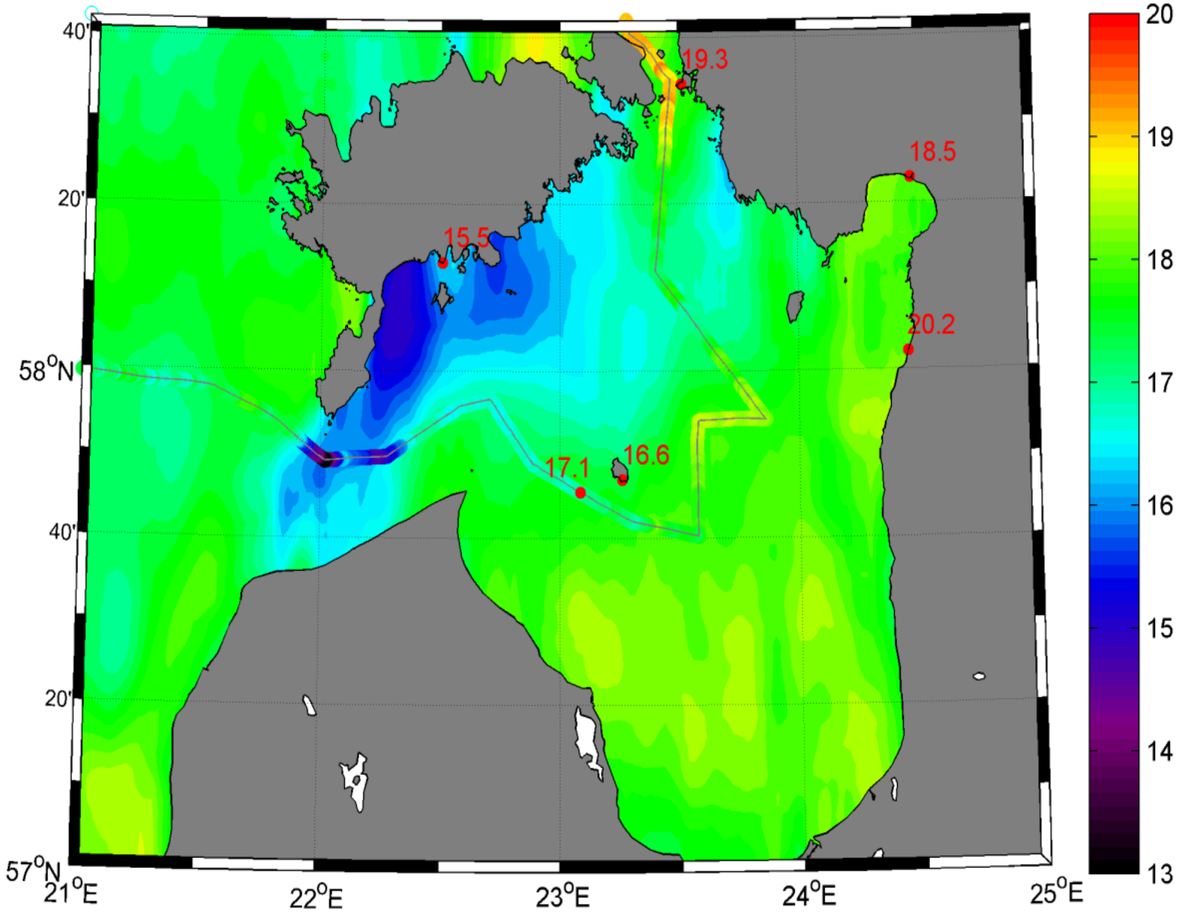
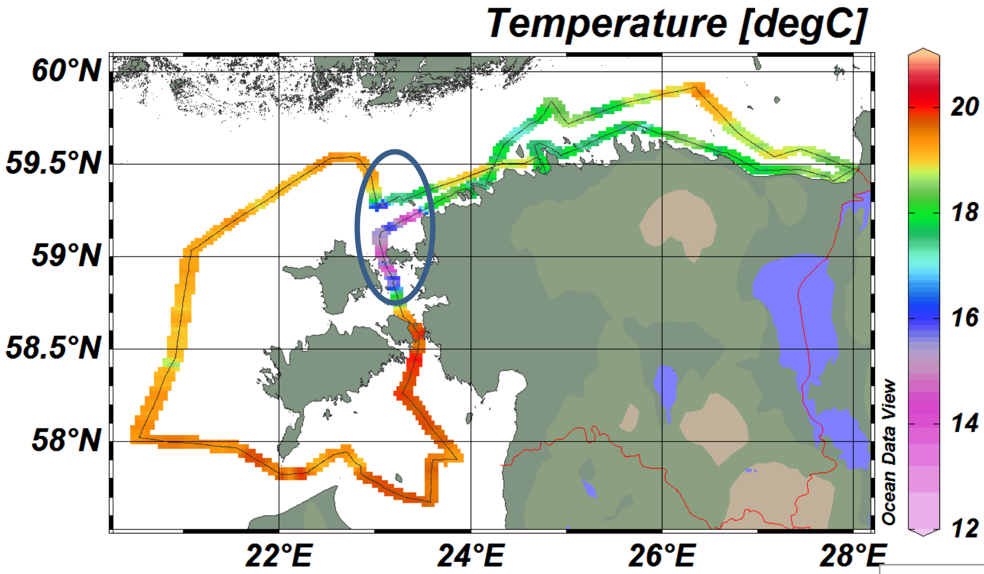


Courtesy by Taavi Liblik, MSI

Satellite derived sea surface temperature; upper layer temperature along RV SALME track by thermosalinograph, at buoy station and in selected coastal stations on 15 July 2015.
Coastal upwelling events is observed along the southern shore of the Saaremaa Island

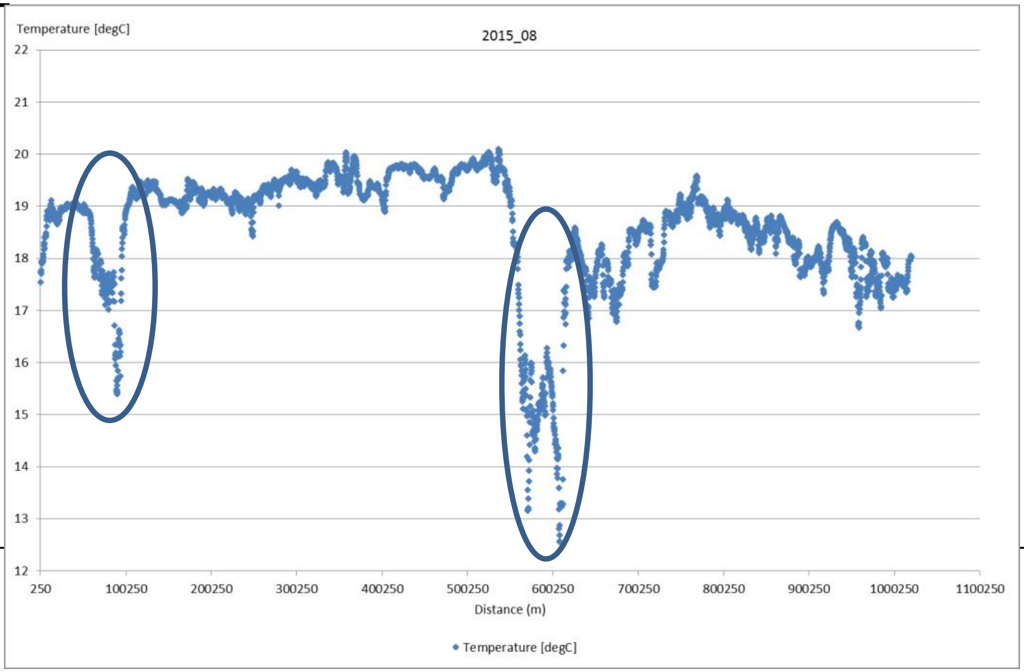
Horizontal variability of surface layer temperature



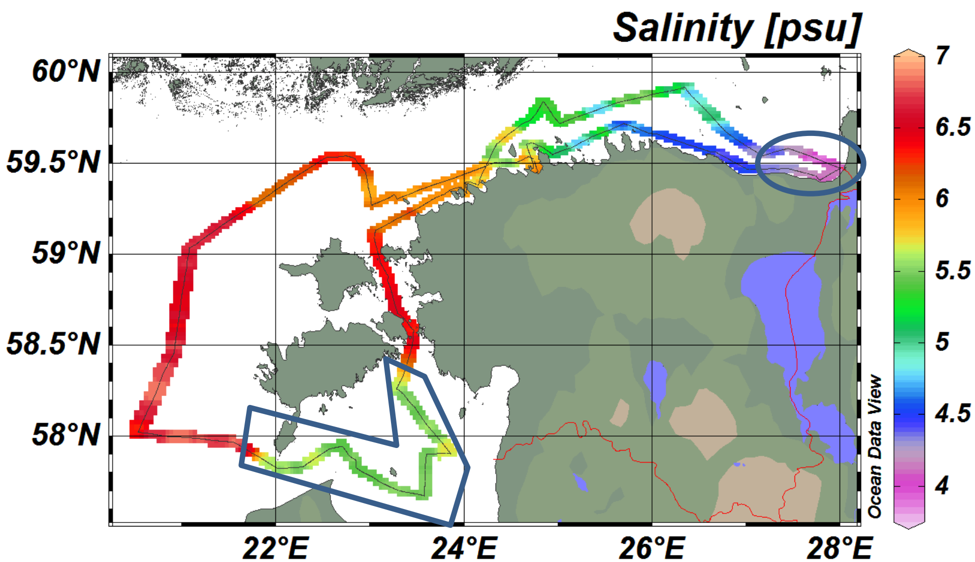
24-28 August 2015

Characteristic signatures of a coastal upwelling event in the western Gulf of Finland (along Estonian coast)

Characteristic sharp temperature fronts; temperature change through the front up to 7.5 °C



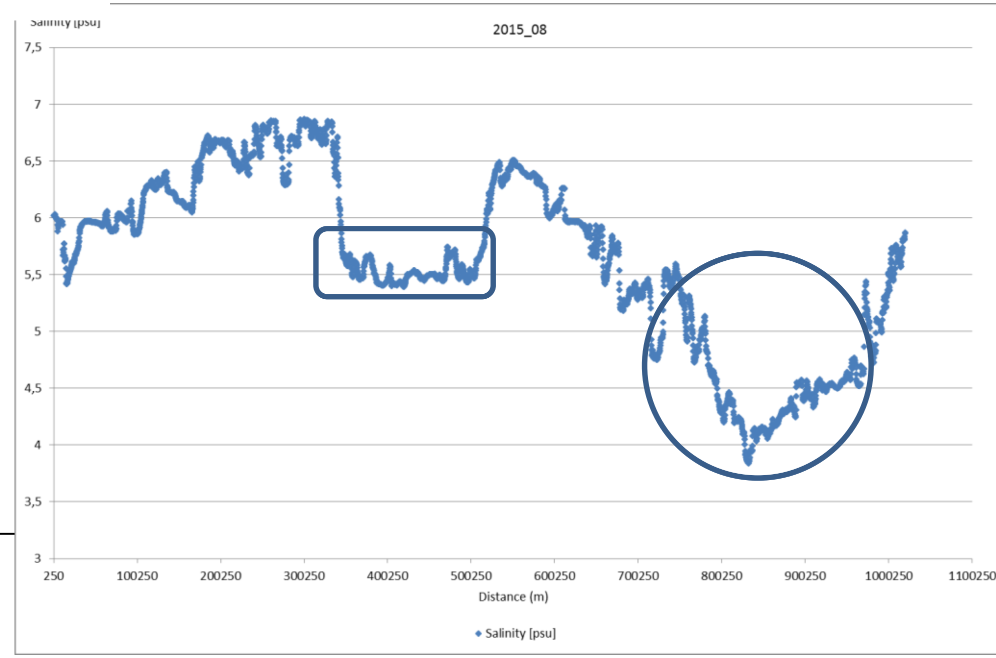
Horizontal variability of surface layer salinity



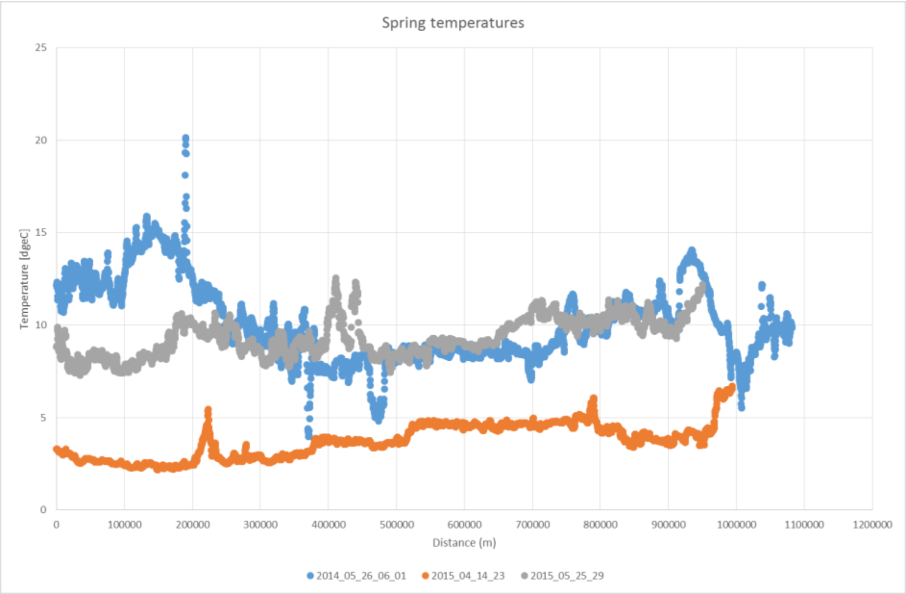
24-28 August 2015

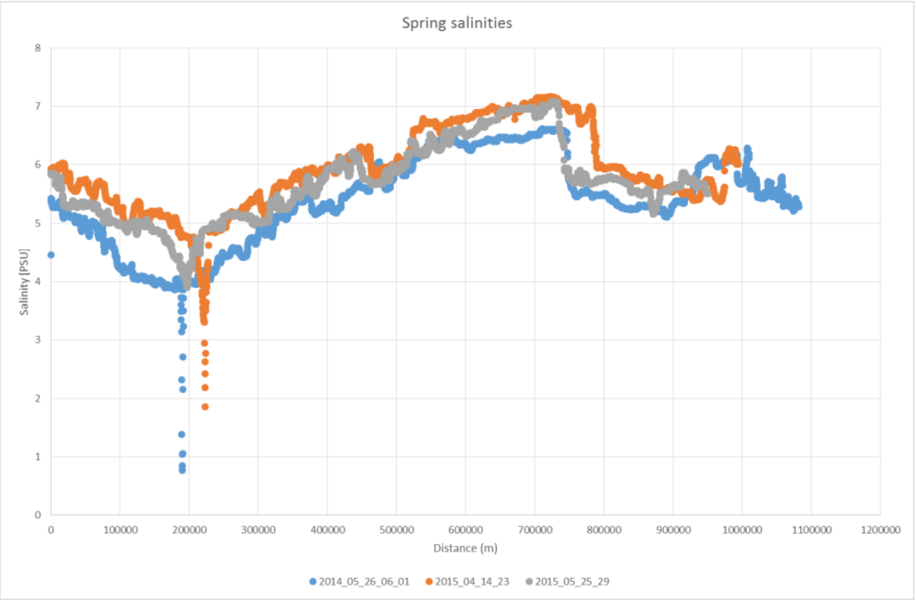
Characteristic differences between the sub-basins; sharp salinity fronts in the straits connecting Baltic Proper and Gulf of Riga

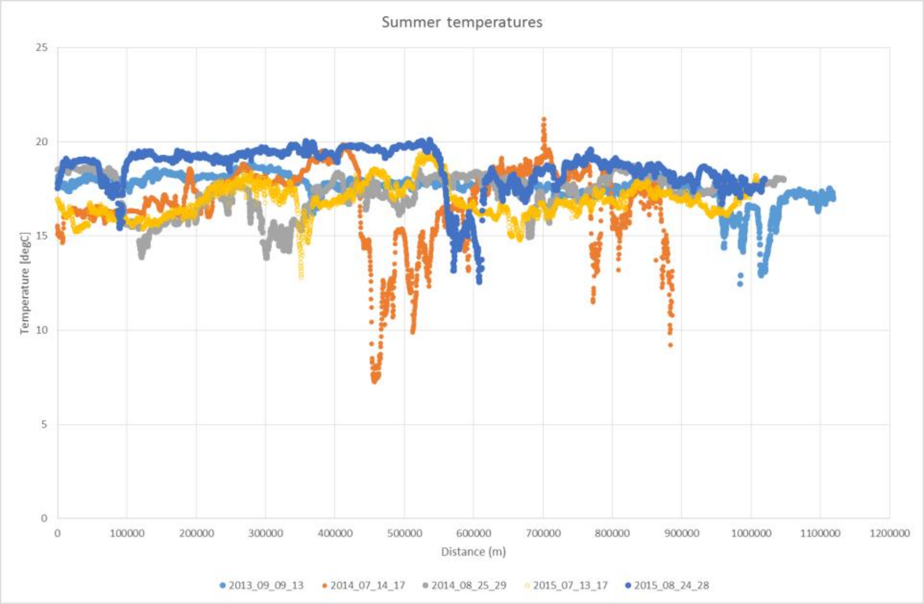
Low salinity water in the eastern part of the Gulf of Finland – influence of river waters

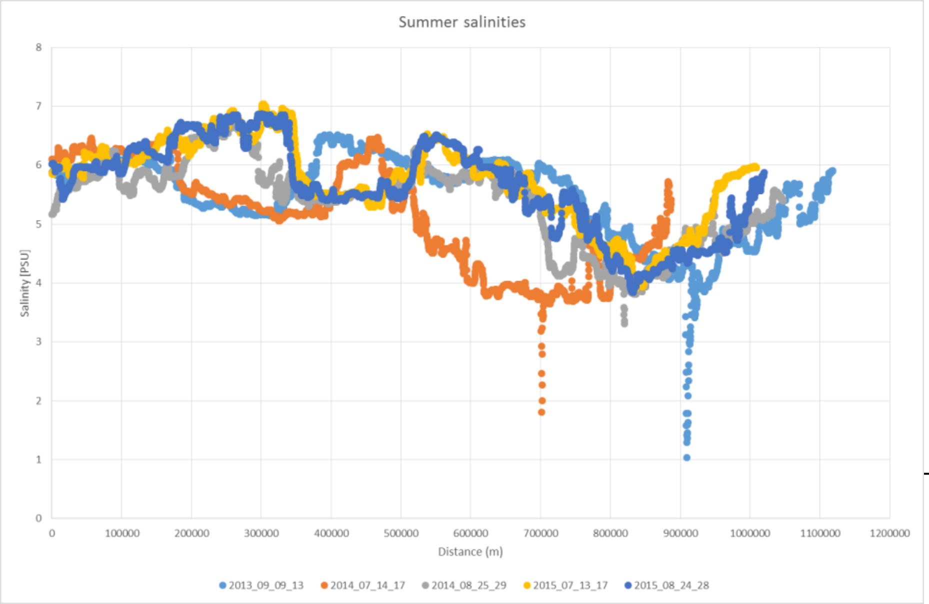


Seasonal thermohaline variability during spring and summer

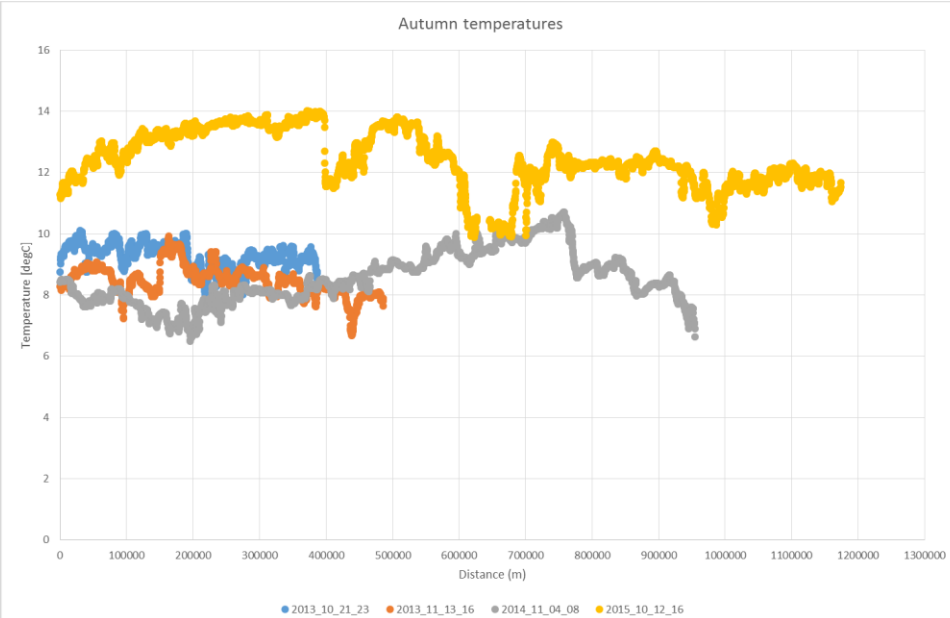


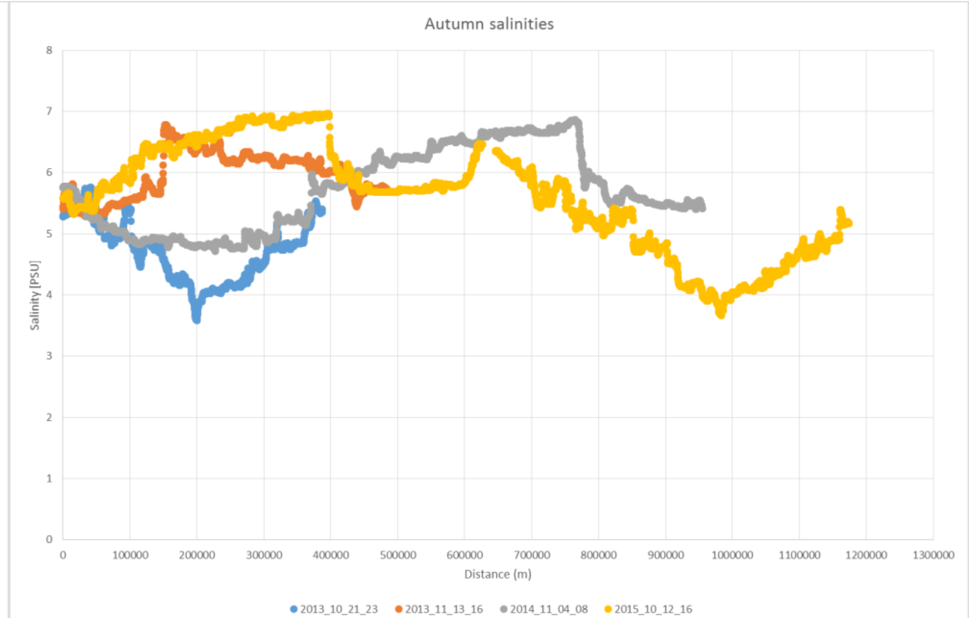


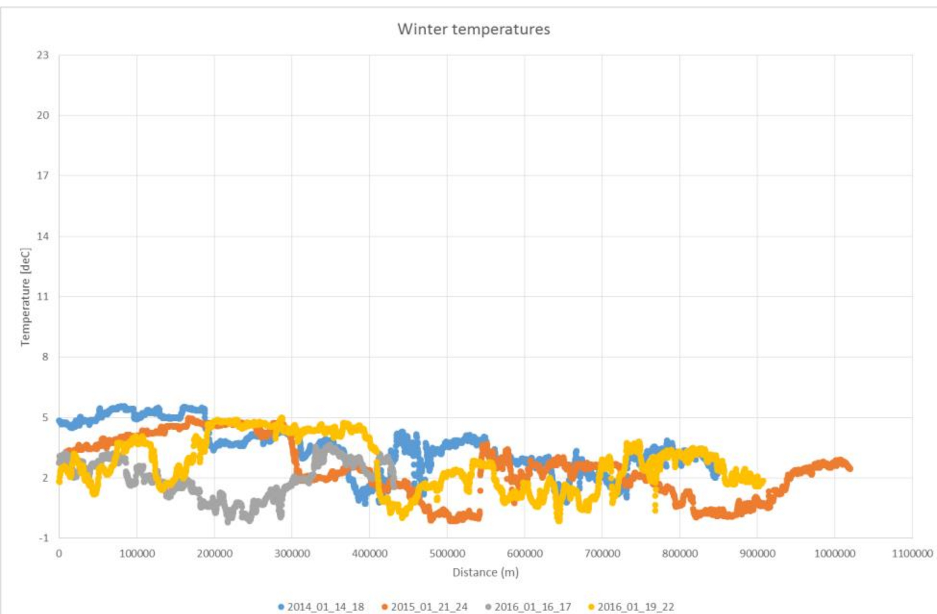


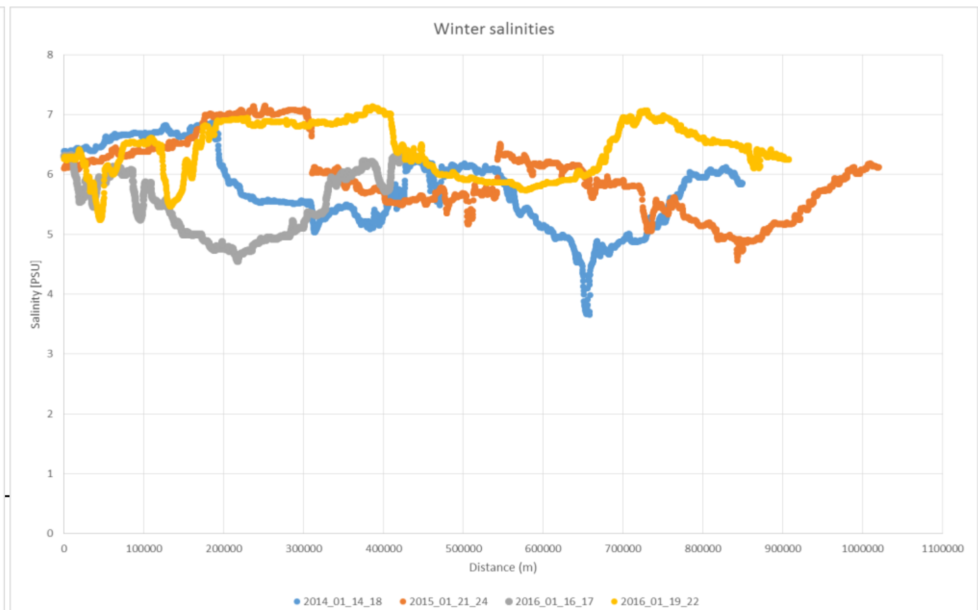


Seasonal thermohaline variability during autumn and winter









Statistics of horizontal variability of surface layer temperature and salinity

Dates	Season	Min T (degC)	Max T (degC)	Min S (psu)	Max S (psu)
9-13 Sep 2013	Summer	11.51	18.86	0.71	6.51
21 Oct - 13 Nov 2013	Autumn	6.69	10.11	3.59	6.79
14-18 Jan 2014	Winter	0.72	5.58	3.66	6.86
26 May - 1 Jun 2014	Spring	3.97	20.21	0.69	6.62
14-17 Jul 2014	Summer	7.23	21.22	1.61	6.47
25-29 Aug 2014	Summer	13.82	18.80	3.25	6.68
4-8 Nov 2014	Autumn	6.35	10.71	4.71	6.86
21-24 Jan 2015	Winter	-0.15	4.98	4.50	7.15
14-23 Apr 2015	Spring	2.19	6.88	1.73	7.17
25-29 May 2015	Spring	6.83	12.55	3.71	7.09
13-17 Jul 2015	Summer	12.64	19.44	3.88	7.04
24-28 Aug 2015	Summer	12.55	20.10	3.84	6.87
12-16 Oct 2015	Autumn	9.89	14.01	3.67	6.97
16-22 Jan 2016	Winter	-0.19	5.00	4.55	7.14

Maximum temperature in summer 18.8-21.2 C while minimum could be as low as 7.23
Minimum salinity in spring or in autumn; caused by river inflow
Slightly higher surface layer salinity in 2015-2016 than in 2013-2014

Statistics of horizontal variability of surface layer temperature and salinity

Dates	Season	Overall dT (degC)	Overall dS (psu)	Max dT over 1 km (degC)	Max dS over 1 km (psu)	dT (1 km) / dT (overall)	dS (1 km) / dS (overall)
9-13 Sep 2013	Summer	7.35	5.80	3.70	2.04	0.50	0.35
21 Oct - 13 Nov 2013	Autumn	3.42	3.20	0.86	0.64	0.25	0.20
14-18 Jan 2014	Winter	4.86	3.20	2.39	1.29	0.49	0.40
26 May - 1 Jun 2014	Spring	16.24	5.92	4.69	2.45	0.29	0.41
14-17 Jul 2014	Summer	13.99	4.86	3.79	1.48	0.27	0.31
25-29 Aug 2014	Summer	4.98	3.43	1.72	0.66	0.35	0.19
4-8 Nov 2014	Autumn	4.36	2.15	0.71	0.44	0.16	0.20
21-24 Jan 2015	Winter	5.13	2.65	2.04	0.60	0.40	0.23
14-23 Apr 2015	Spring	4.69	5.44	0.97	1.64	0.21	0.30
25-29 May 2015	Spring	5.72	3.38	2.17	0.42	0.38	0.13
13-17 Jul 2015	Summer	6.80	3.17	1.83	0.41	0.27	0.13
24-28 Aug 2015	Summer	7.55	3.03	3.64	0.62	0.48	0.20
12-16 Oct 2015	Autumn	4.13	3.30	1.77	0.48	0.43	0.15
Median		5.13	3.30	2.04	0.64	0.35	0.20

Difference between the maximum and minimum surface layer temperature was on average 5.1 °C whereas the maximum difference could reach 16.2 °C

Difference between the maximum and minimum surface layer salinity was on average 3.34 (psu), which means that the salinity contributes more to the overall horizontal density gradient

Statistics of horizontal variability of surface layer temperature and salinity

Dates	Season	Overall dT (degC)	Overall dS (psu)	Max dT over 1 km (degC)	Max dS over 1 km (psu)	dT (1 km) / dT (overall)	dS (1 km) / dS (overall)
9-13 Sep 2013	Summer	7.35	5.80	3.70	2.04	0.50	0.35
21 Oct - 13 Nov 2013	Autumn	3.42	3.20	0.86	0.64	0.25	0.20
14-18 Jan 2014	Winter	4.86	3.20	2.39	1.29	0.49	0.40
26 May - 1 Jun 2014	Spring	16.24	5.92	4.69	2.45	0.29	0.41
14-17 Jul 2014	Summer	13.99	4.86	3.79	1.48	0.27	0.31
25-29 Aug 2014	Summer	4.98	3.43	1.72	0.66	0.35	0.19
4-8 Nov 2014	Autumn	4.36	2.15	0.71	0.44	0.16	0.20
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14-23 Apr 2015	Spring	4.69	5.44	0.97	1.64	0.21	0.30
25-29 May 2015	Spring	5.72	3.38	2.17	0.42	0.38	0.13
13-17 Jul 2015	Summer	6.80	3.17	1.83	0.41	0.27	0.13
24-28 Aug 2015	Summer	7.55	3.03	3.64	0.62	0.48	0.20
12-16 Oct 2015	Autumn	4.13	3.30	1.77	0.48	0.43	0.15
Median		5.13	3.30	**2.04**	**0.64**	**0.35**	**0.20**

Maximum horizontal temperature and salinity gradients (for a single cruise) were on average as large as 2.04 °C/km and 0.64 psu/km being larger in spring-summer than in autumn-winter. Ratio of gradients over 1 km to the overall variability range was higher for the surface layer temperature than salinity; this resulted in on average similar contribution of small-scale temperature and salinity variations to the density variations

Conclusions

- Overall horizontal variability and mesoscale/sub-mesoscale gradients are very well represented
- High-resolution measurements show sharp fronts and high variability of temperature and salinity in the coastal waters – revealing coastal upwelling events and related sub-mesoscale variability and impact of river water discharge
- Flow-through data from routine monitoring cruises repeatedly covering large sea areas allow to detect long-term (inter-annual) changes and short-term events
- It can be shown that on a basin scale overall horizontal gradient of surface layer salinity has larger contribution to the density gradient; nevertheless at meso- and sub-mesoscale both temperature and salinity have similar contribution to the density variations

Thank you for your attention.