An analysis of temperature, salinity and potential energy variability in the surface layer of the Estonian sea area using ten years of **R/V Salme ferrybox** data

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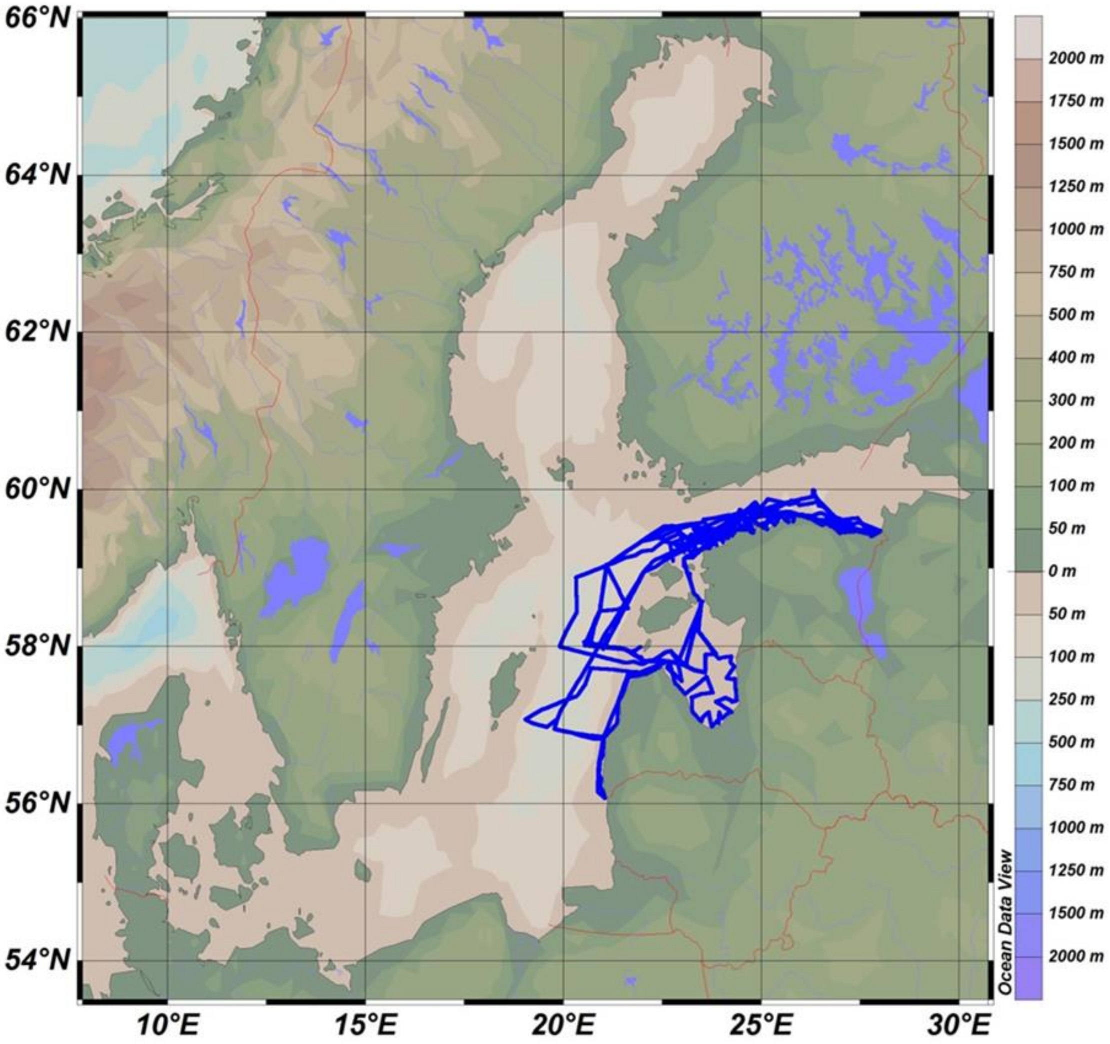
Ferrybox on R/V Salme

Data from ferryboxes on commercial ferries travelling regularly between harbours of the Baltic Sea are used for operational forecasts and environmental assessments. Many research vessels, including those conducting regular environmental monitoring of the Baltic Sea, are also equipped with similar flow-through systems. However, the data collected has not yet been widely used.

R/V Salme, employed for Estonian open sea monitoring six times a year, has carried a flow-through system for over ten years. It records surface layer (water intake is at 2 m depth) temperature, salinity, oxygen, chlorophyll and turbidity with a time step of 1 minute (corresponding to approximately 250 m in space).

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 by PONSEL

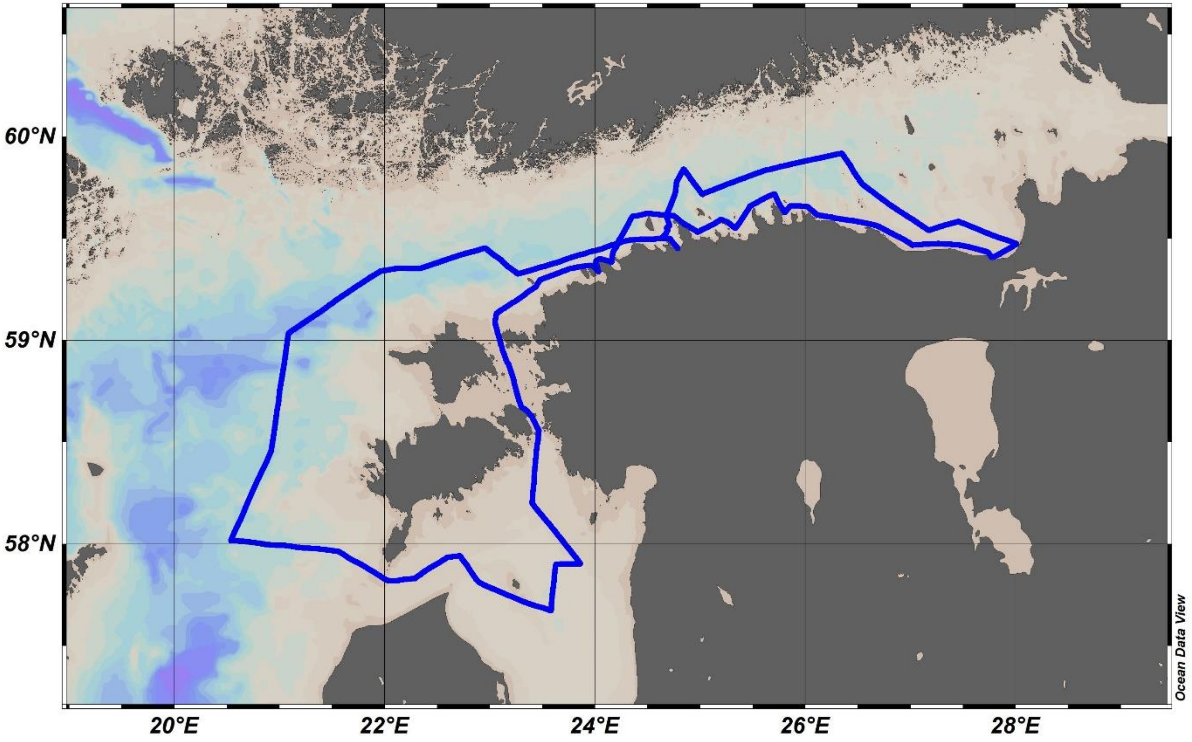
Collected data



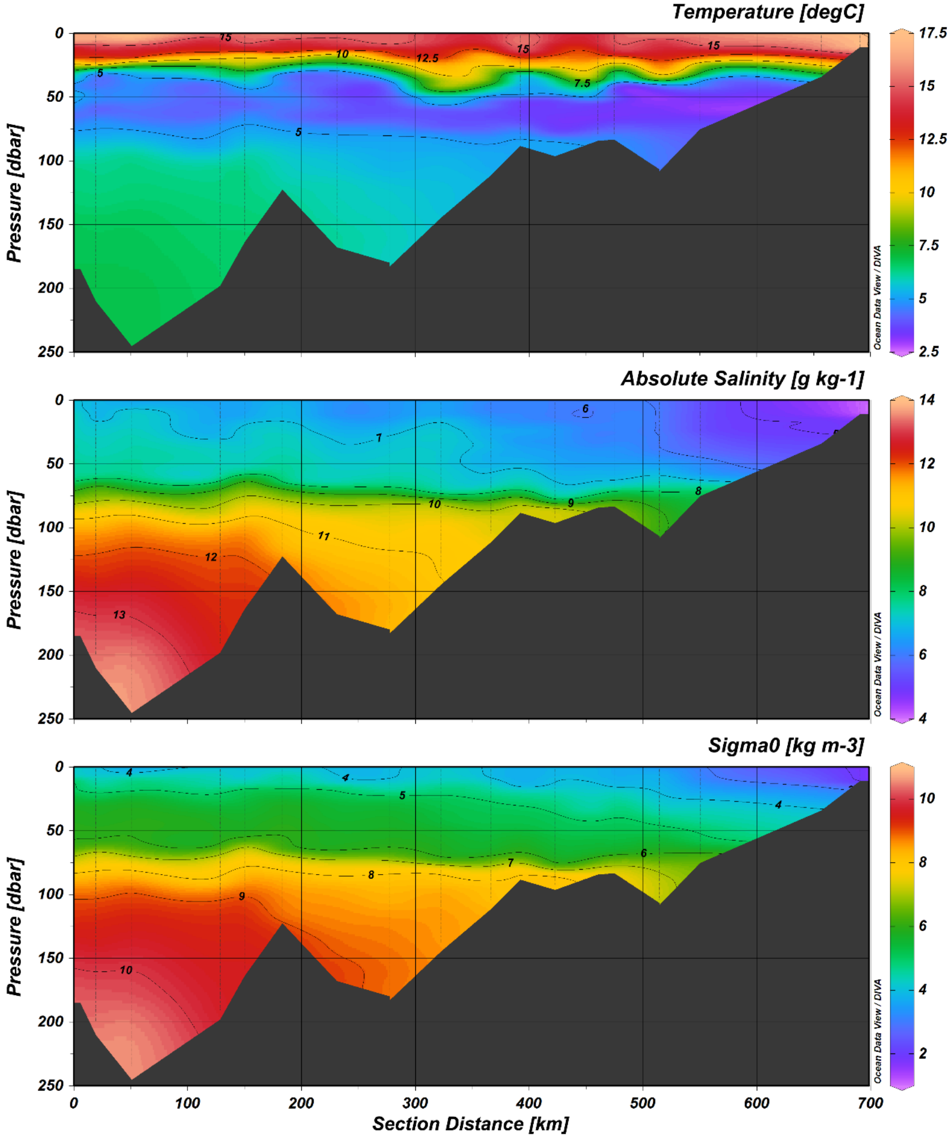
Ferrybox data are collected during all cruises of R/V Salme.

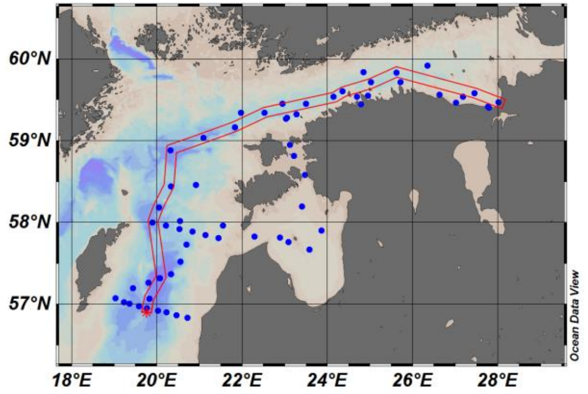
R/V routes during one year are shown in the left figure and an ordinary track for a monitoring cruise in the right figure.

Monitoring cruises with regular coverage of sea areas – 6 times a year since 2013, usually January, April, May-June, July, August and October. Data from over 50 cruises available for the analysis.

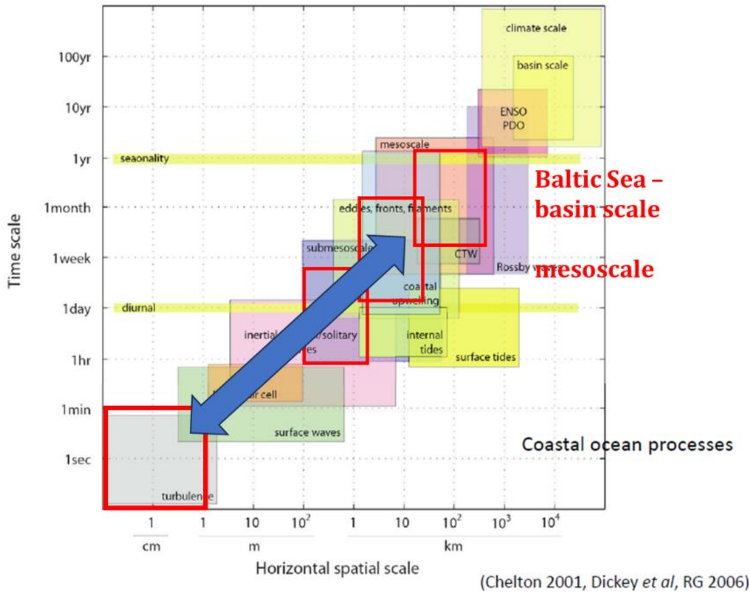


Background





Examples of T, S and D sections from July 2015



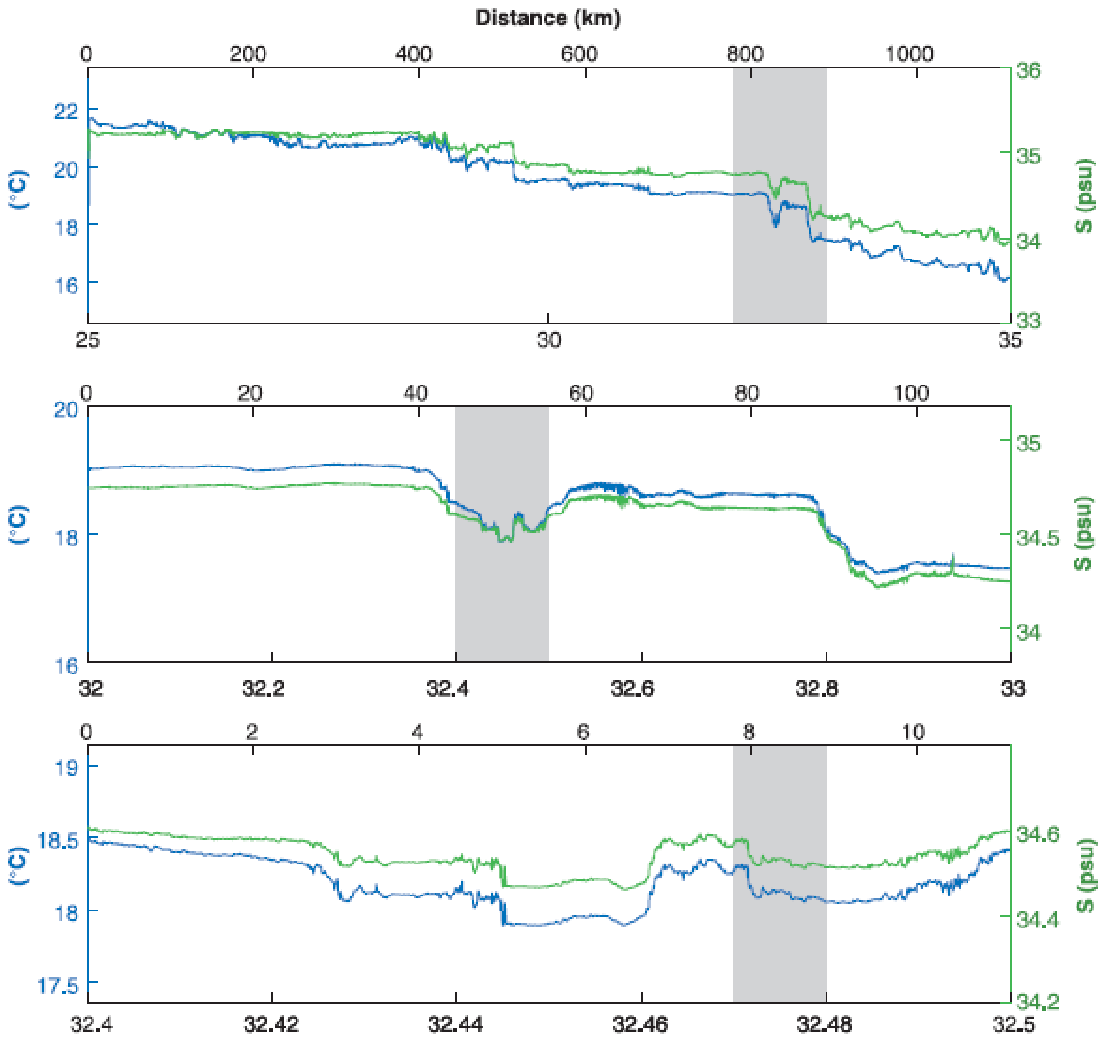
(Chelton 2001, Dickey *et al*, RG 2006)

The main physical forcing components for the Baltic Sea system are the **atmospheric forcing**, **exchange** of heat energy and freshwater **through the sea surface**, and input of **freshwater from rivers** and **saltier water through the Danish Straits**.

The geographically **localized freshwater and saltier water inputs** together with the seasonally variable heat flux and atmospheric forcing create the observed **layered structure** and **lateral gradients** in the Baltic Sea.

How the available energy in horizontal density (buoyancy) gradient is influencing the dynamics and mixing, and via wich processes this potential energy is dissipated at smaller scales?

Motivation



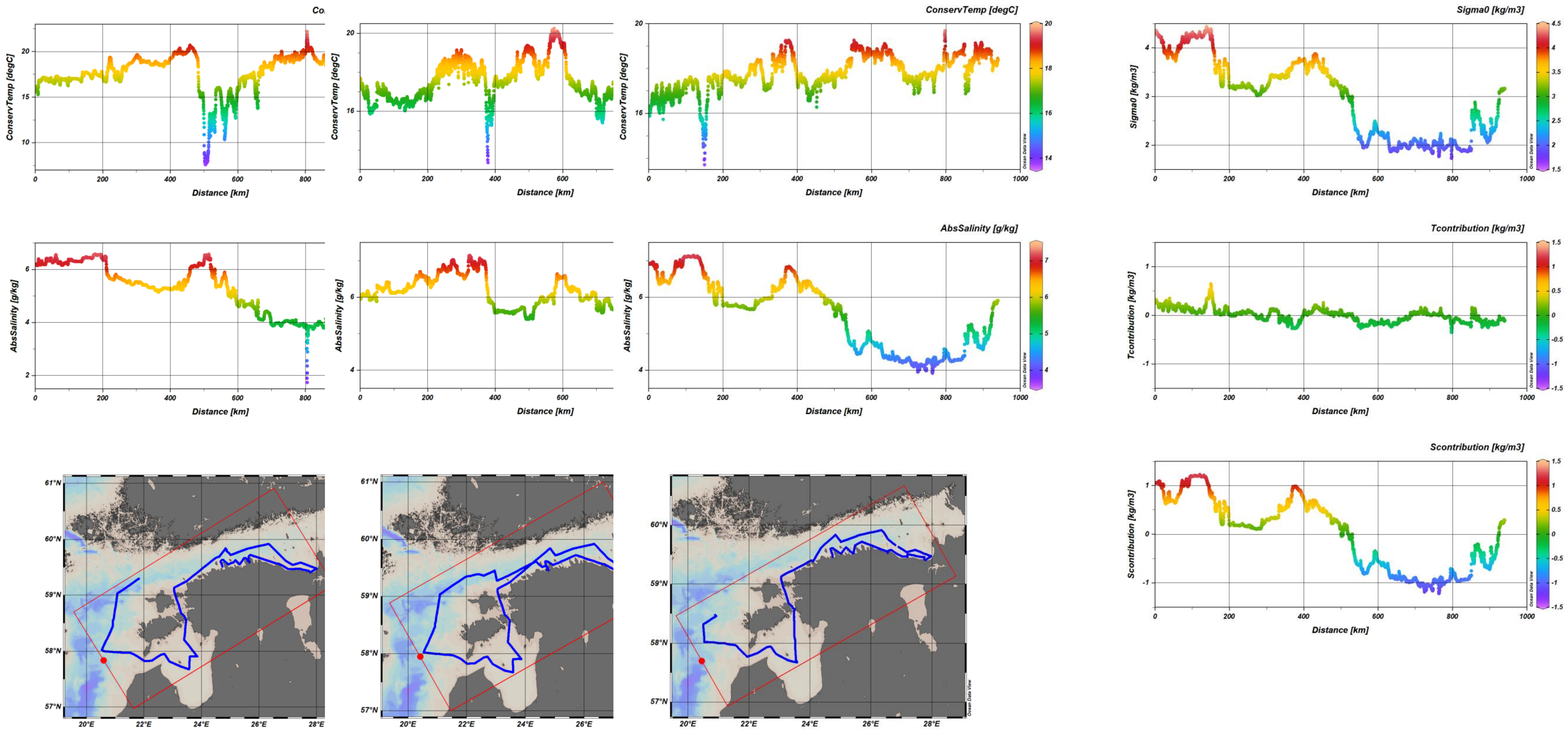
Rudnick and Ferrari (1999) demonstrated that temperature and salinity in the ocean mixed layer are strongly coherent over all length scales. Temperature and salinity gradients coincide in such a way that density gradients are minimized – fronts in the open ocean tend to be warm and salty on one side and cold and fresh on the other.

What is the case in the Baltic Sea where temperature and salinity deviations could both contribute to the density field on the same direction; e.g., in the case of coastal upwelling.

Fig. 2. Potential temperature θ and salinity S at 50 dbar. (**Top**) Potential temperature and salinity over the entire tow from 25°N to 35°N. Each succeeding panel is a magnification by a factor of 10 of the shaded region of the panel above. Note change in scale on the horizontal axis of each panel. Vertical axes are scaled by the thermal and haline expansion coefficients so that equal excursions of temperature and salinity imply identical effects on density. Temperature and salinity structure is compensated at all scales.

Rudnick and Ferrari, 1999. Compensation of Horizontal Temperature and Salinity Gradients in the Ocean Mixed Layer, Science.

Summer



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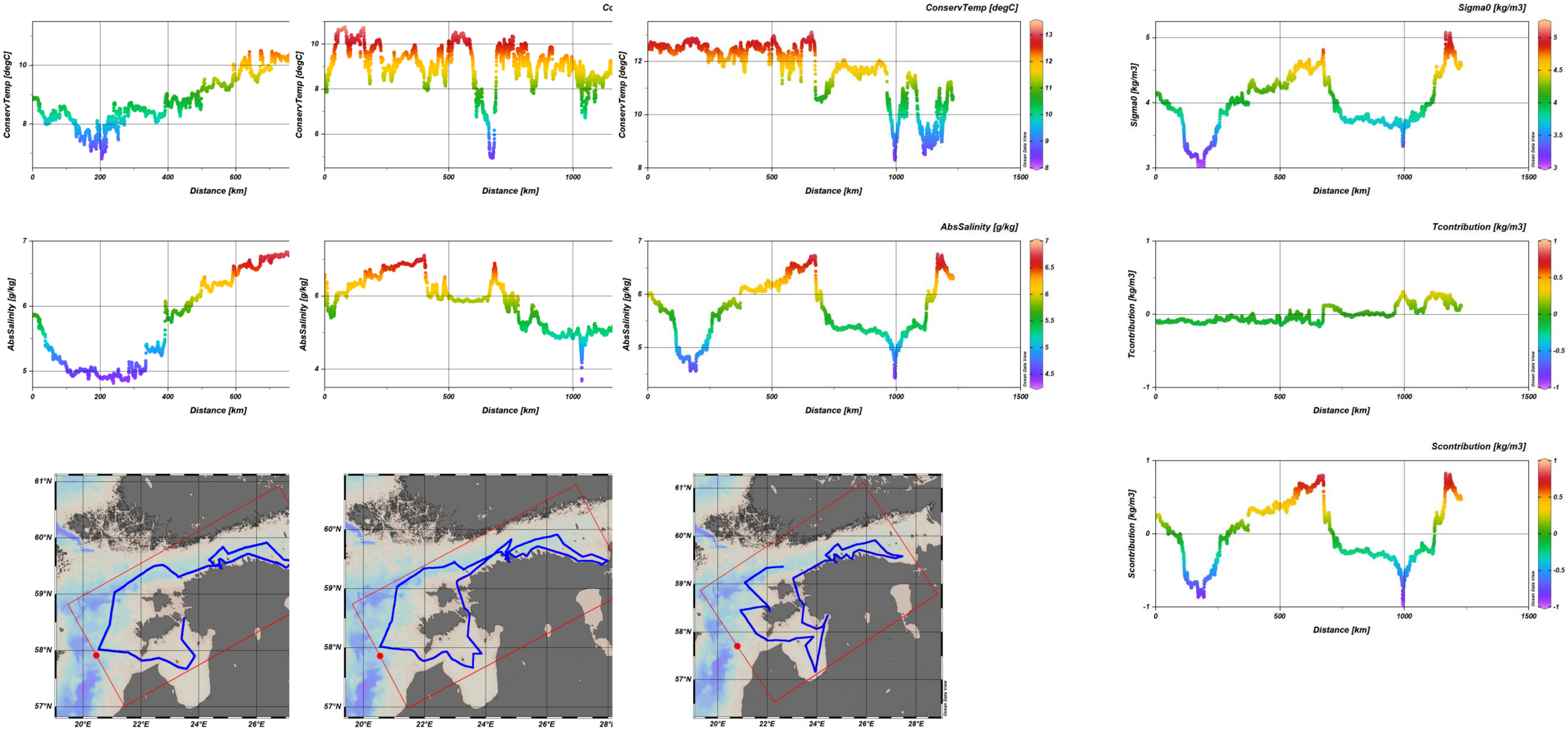
Ocean Data View

Autumn



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Ocean Data View
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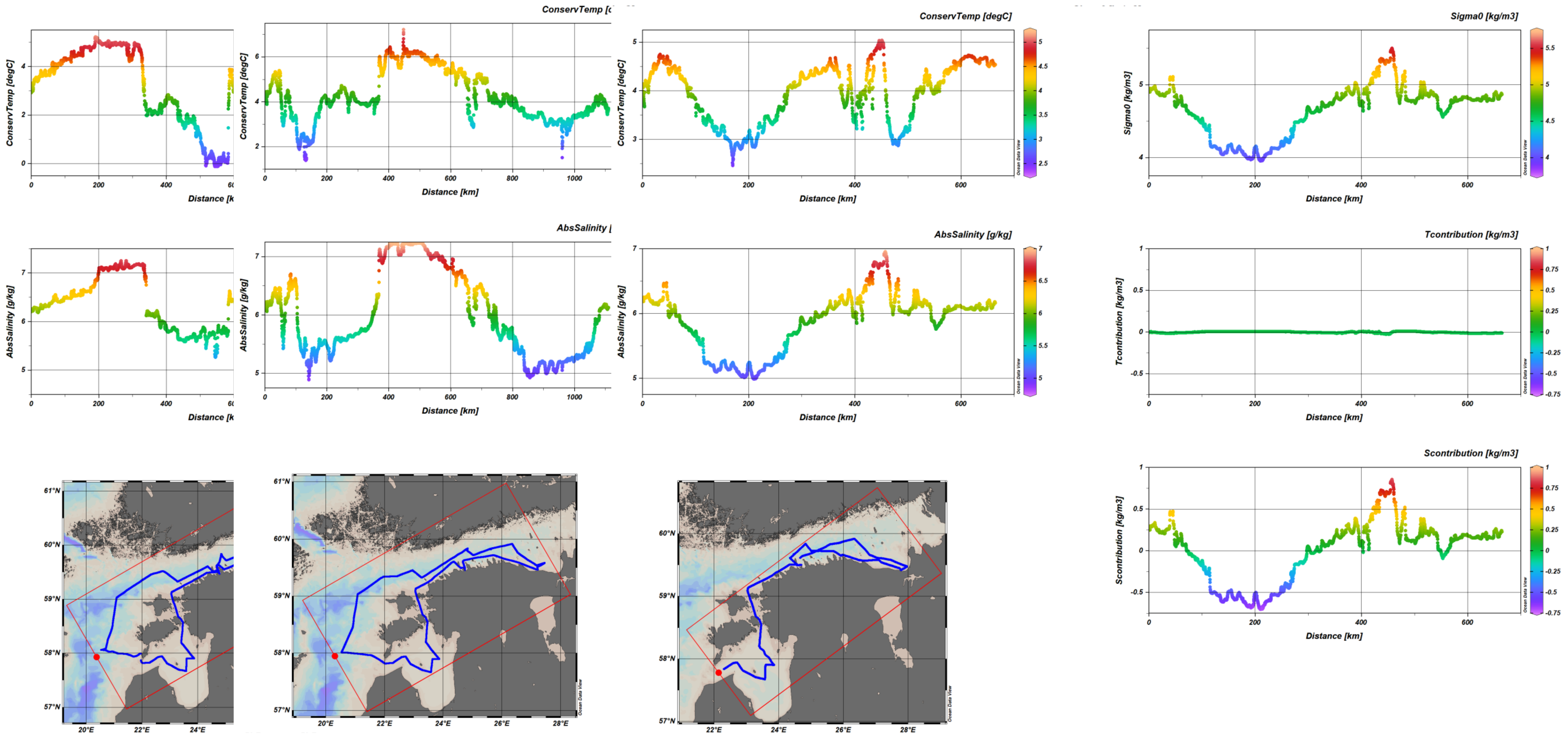
Winter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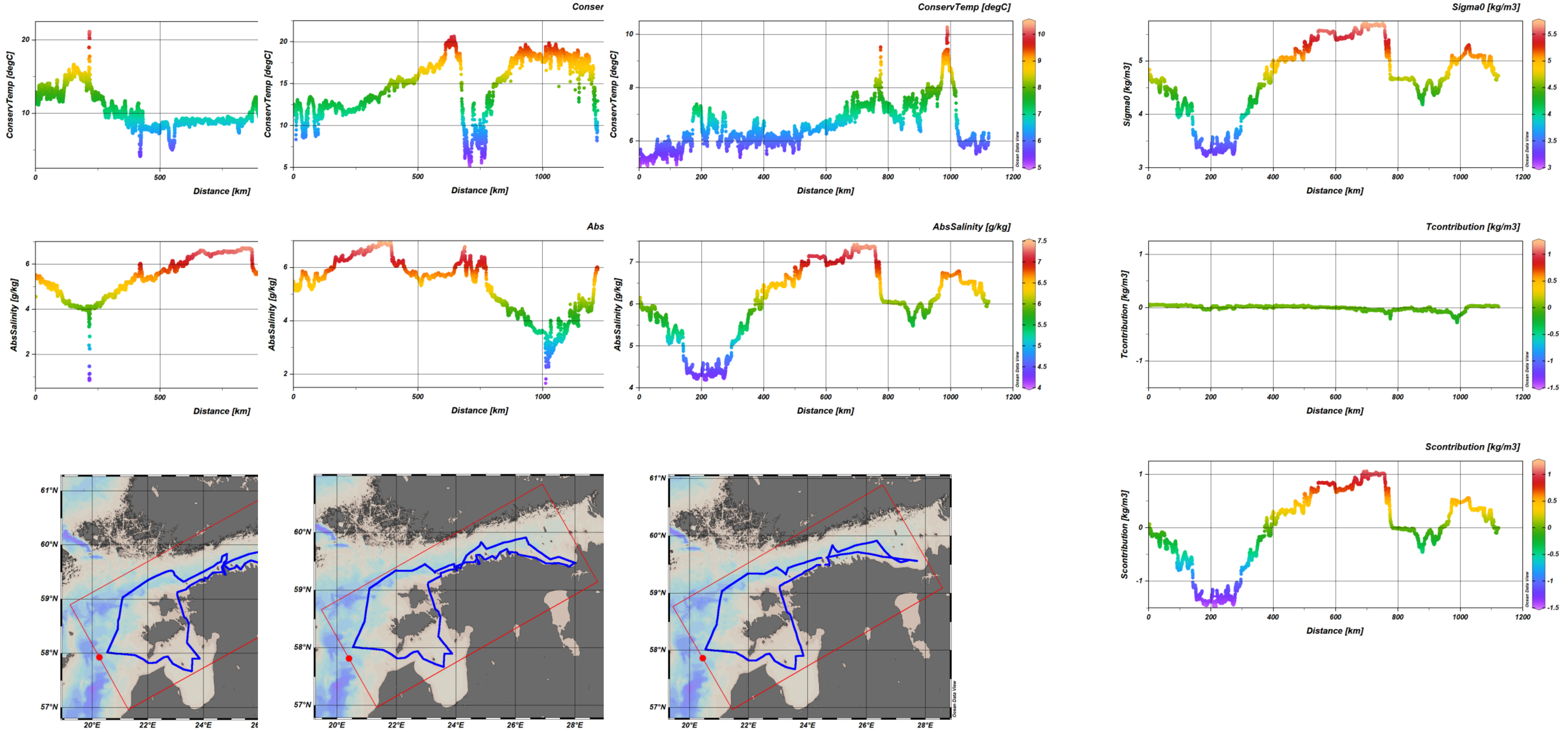
Ocean Data View

Spring



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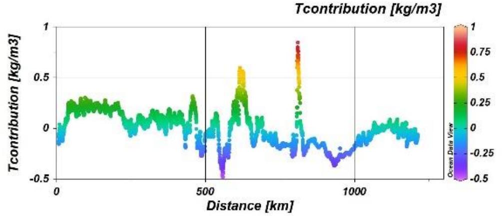
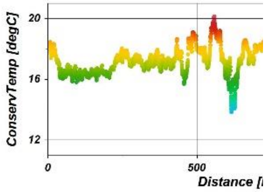
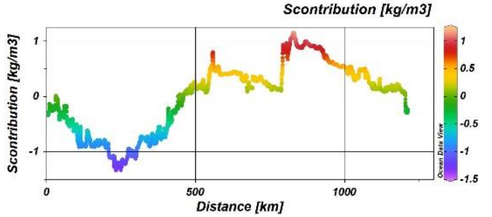
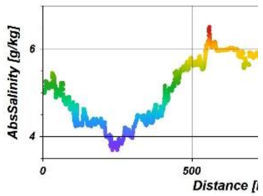
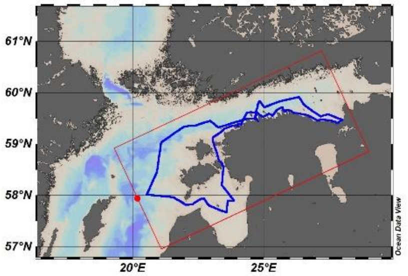
Example of July 2017

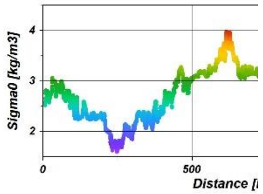


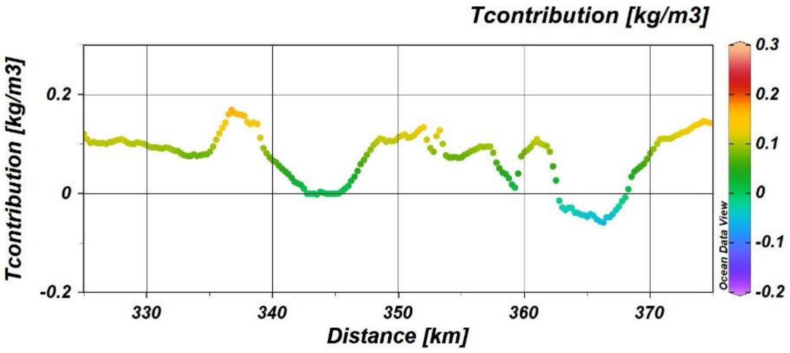


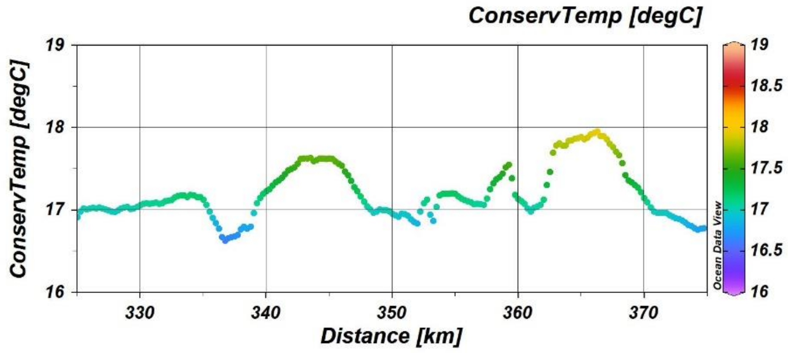


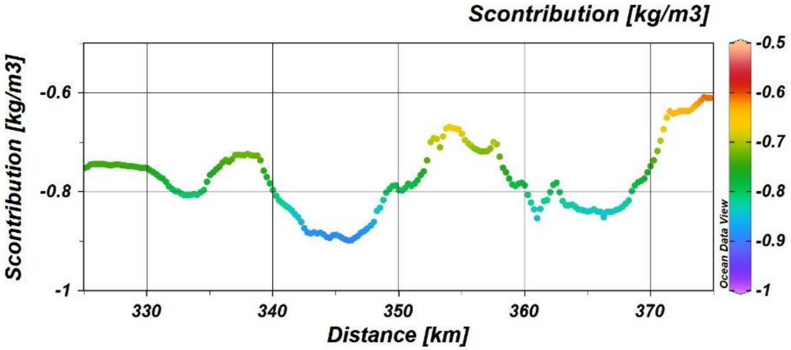


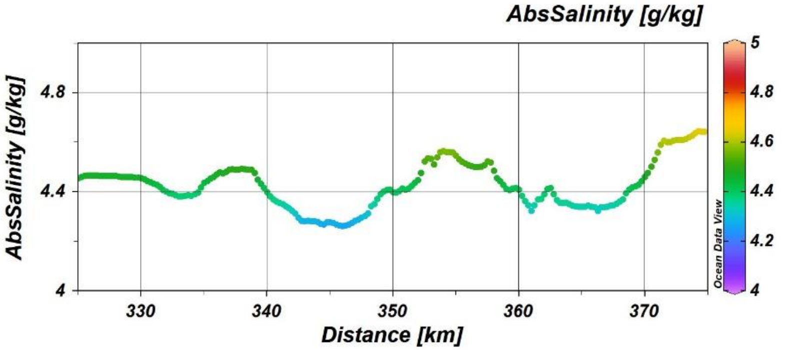


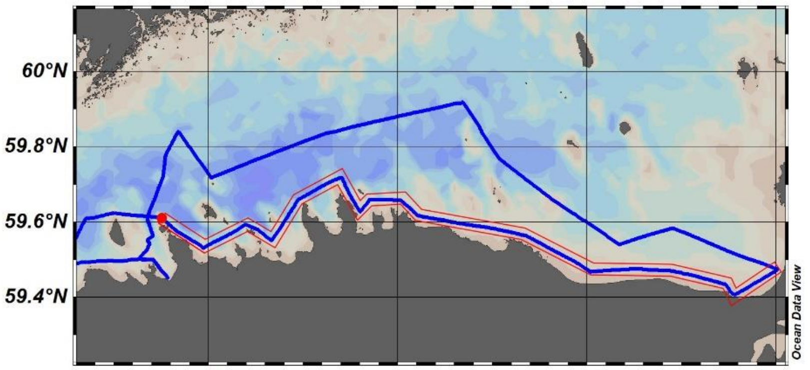


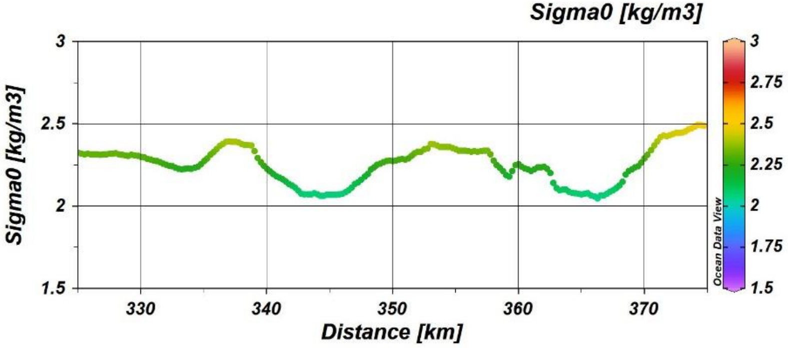






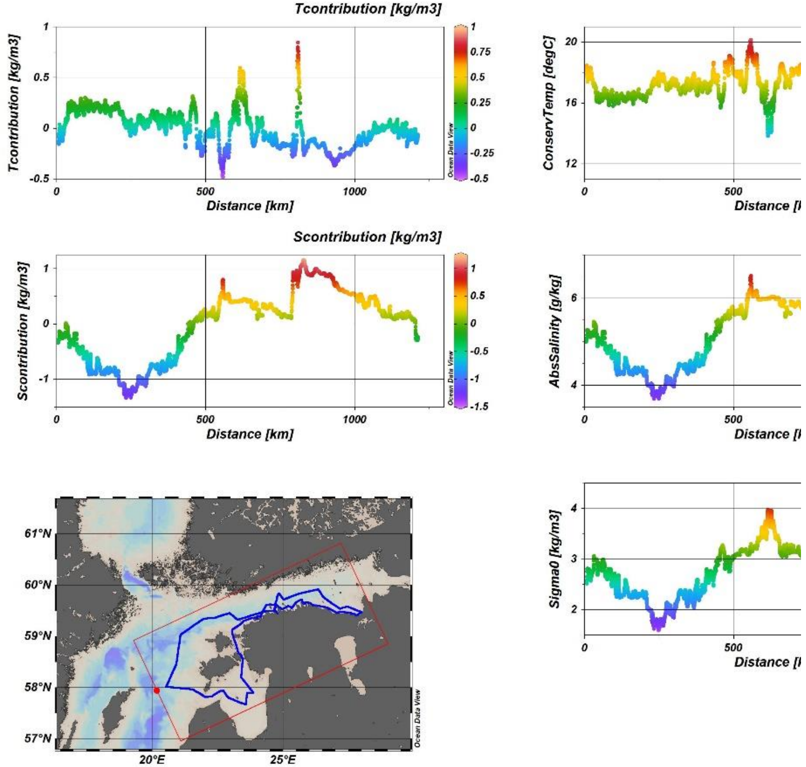


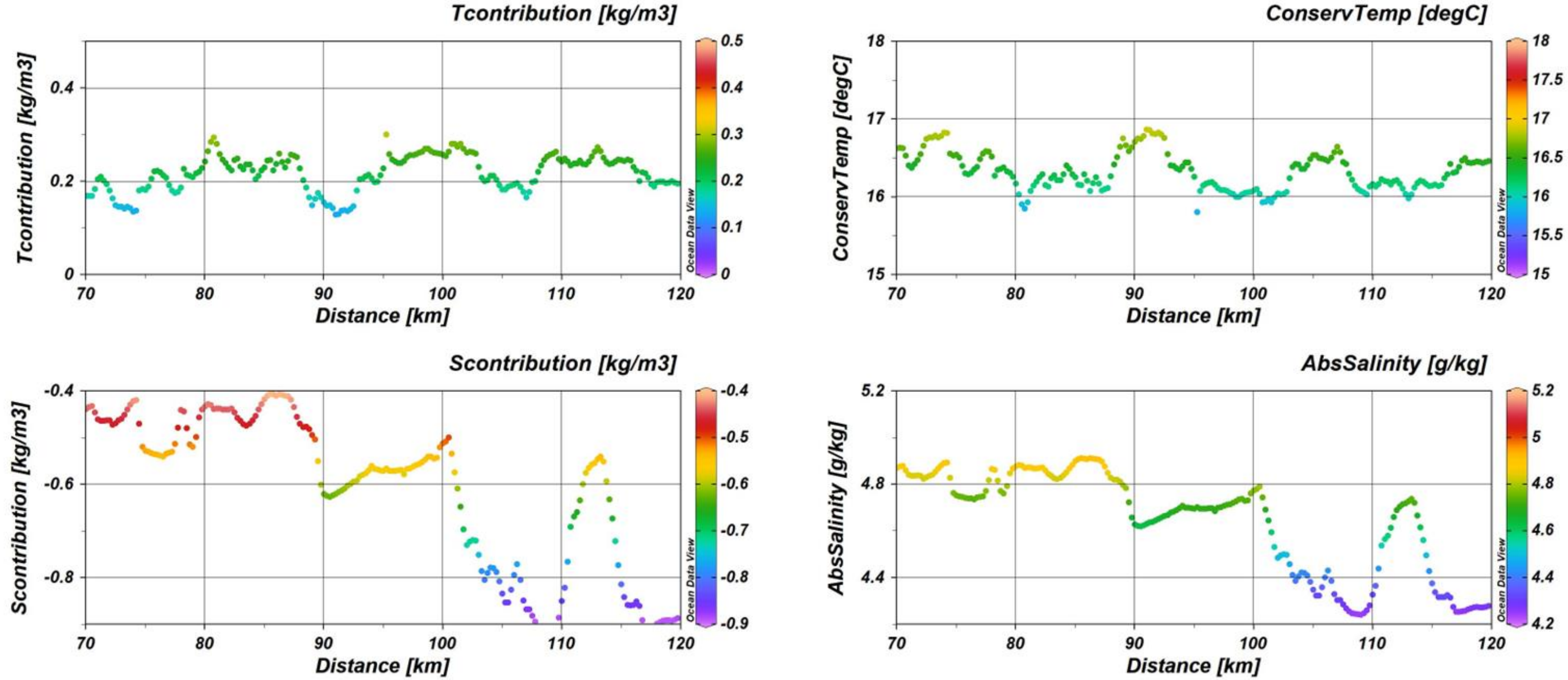


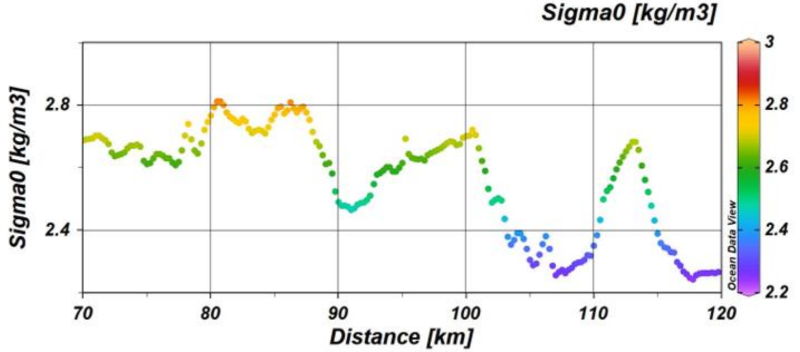


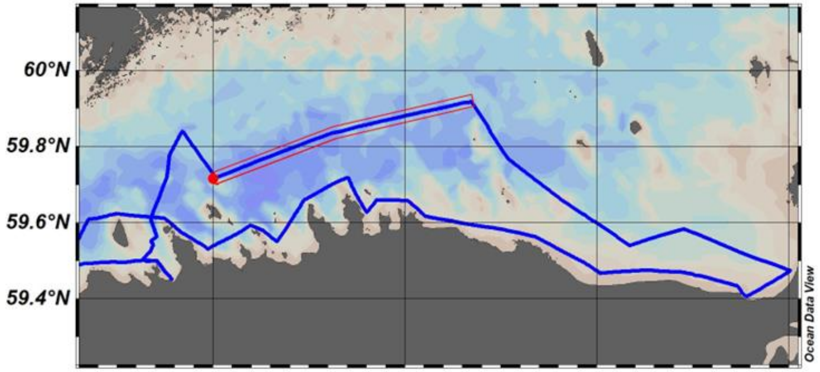
T and S contributions to variability in density (buoyancy) near the coast are at the same level

Example of July 2017



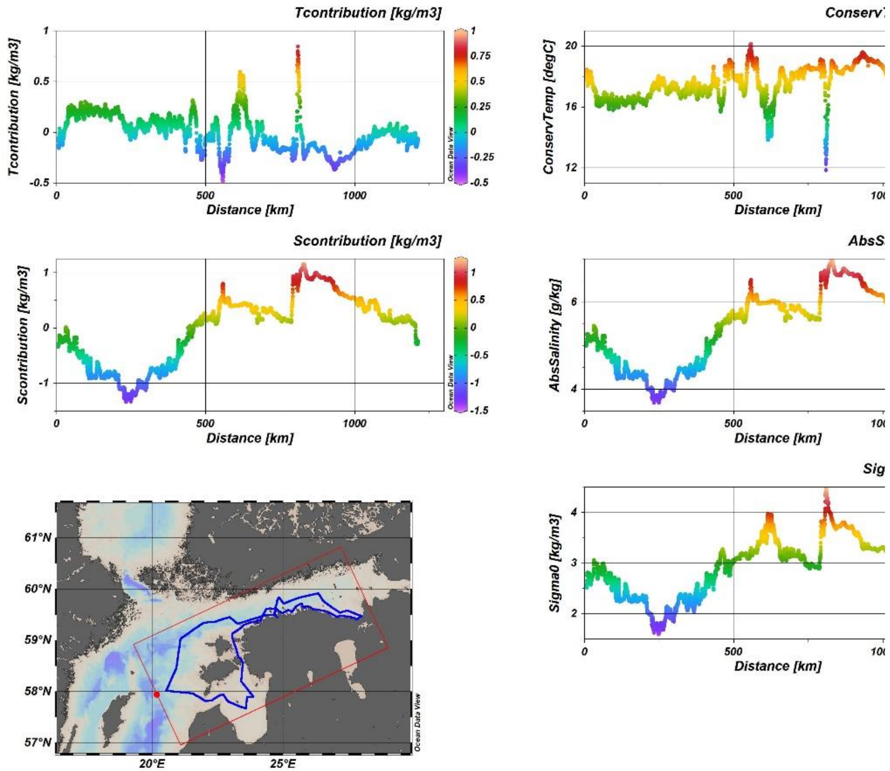


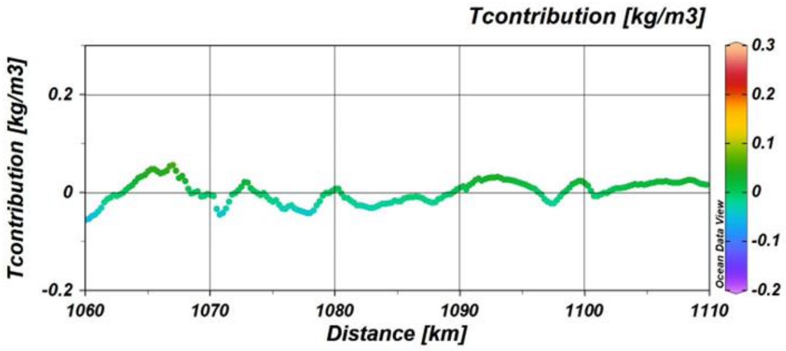


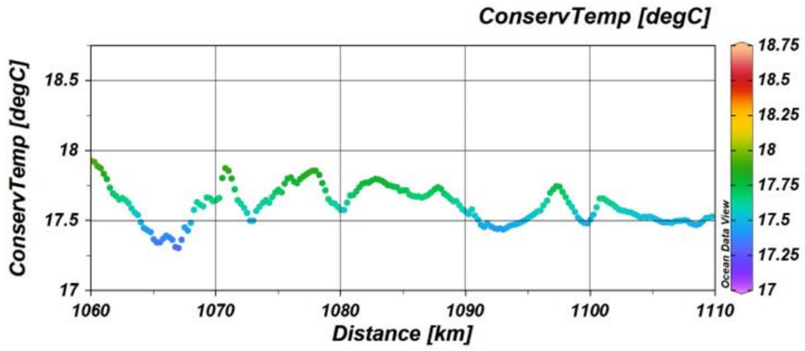


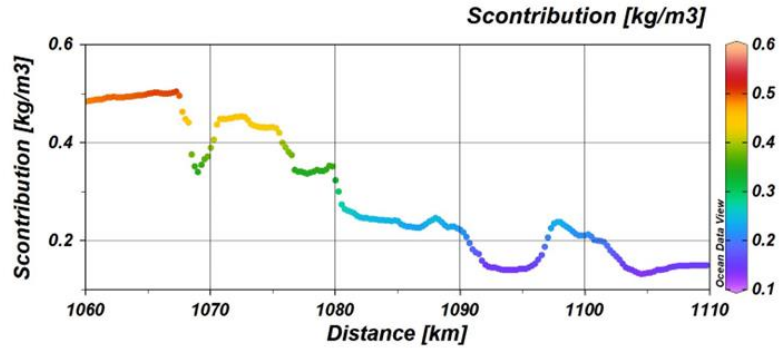
At the same time, salinity gradient and contribution dominate in the off-shore areas

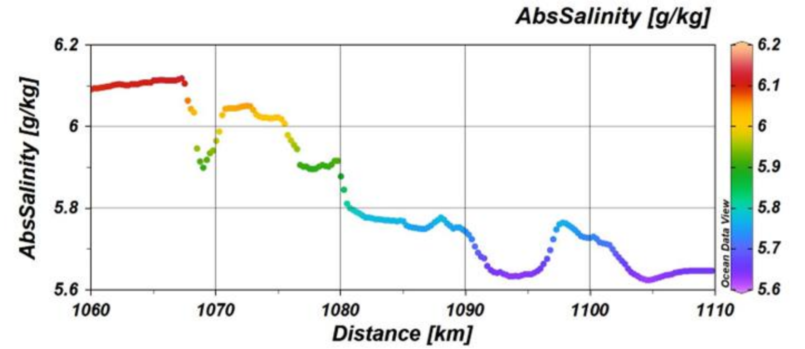
Example of July 2017

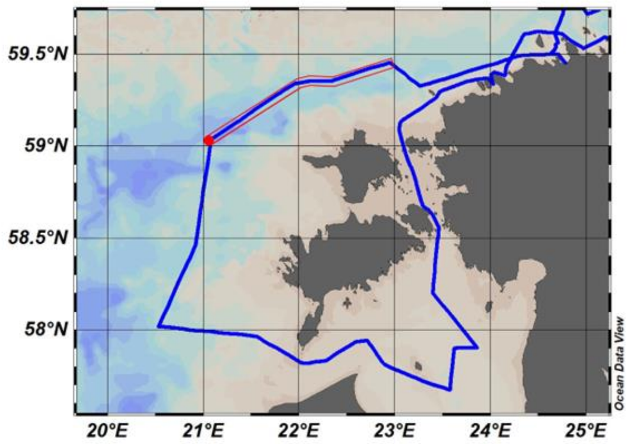


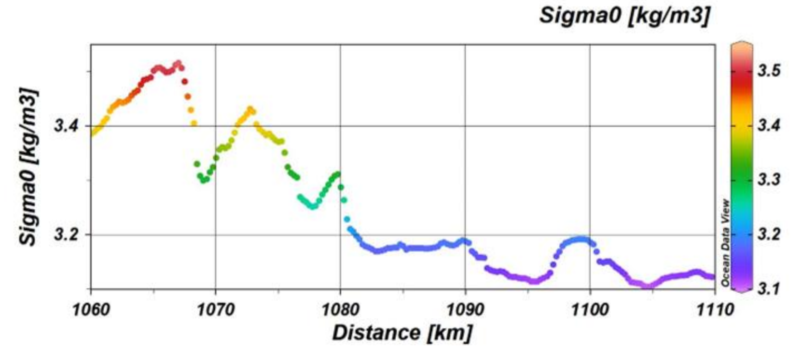






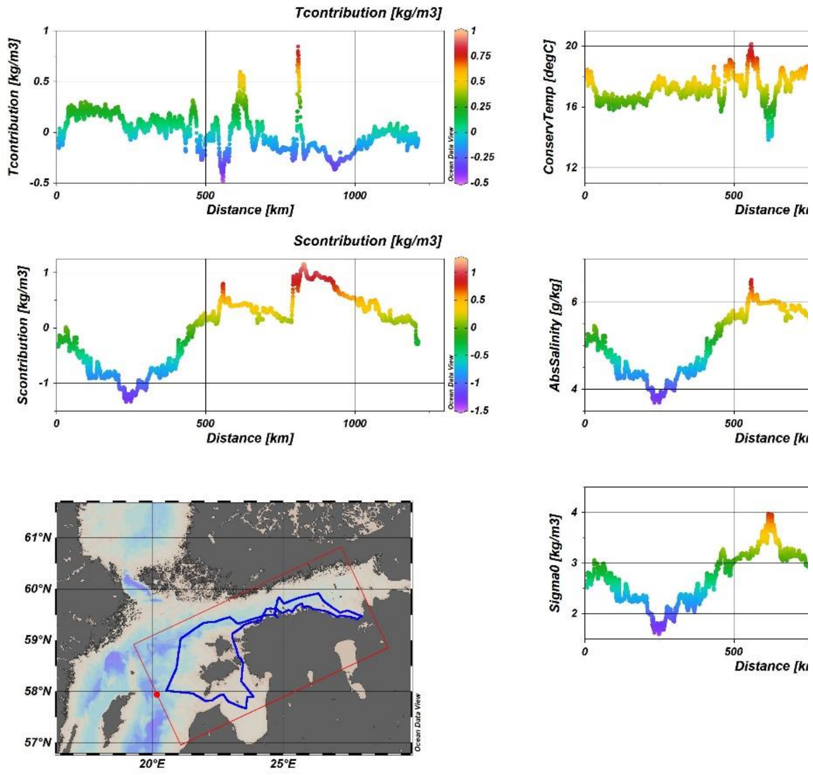


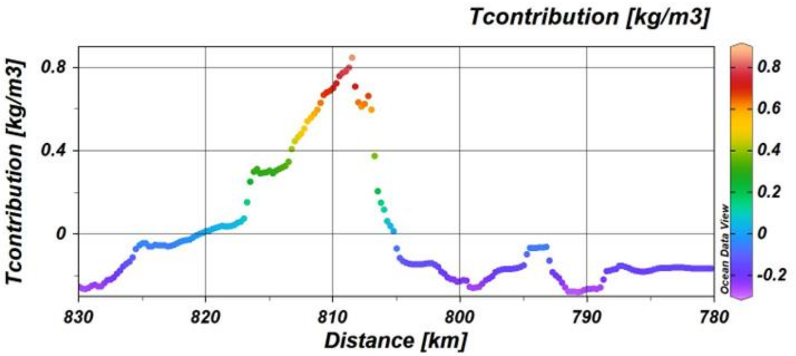


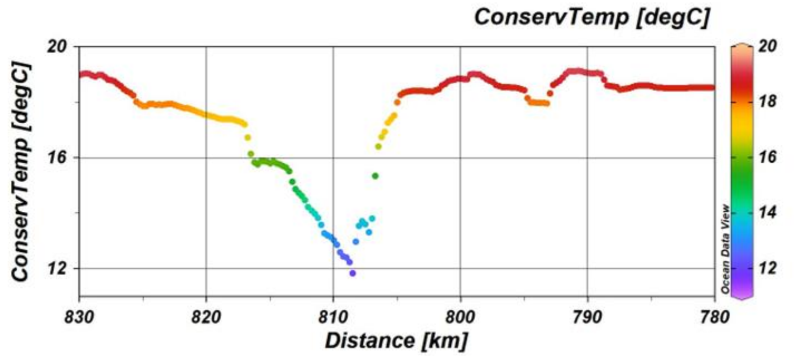


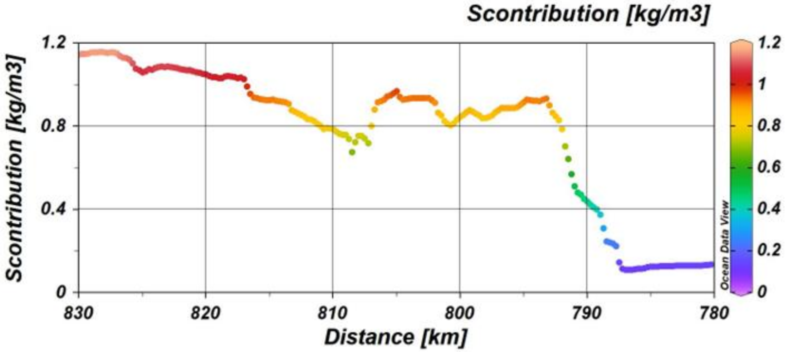
Similarly, salinity gradient and contribution dominate in the GoF-NBP transition area

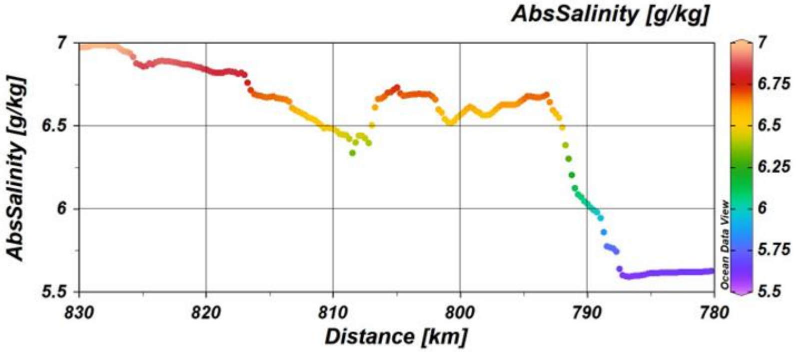
Example of July 2017

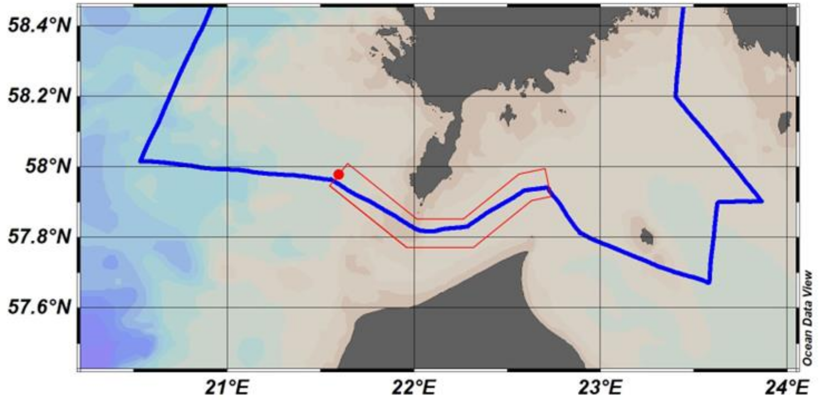


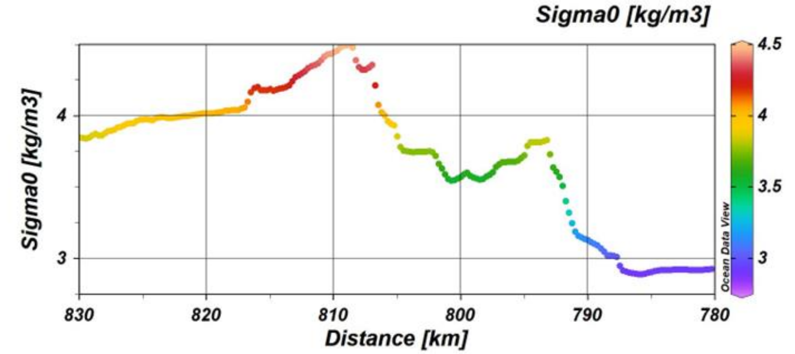






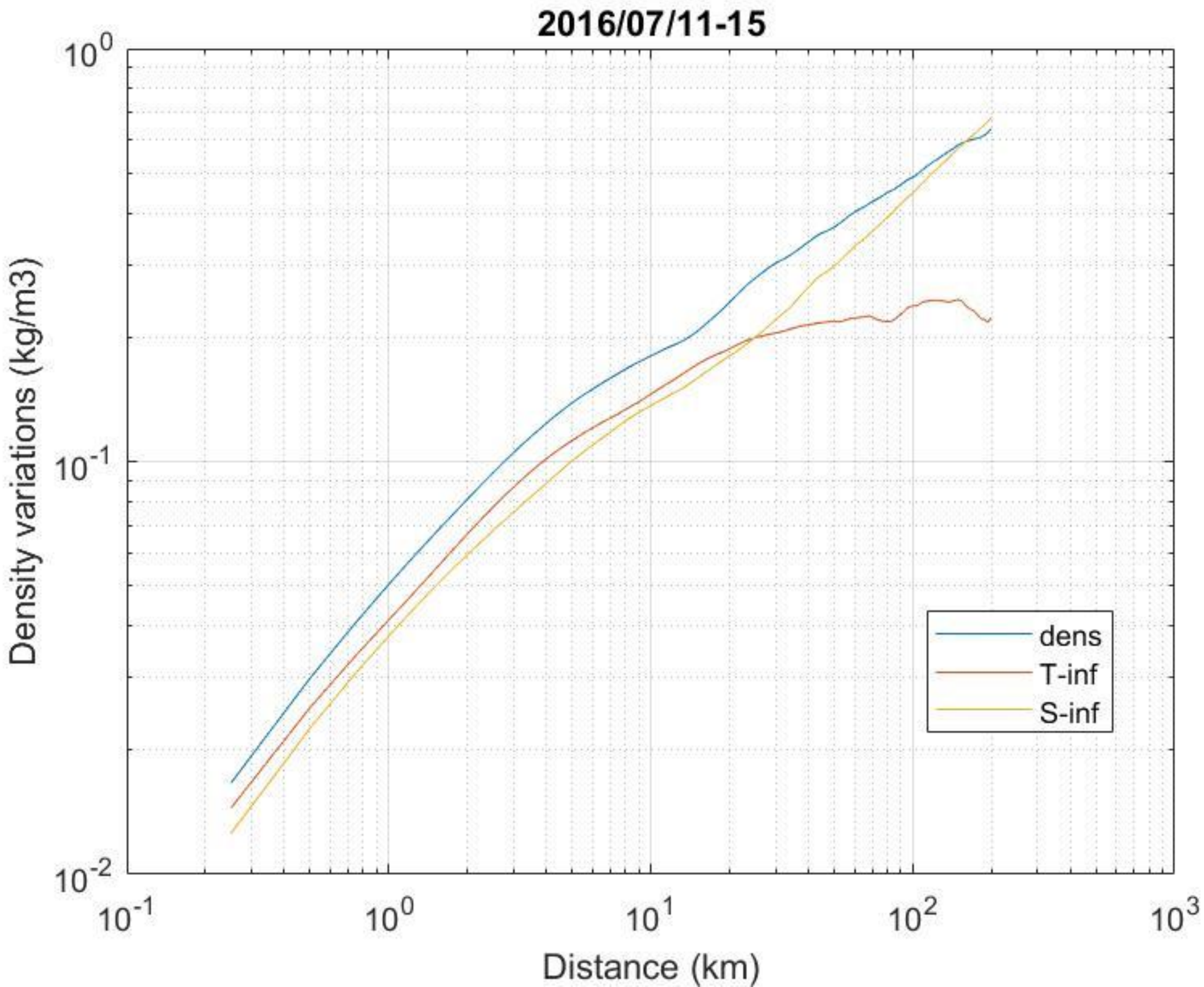






In the Irbe Strait, salinity and temperature-dominated density fronts can occur

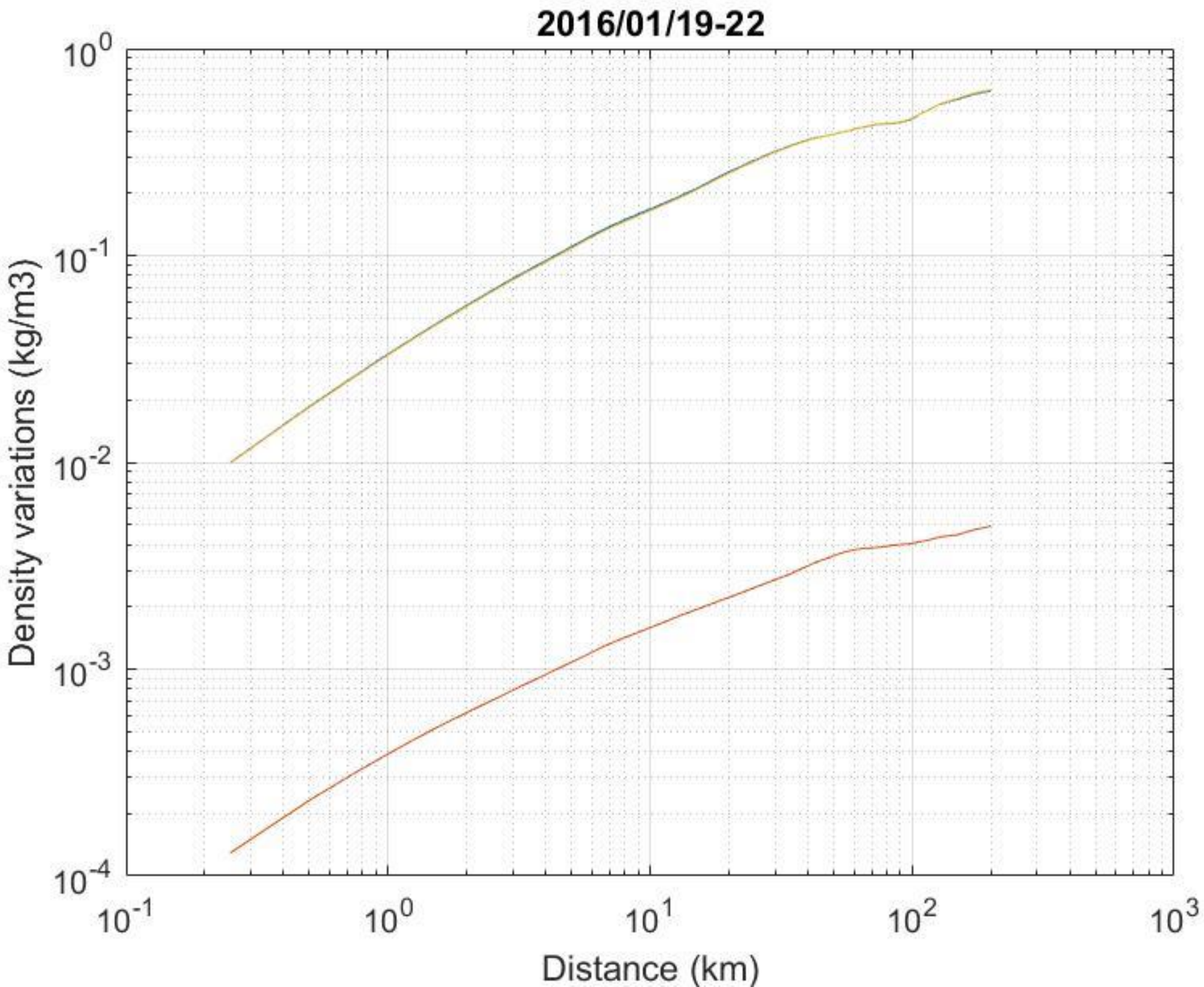
Variability in summer



Root mean square of density differences (dens) over a distance along the ship track. The temperatures and salinity differences contributions are shown as red and yellow curves, respectively.

At spatial scales < 25 km the temperature contribution is larger while it does almost not increase with increasing spatial scales at > 25 km, where salinity contribution clearly dominates.

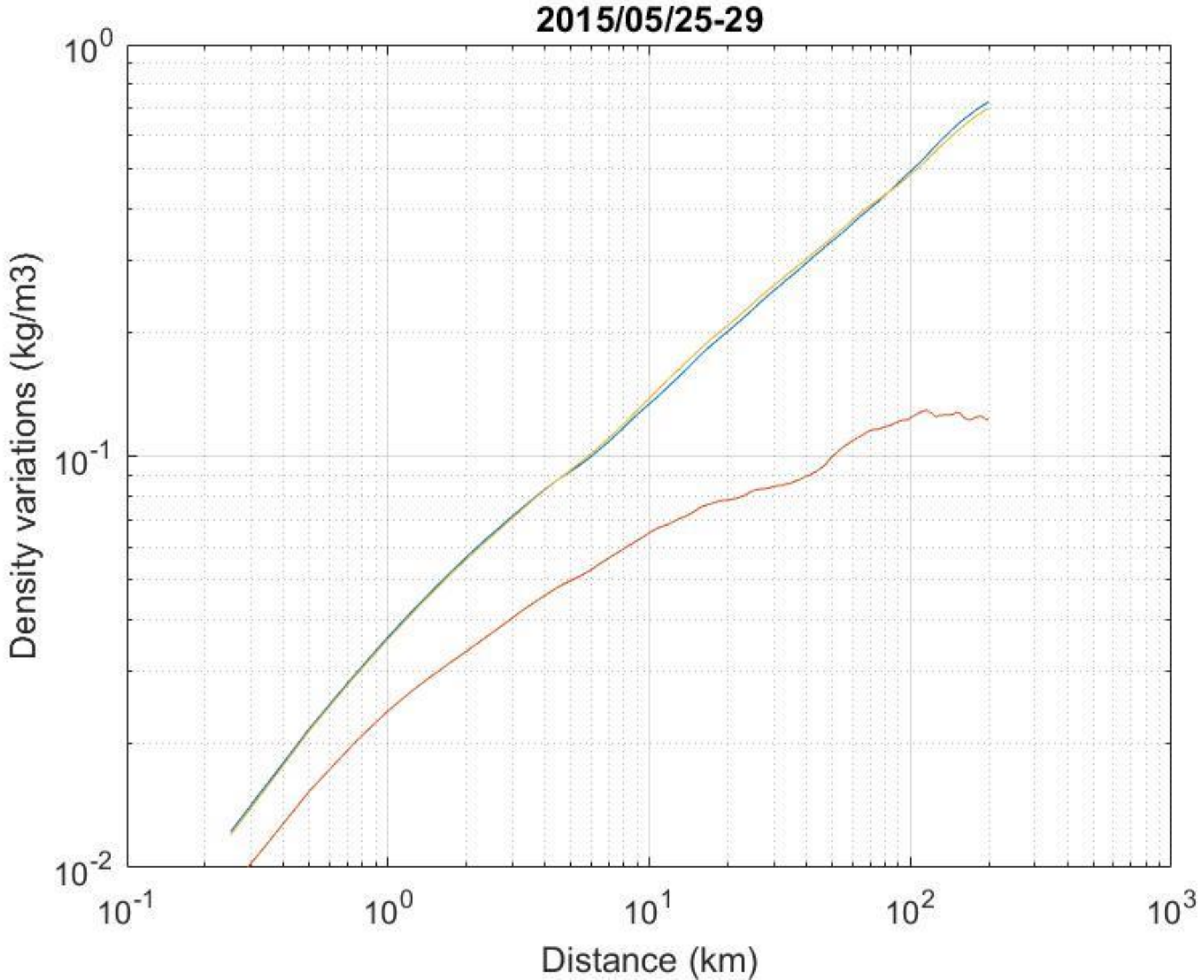
Variability in winter



Root mean square of density differences (dens) over a distance along the ship track. The temperatures and salinity differences contributions are shown as red and yellow curves, respectively.

In winter, the spatial variability in density and horizontal buoyancy gradients are entirely defined by salinity distribution (over the whole spatial domain)

Variability in spring



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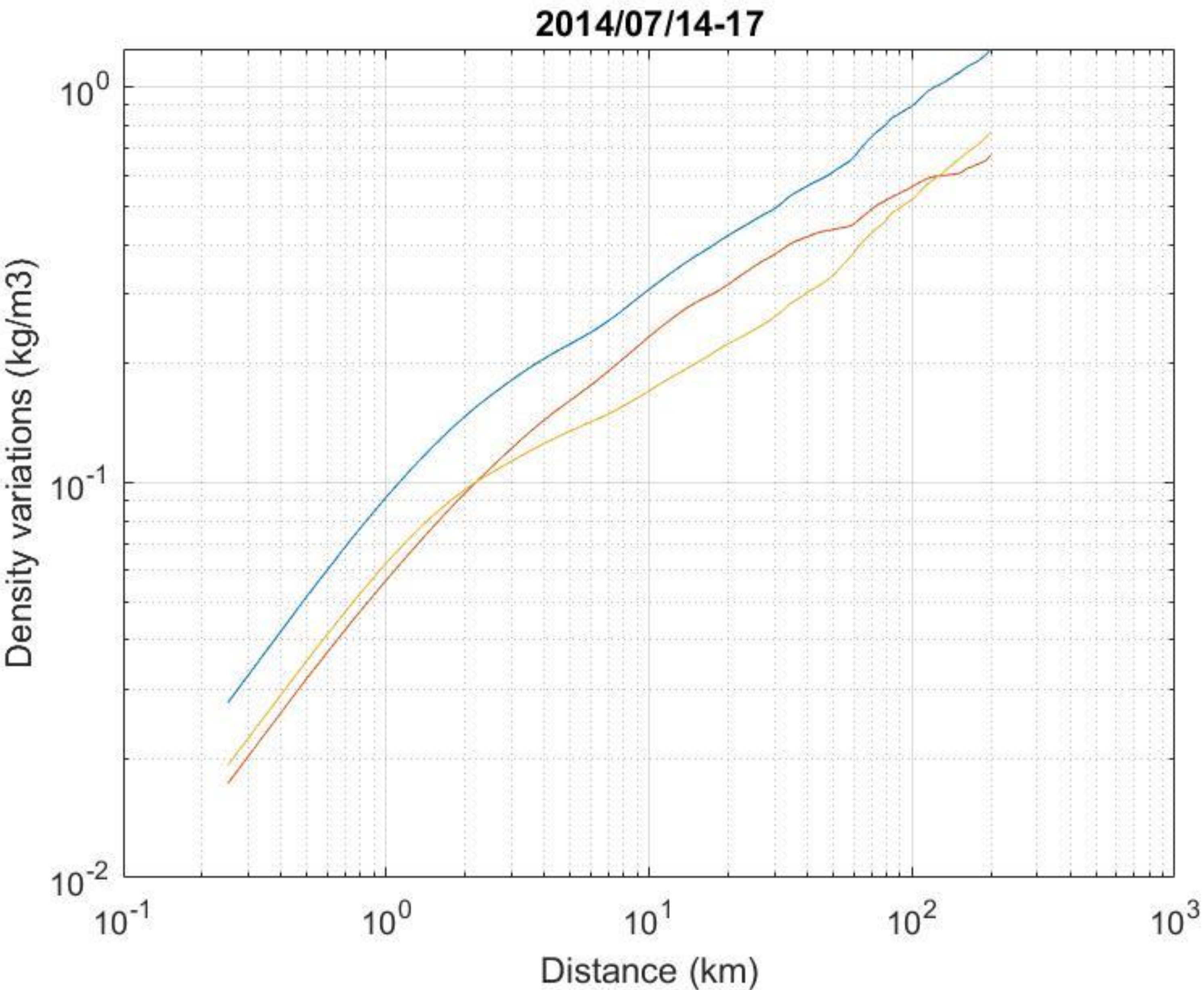
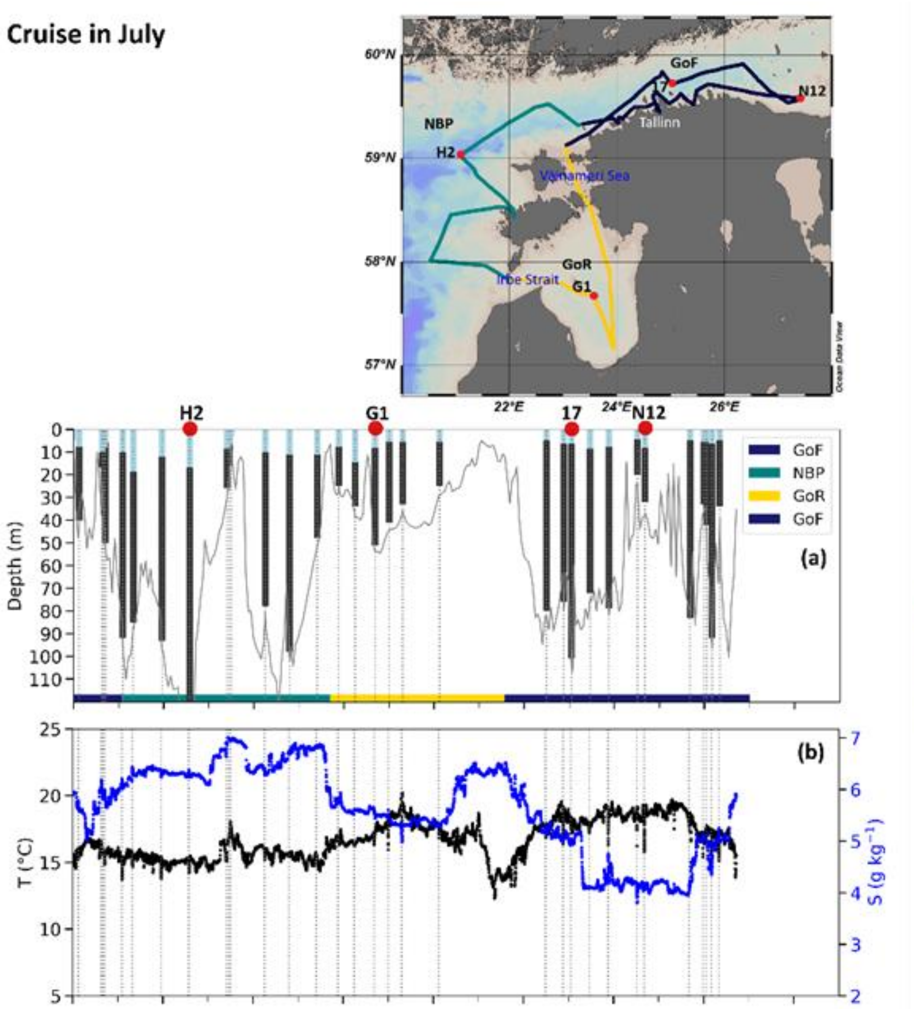
Variability in summer (upwelling dominance)



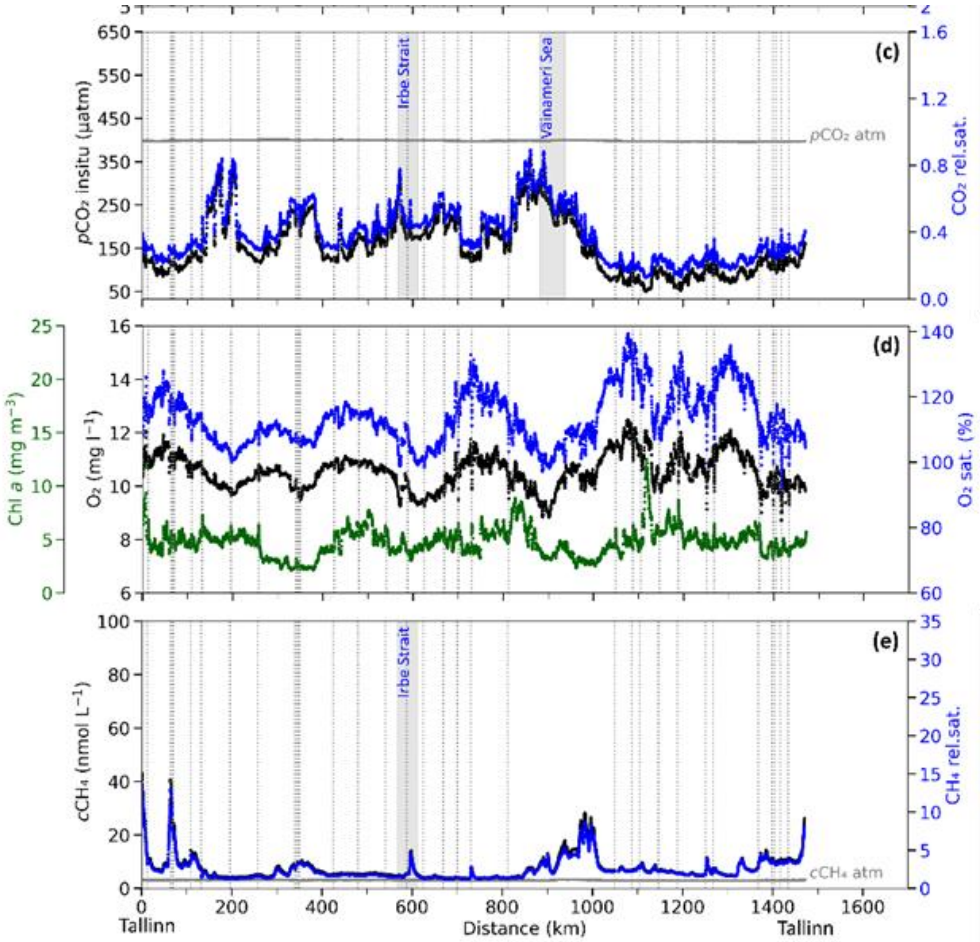
Root mean square of density differences (dens) over a distance along the ship track. The temperatures and salinity differences contributions are shown as red and yellow curves, respectively.

In the case of coastal upwelling, as a dominant feature, temperature contribution to the density gradients can be larger at the mesoscale-submesoscale (2-50 km)

High-resolution pCO_2 and cCH_4 measurements



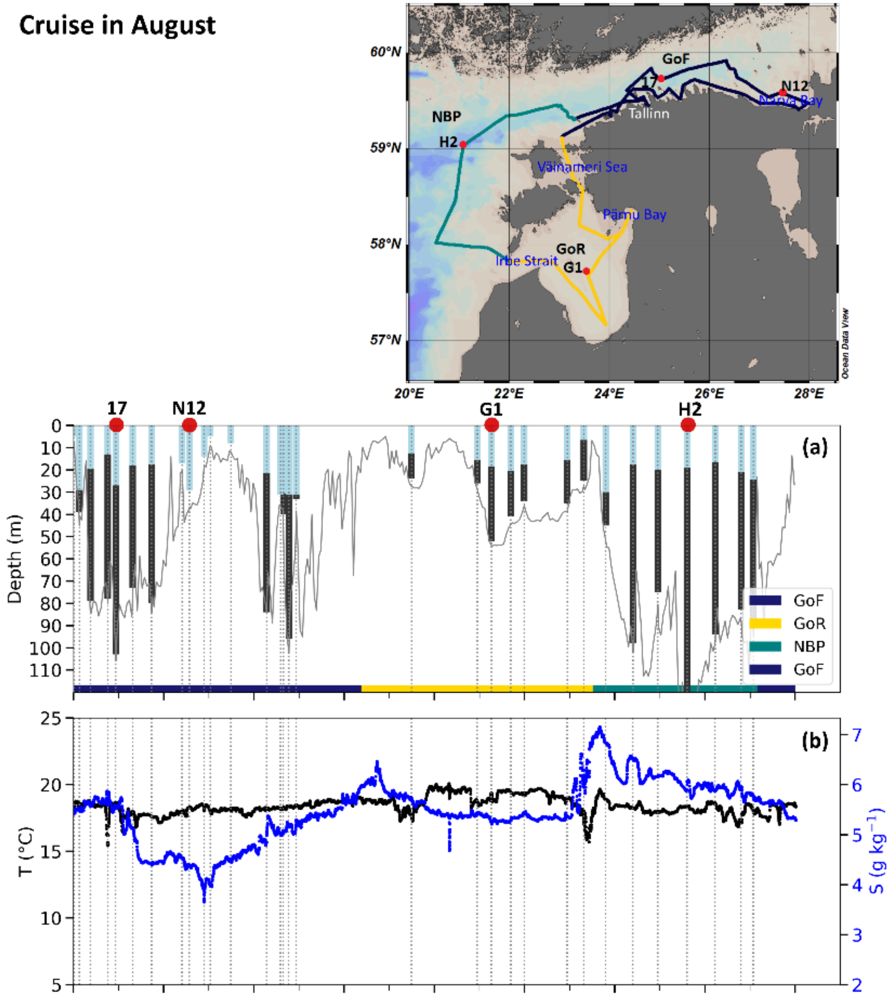
In 2018, pCO2 and cCH4 were recorded in the surface layer during six monitoring cruises. The general seasonal pCO2 pattern showed oversaturation in autumn-winter and undersaturation in spring-summer in all three areas. Extremely low pCO2 levels were observed in July, when the productive surface layer was separated from the seabed by strong stratification.



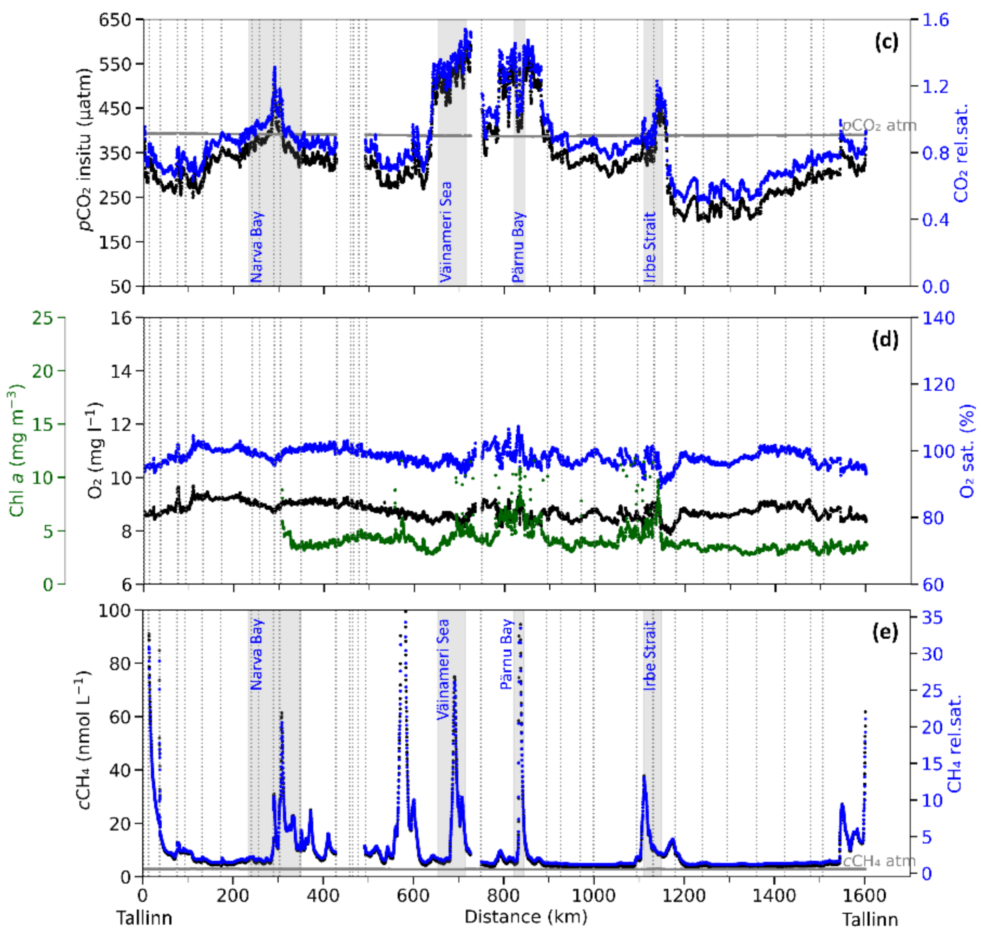
Lainela et al., 2024. Seasonal dynamics and regional distribution patterns of CO2 and CH4 in the north-eastern Baltic Sea, Biogeosciences, https://doi.org/10.5194/egusphere-2024-598

High-resolution pCO_2 and cCH_4 measurements

Cruise in August



Observed local maxima were related to river bulges, coastal upwelling events, fronts, and occasions when vertical mixing reached the seabed in shallow areas. In August, vertical mixing reached the seabed in shallow areas and local maxima in pCO_2 and high peaks in cCH_4 were observed. In October, higher concentrations of pCO_2 were registered in deeper areas.



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Conclusions and outlook

- Ferrybox data from research vessels are not routinely processed and shared. This data source is valuable both in near real-time (for operational services) and in delayed mode (for assessments and studies on seasonal dynamics).
- Spatial variations in salinity (due to geographically located fresh water and saltier water sources) are dominating in horizontal buoyancy gradients in the Baltic Sea, except in summer (periods with seasonal stratification), especially in the case of coastal upwelling events.
- In summer, temperature contribution to buoyancy are dominating at smaller spatial scales. In the case of upwelling events, at the mesoscale-submesoscale.
- Physical processes (vertical mixing, fronts, upwelling events) determine the spatial variability in $p\mathrm{CO_2}$ and $c\mathrm{CH_4}$. High concentrations are observed in areas and periods where and when the mixing reaches the seabed.
- An action to make data available is needed (processing, quality control, etc.).
- Similarly to R/V ferrybox data, long-term data sets from Baltic Sea ferries need to be analyzed to contribute to the understanding of the processes leading to mixing and dissipation of potential energy in the Baltic Sea.

Thank you for your attention!

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