Submesoscale variability during the formation of the seasonal thermocline in the Baltic Sea

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Submesoscale: The analysed glider profiles have high vertical (0.5 m in processed profiles) and horizontal resolution which allow resolving the submesoscale variability - the internal Rossby radius of deformation in the Gulf of Finland is 2-5 km.

The mesoscale dynamics is characterized by geostrophic velocities across the glider sections. To detect submesoscale features, the temperature variance was calculated along selected isopycnal surfaces at scales smaller than 4 km. Peaks in temperature variance indicate diapycnal mixing events and suggest the possible presence of submesoscale processes. The locations with more intense fluctuations were analysed by examining the forcing and distributions of temperature deviations (at scales <4 km) along isopycnal surfaces.

Background: The Baltic Sea is a brackish, non-tidal basin positioned in Northern Europe. The Gulf of Finland is a 400 km long and 48-135 km wide estuary (max depth 123 m) in the NE part of the Baltic Sea. It experiences strong vertical stratification that is sensitive to atmospheric forcing. Variable thermohaline structure favours the occurrence of mesoscale processes and changes in the mesoscale flow field that successively generates submesoscale dynamics.

Aim of the study is to describe the fine-scale structure of thermohaline fields based on glider data and to define submesoscale features during the development of the seasonal thermocline.

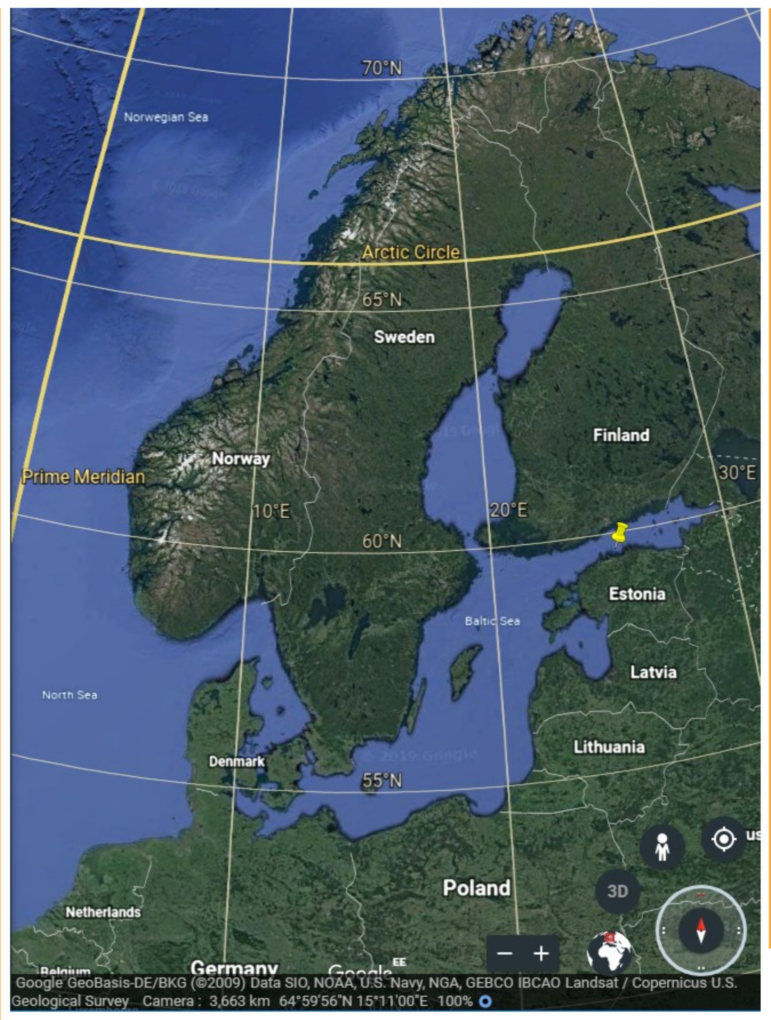

Figure 1. Study area (Baltic Sea) and location of the glider experiment (yellow pin).

Data: Glider measurements in the 19 km long section (S-N direction) across the gulf were arranged (**Fig. 1**). The section was sampled 28 times, and profiles of temperature, salinity, chl a fluorescence, turbidity and oxygen were collected from 9 May to 6 June 2018.

During the field experiment, glider covered 1555 km with an average horizontal speed of 0.32 ± 0.013 m/s. Both ascending and descending profiles were recorded. The mean horizontal resolution (average distance between the profiles) was 140 ± 51 m, and a profile took 7.4 ± 1.3 min to complete (the characteristic depth was 90 m).

MODIS and SLSTR SST data with a resolution of 1 km and meteorological data, including solar radiation and wind for the study period from the atmospheric model HIRLAM and the climate reanalysis dataset ERA5 were used to complement in-situ observations.

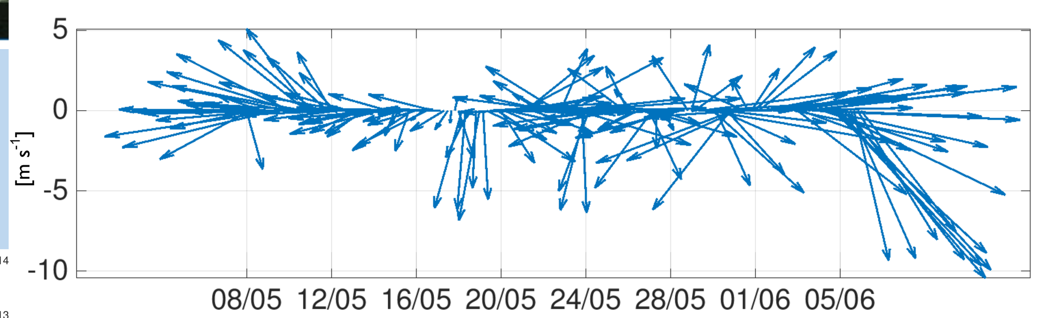

Figure 2. Wind vector time-series (ERA5 data). An arrow represents 4H mean.

The wind was mainly weak (2-6 m/s). Eastward winds were prevailing during the first half of the experiment. Northwest winds started to dominate in the last days of May and strengthened in early June.

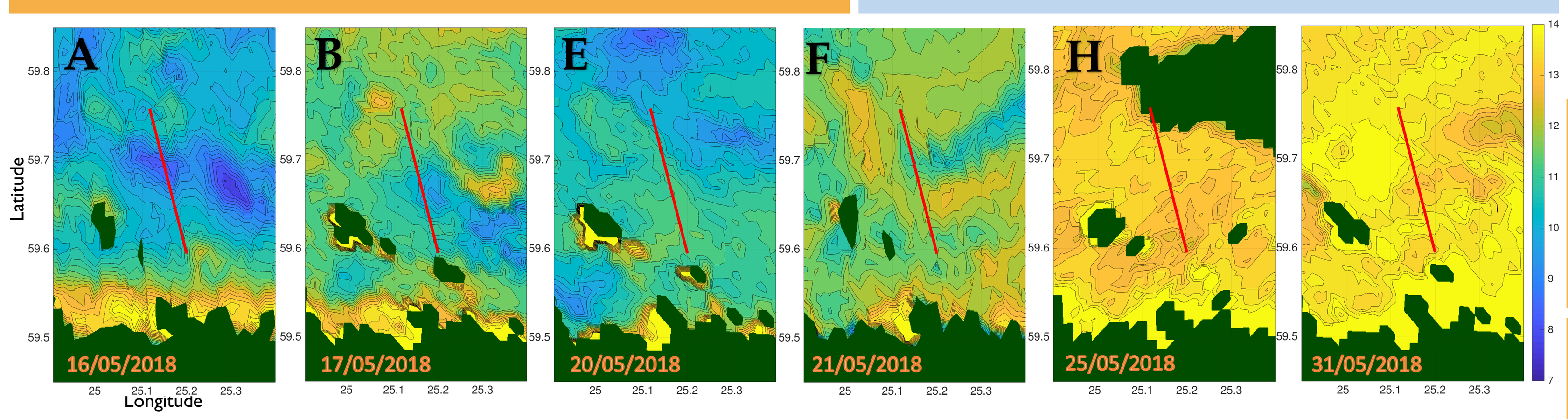

Figure 3. Sea surface temperature (SST) with letters referring to sections.

Temperature distributions: Warming of the sea surface (**Fig. 3**) and associated strengthening of the seasonal pycnocline from 5-7 °C to 12-15 °C and from 1.4-1.6 kg m^{-3} to 2.6-3.6 kg m^{-3}, respectively, were observed during the 4-weeks period. Eight sections are presented (**Fig. 6**) to show the variability in the temperature distribution over the study period. Increasing surface temperatures indicate intensified solar radiation and correspond to the seasonal cycle of SST. In addition, variable mesoscale fronts and patches were always present, and the lateral SST gradient was very variable.

Geostrophic velocities: Temperature and salinity profiles were used to estimate the cross-sectional geostrophic current velocities (**Fig. 4**) that represent the mesoscale flow field. Observed geostrophic velocities revealed two flow regimes. First, a core with an eastward flow (i.e., positive values), where velocities increased from 10 cm/s to 17.5 cm/s, developed in the middle part of the section. It was accompanied by reversed flows on both sides (**Fig. 4 A-D**). After a 2-day period (**Fig. 4 E-F**) with weak flow (5 cm/s), a baroclinic front and intensive geostrophic current with velocities in its core extending up to 30 cm/s (**Fig. 4 G-H**) developed in the central part of the section.

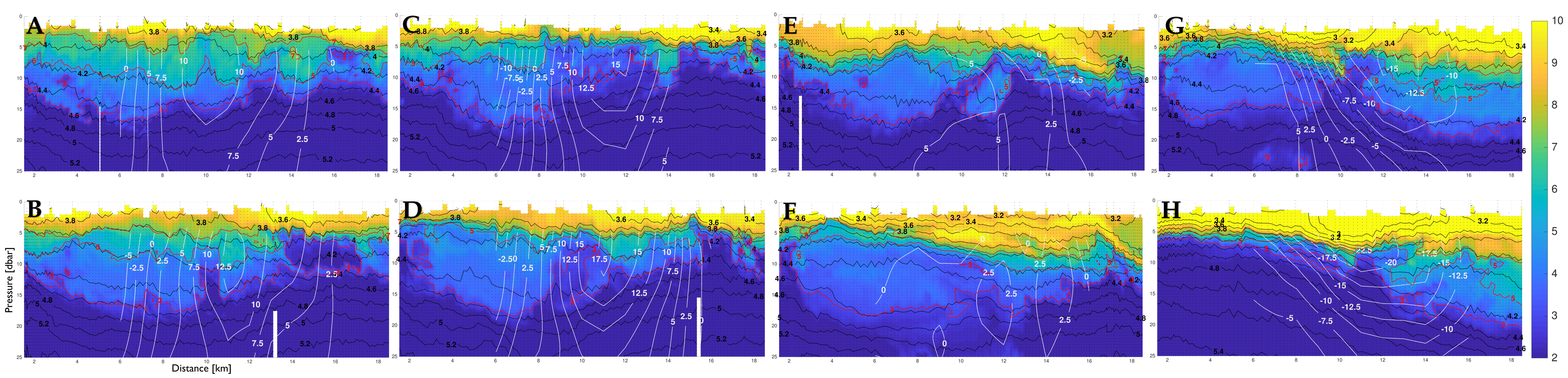

Figure 4. Distributions of temperature, density anomaly (black lines) and geostrophic velocity (white lines) in the upper 25 m.

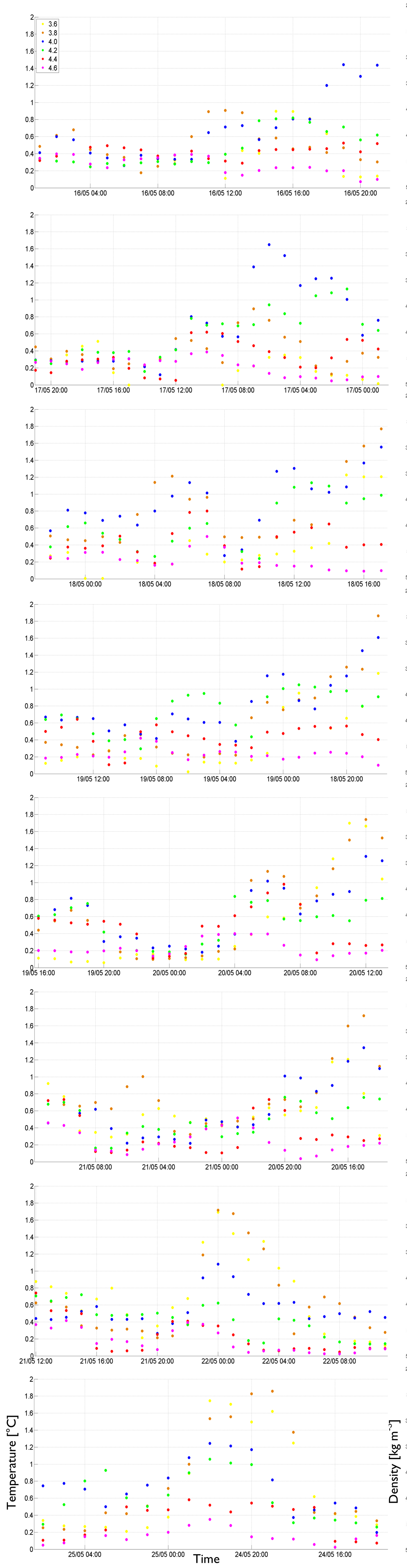

Figure 4. Temperature STD along isopycnal surfaces at scales <4 km.

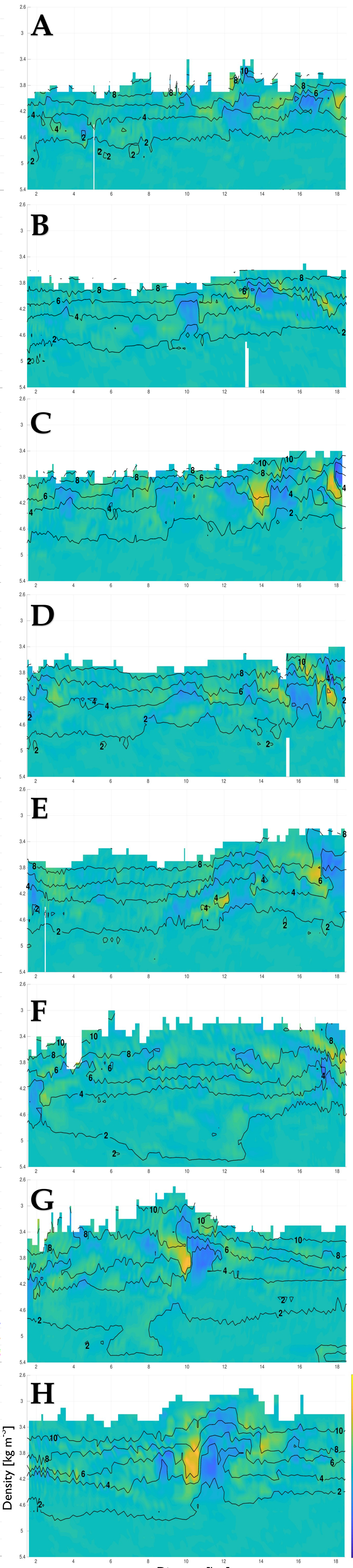

Figure 5. Temperature DEV along isopycnals at scales <4 km.

Results:

- Submesoscale intrusions arise between different flow fields. **Fig. 5 A-F** Fluctuations have developed within adjacent reverse geostrophic flows.
- Submesoscale intrusions occur in fronts. **Fig. 5 G-H** the fluctuations may represent secondary circulation. The most intense upward movement (10-12 km) on the lighter side is paired (based on the tilt at the top) with the less intense downward movement on the heavier side.
- The higher the gradient the stronger the submesoscale intrusion. **Fig. 5 G-H** the density difference is higher than other sections and fluctuations are more intense and have greater scope.
- Stronger mesoscale flow field may enhance submesoscale intrusions. Magnitude of the zonal wind stress was greater in **Fig. 5 G-H**. It reversed the geostrophic flow and therefore enhanced the stratification of the water column in the second half of the experiment.

Conclusion: During a month-long experiment several submesoscale structures with variable intensity were captured. Feature is characterised by coupled up- and downward flows, which are seen as neighbouring negative and positive temperature deviations. Especially intense fluctuations occur when mesoscale front and currents are strong. In order to quantify those structures further research need to be conducted.

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