MESOSCALE AND SUB-MESOSCALE VARIABILITY REVEALED BY COMBINING DATA FROM A FERRYBOX SYSTEM AND AUTONOMOUS BUOY PROFILER IN THE GULF OF FINLAND IN SUMMERS 2009-2012.

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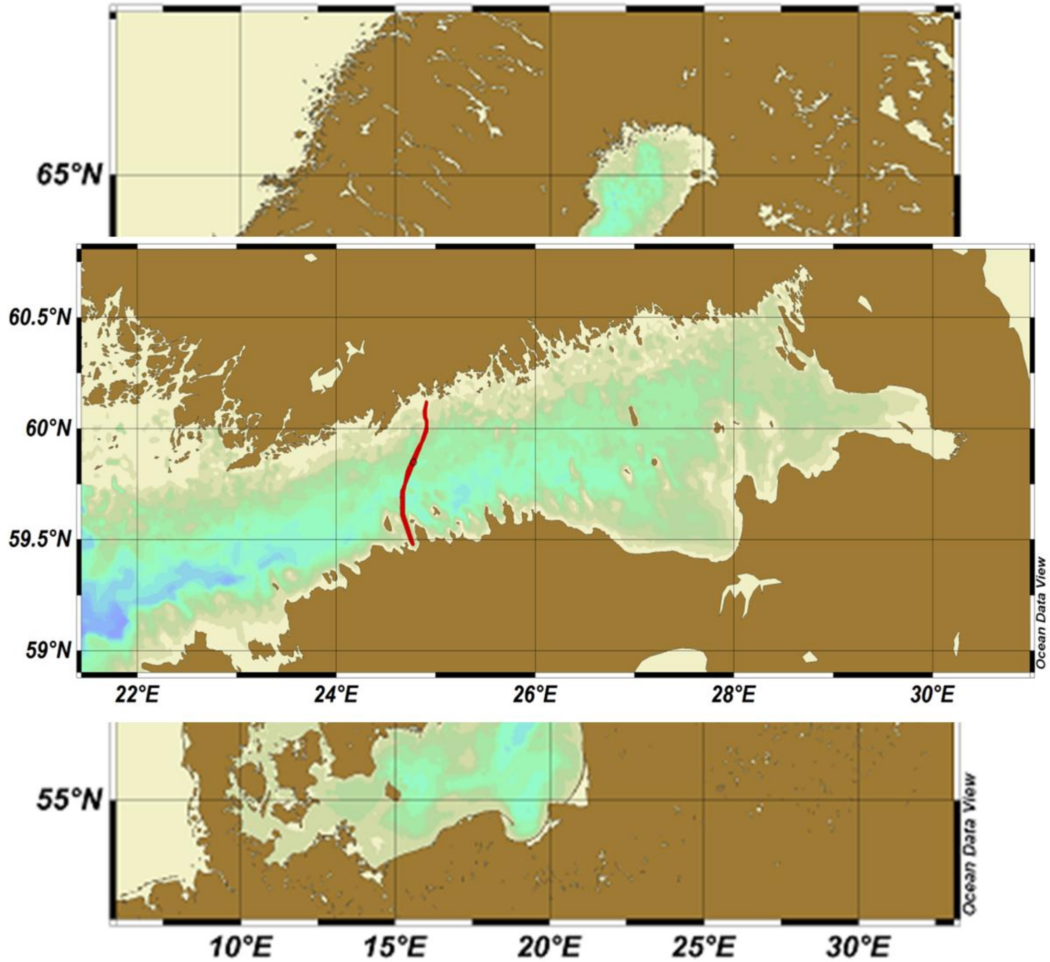
Gulf of Finland

The Gulf of Finland is a typical deep/stratified and wide estuary with remarkable horizontal and vertical gradients of salinity and density. In addition, seasonal thermocline forms at the depths of 10-20 m in spring-summer.

Residual circulation consists of an outflow of gulf's waters in the northern part and an inflow of open Baltic Sea waters in the southern part of the gulf.

Wind-driven circulation in the gulf is highly variable and characterized by intense mesoscale features – eddies, upwelling/downwelling, coastal and frontal jet currents.



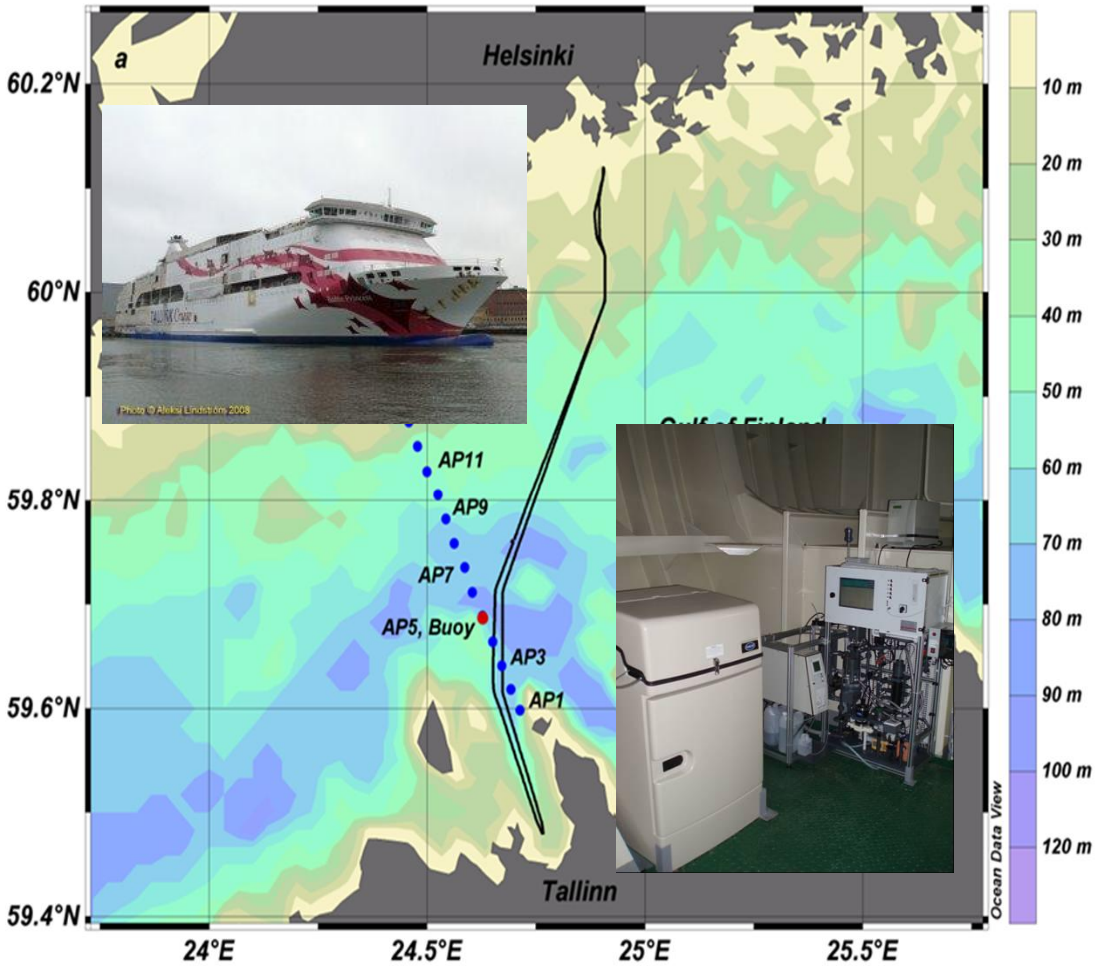
Meso- and submesoscale processes

- Increased spatial resolution in recent observations and modelling has revealed a richness of structures and processes on lateral scales of a kilometre in addition to the mesoscale variability in the upper ocean.
- These submesoscale processes (eddies, fronts and filaments, squirts) are distinguished by order-one ($O(1)$) Rossby and Richardson numbers.
- It is estimated that 90% of the kinetic energy of ocean circulation is contained in features at the mesoscale and submesoscale, whereas 50% of the vertical exchange of water mass properties may occur at these scales.
- Vertical velocities related to the meso- and submesoscale processes, can drive episodic nutrient pulses to the euphotic zone, and subduct organic carbon into the ocean's interior; they can locally increase the mean time that photosynthetic organisms spend in the well-lit euphotic layer and promote primary production.

AIM – to reveal meso- and submesoscale variability using high-resolution observations in the Gulf of Finland, estimate the scales and consequences to the phytoplankton growth (Chl *a* dynamics)

Ferrybox system

- Autonomous measurements, water intake from the surface layer (4 m) – sampling rate 20 s (spatial resolution about 150 m) - temperature (PT100), salinity (FSI thermosalinograph), Chl *a* fluorescence and turbidity (SCUFA)
- Data retrieval once a day via GSM connection, delivered for operational models (http://sahm.ttu.ee/ferrybox/)
- Water samples once a week by Hach Sigma 900 MAX, 17 sampling points
- Nutrients (PO_4^-, NO_2^-+NO_3^-) autoanalyzer Lachat; Chl *a* analyses by spectrophotometer Thermo Helios γ; phytoplankton counting; salinity by Autosal



Buoy profiler

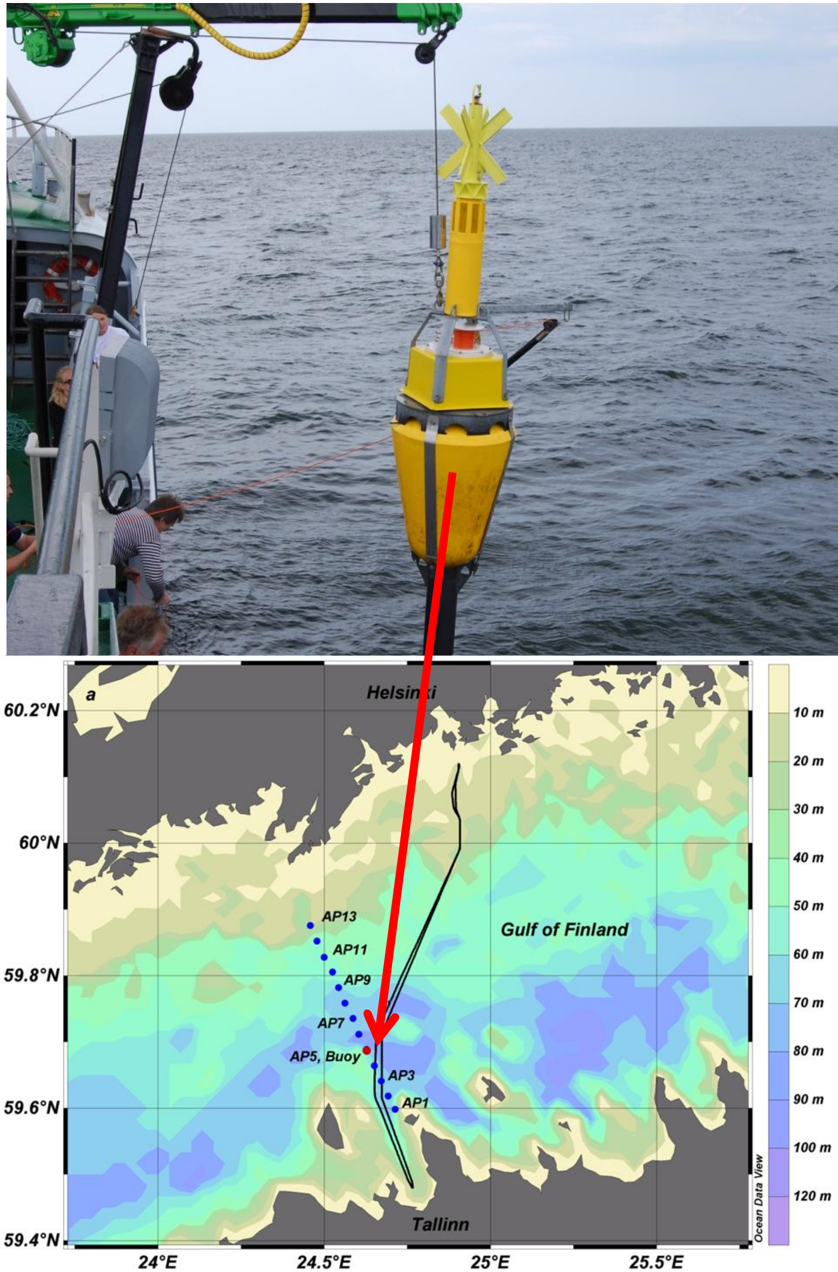
- Profiling system from Idronaut s.r.l. (Italy); sensors – OS316 CTD probe with Seapoint flourometer
- Buoy designed and constructed by Flydog Solutions (Estonia)
- Measures T, S, Chl *a* fluorescence; sampling interval 3 hours; profiles from 2 to 50 m
- Data delivered via GSM connection after every profiling
- Energy supply – replaceable 12V alkaline battery back 3x638 Ah
- Bi-weekly sampling by research vessel close to the buoy for calibration and analyses (PO_4^-, NO_2^-+NO_3^-; Chl *a* ; phytoplankton; salinity)

Deployment site and data

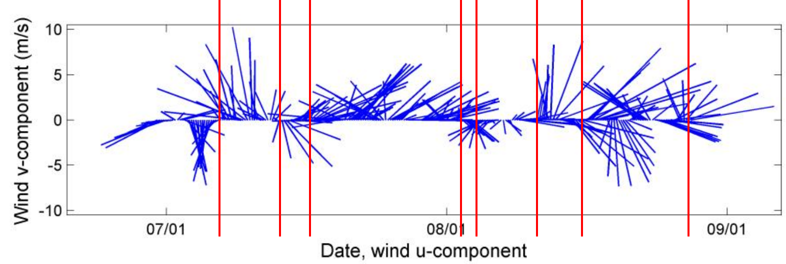
Forcing – wind data from the Kalbådagrund meteorological station (FMI) are used

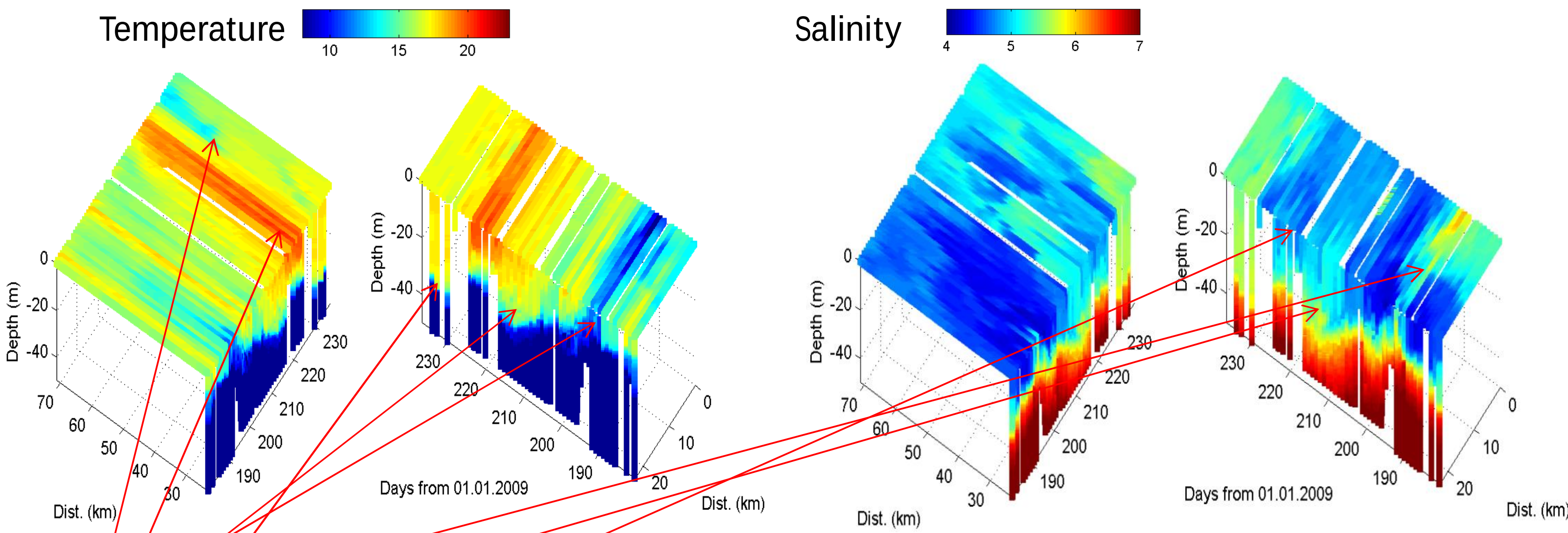
Analysis period in different years is mainly depending on success rate of autonomous profiler:
2009 – deployment period 60 days (temporal resolution 3 hours), success rate 317/480 – 66%
2010 – deployment period 56 days, successfully delivered 375 profiles, success rate – 84%
2011 – deployment period 97 days, successfully delivered 438, success rate – 56%
2012 – deployment since 26 April until November, success rate – 81 %

Main failures – cable, energy problems, humidity problems, modem failure, anchor system damaged



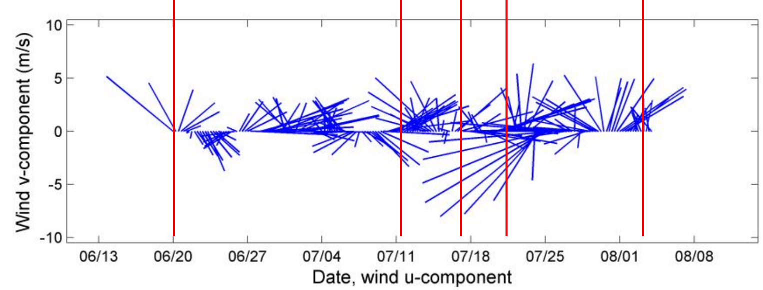
30.06-25.08.2009

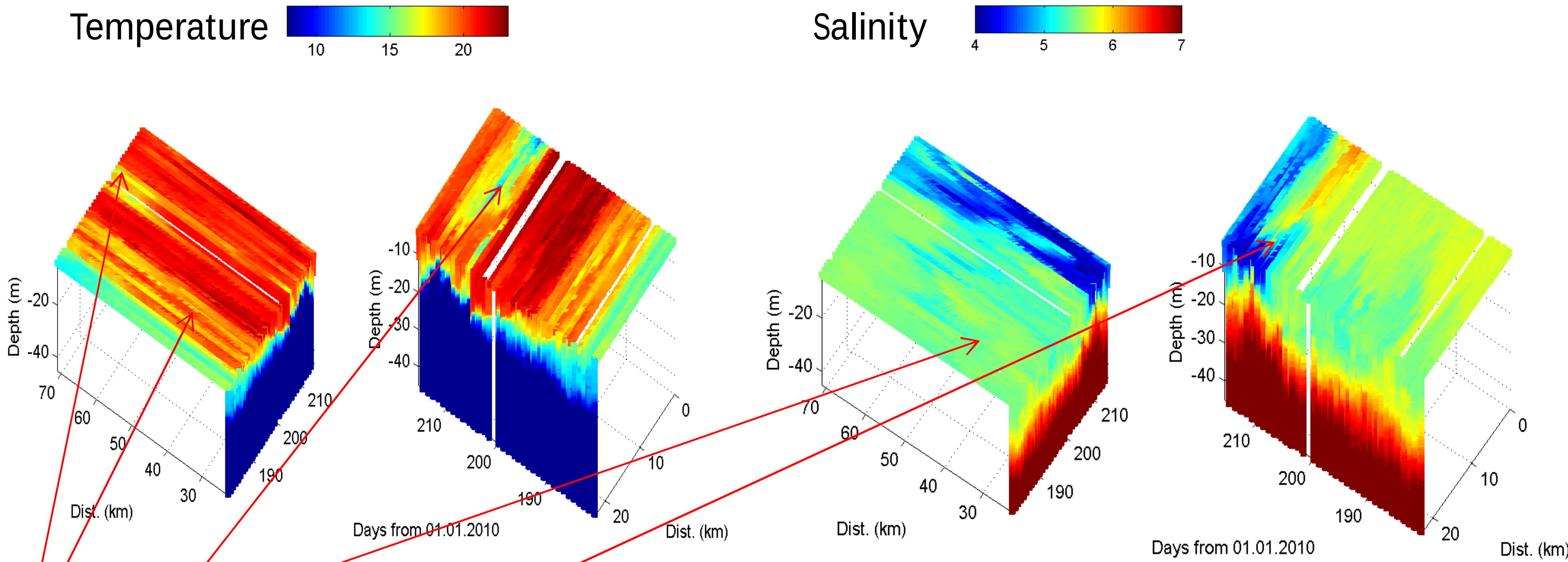




1. Upwelling near the southern coast, relatively large variations of T and S across the gulf
2. Deepening of the thermocline, intrusions of waters with different S in the sub-surface layer, moderate variations of T and S across the gulf
3. Weak winds, shallow and warm upper layer, almost no variations across the gulf
4. Coupled upwelling and downwelling, relatively high variations of T and S across the gulf

30.06-04.08.2010





1. Weak or variable moderate winds, low variations of T and S across the gulf
2. Weak upwelling in the northern part and deepening of the thermocline in the southern part; moderate variations of T and S across the gulf
3. Strong upwelling near the southern coast, very high temporal variability (both in the surface layer and vertical stratification) and high variations of T and S across the gulf

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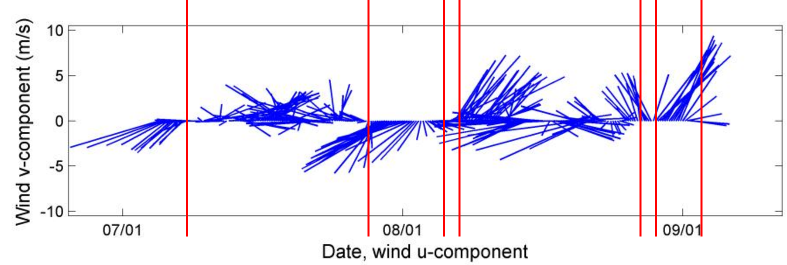
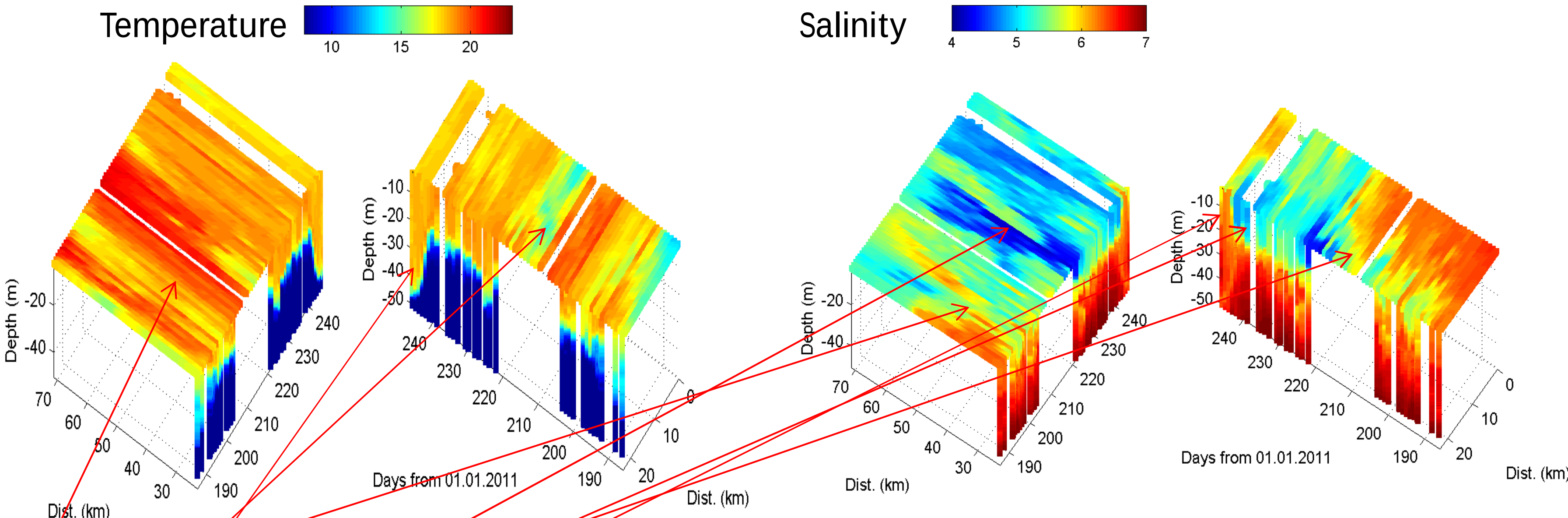
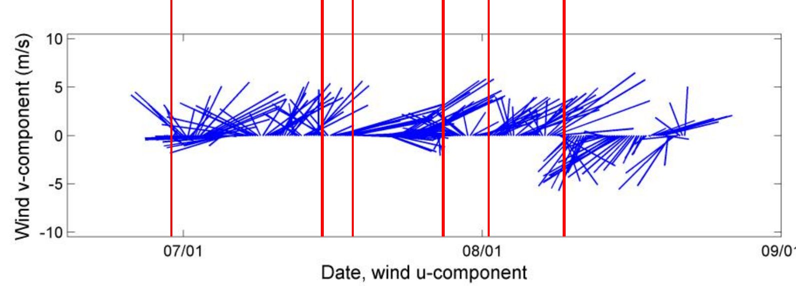
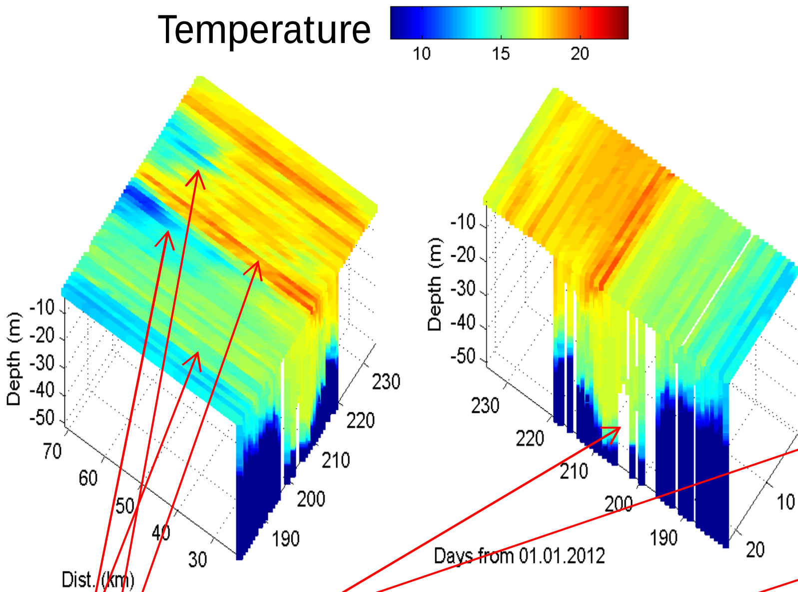


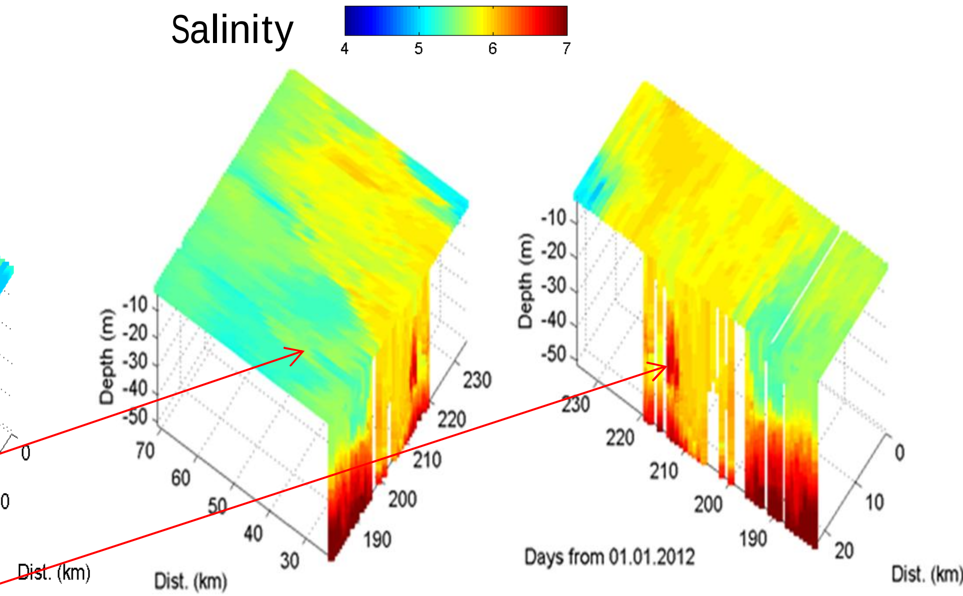


1. After a weak upwelling a period with weak to moderate winds with relatively low variations of T, but high variations of S occurred
2. Extensive upwelling event in the southern part and high variability of T and S across the gulf
3. Strong winds of variable directions, high variability of S (both temporal and spatial)
4. Strong mixing and deepening of the thermocline

29.06-22.08.2012



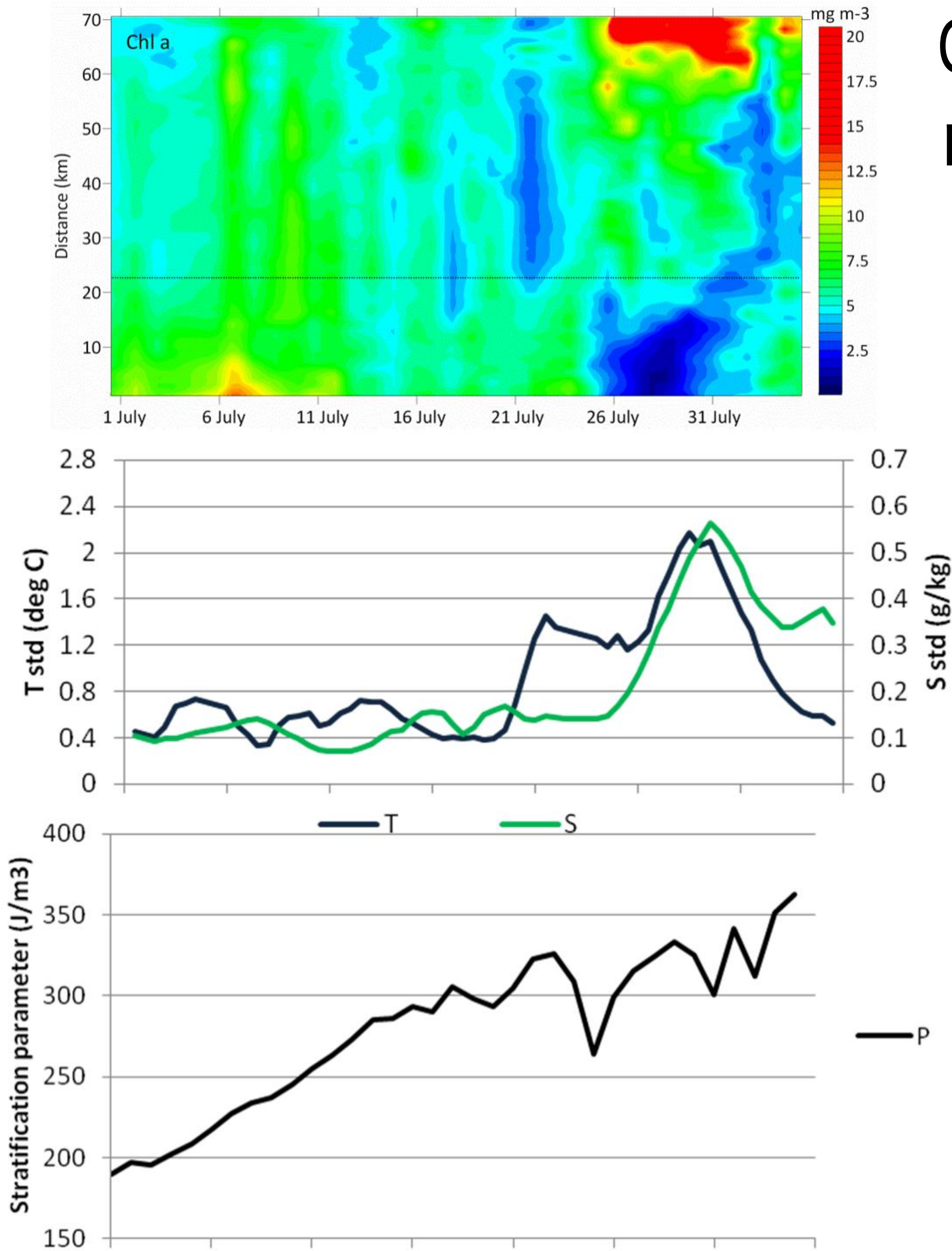




1. Strong winds from variable directions, cold surface layer, moderate spatial variations
2. Upwelling near the northern coast, deepening of the thermocline in the southern part
3. Short period of weak winds, heating of the shallow surface layer, almost no variations of T and S across the gulf, appearance of high salinity intrusions in the sub-surface layer
4. Upwelling near the northern coast

Stratification parameter and horizontal variability

- Horizontal variability of temperature and salinity was estimated on the basis of Ferrybox data between Tallinn and Helsinki as standard deviations. Smoothing of the temporal course was applied over 2 days (4 crossings).
- Vertical stratification was described by the potential energy anomaly *P* (Simpson and Bowers, 1981; Simpson et al., 1990) calculated on the basis of vertical density profile (in the upper layer down to 40 m). The stratification parameter *P* (J m^{-3}) is the work required to bring about complete mixing of the water column under consideration.



Chl *a* dynamics related to meso- and submesoscale variability (July 2010)

- The highest Chl a concentrations were measured in the northern part of the ferry route after a moderate upwelling event and simultaneously with the intense downwelling event near the opposite coast
- The variations of temperature and salinity were the highest during this period as well
- At the buoy station in the southern part of the gulf, high temporal variability in vertical stratification was observed simultaneously with the formation of the high Chl *a* patch

Conclusions

- Wind forcing favourable for formation of upwelling events (either near the southern or northern coast) creates high variability of vertical stratification and consequently vertical movement of waters
- During these events and their relaxation high spatial variability of temperature and salinity in the surface layer at the mesoscale (and submesoscale) is observed
- It could result in significant changes in surface layer salinity in time (replacement of surface waters by water masses with different salinity)
- In the sub-surface layer, often layered vertical distribution of salinity was observed during these dynamic events
- The observed horizontal and vertical variability of temperature and salinity is related to mesoscale dynamics, and this will cause also high variability in Chl *a* distribution
- Highest Chl *a* concentrations were observed simultaneously with the upwelling events, but close to the opposite coast

Thank you for attention

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