Measuring and Modeling of Multi-Scale Interactions in the Marine Environment

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How to differentiate between coastal cooling and upwelling events on SST images?

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ABSTRACT: **We aim to find on MODIS (Aqua, Terra) SST-pictures of the South-Eastern Baltic those characteristic features, which allow to distinguish the differential coastal cooling from the coastal upwelling events, even though their manifestations look much alike. The basis is data of MODIS (Aqua, Terra) spectroradiometers for 2000-2013. We analyze horizontal SST-profiles above coastal slopes under conditions of autumnal cooling and during well known upwelling events. The SST profiles above slopes are formed as a result of joint contribution of heat exchange with the atmosphere and horizontal transport of heat from the sea. Satellite images of October-November, corresponding to the periods of well pronounced decrease in air temperature (with time rate of change as large as 0.86-2.54 C/day) were analyzed. Typical shape of the profiles, demonstrating the presence of differential coastal cooling over the distance of 10-20 km from the shore, allows for allocation of the region where thermocline meets the slope, what gives (for the given bathymetry) an information on current thickness of the upper mixed layer (UML). Shape of the SST profile is quite conservative, not sensitive to both the steepness of the bottom slope, bathymetry peculiarities, and intensity of cooling and even wind conditions, indicating that sea-shelf heat exchange is in general close to the steady state. The SST drop from open to coastal area is about 2-3 C and does not depend on the thickness of the UML or the steepness of the slope. On the other hand, about 90 events of coastal upwelling in May-November 2000-2013 in South-Eastern Baltic were selected and the features of the horizontal SST-profiles above the same coastal slopes were analyzed. It appeared that the shape of the SST-profiles demonstrates the presence of upwelling quite definitely, what allows for effective differentiation from the coastal cooling effects.**

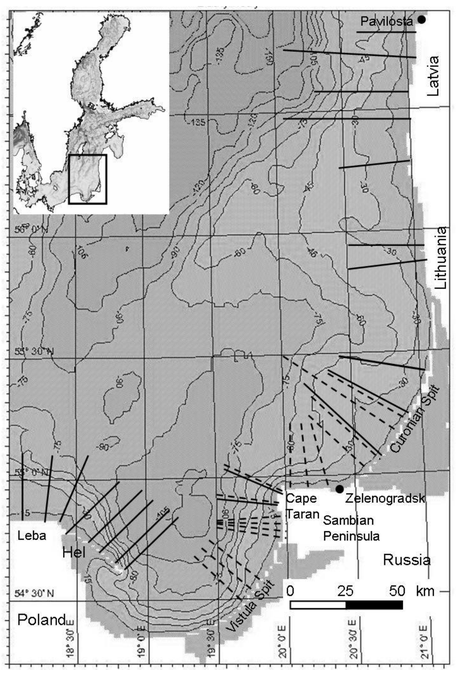

Fig. 1. Overview map of the research area in south-eastern Baltic. Cross-sections are located over costal slopes: 20 cross-sections - the coast from Pavilosta (Latvia) to Leba (Poland) (solid lines), 16 cross-sections - the coast of Kaliningrad region (dashed lines). The analyzed SST-profiles were taken from SST satellite images along these cross-sect

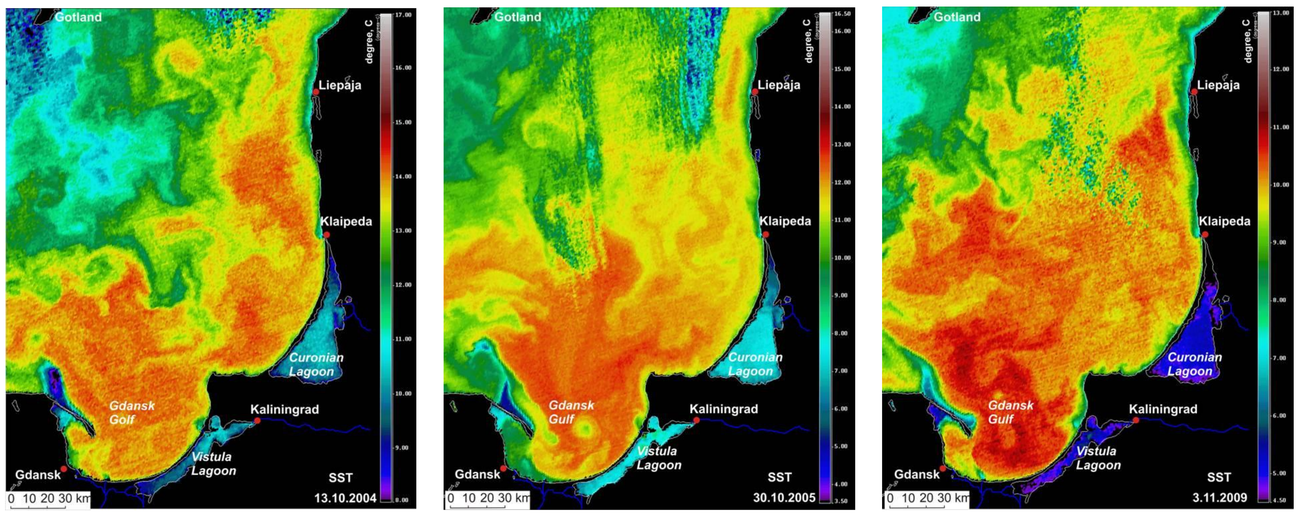

Fig. 2. MODIS SST images ***13.10.2004, 30.10.2005, 3.11.2009*** (level of the processing L1A) were obtained from archives LAADS (Level 1 and Atmosphere Archive and Distribution System). **Autumnal cooling** is above the underwater slopes of the South-Eastern Baltic Sea and the **upwelling** above the coastal slope near the Hel Peninsula:

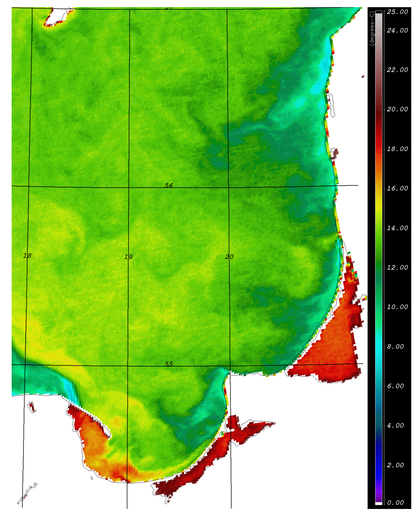

Fig. 3. MODIS SST image 3.06.2008 – the **upwelling** above the coastal slopes of the South-Eastern Baltic Sea

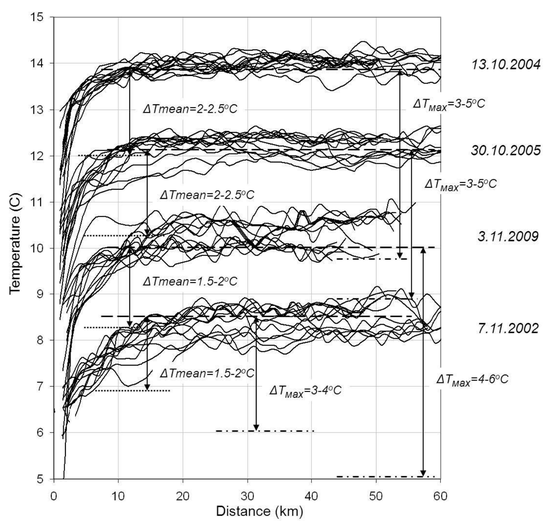

Fig. 4 Set of SST-profiles for episodes I, II, III and IV (the date is shown in the figure) **during autumnal cooling** in the coastal zone in south-eastern Baltic (data: MODIS Aqua).

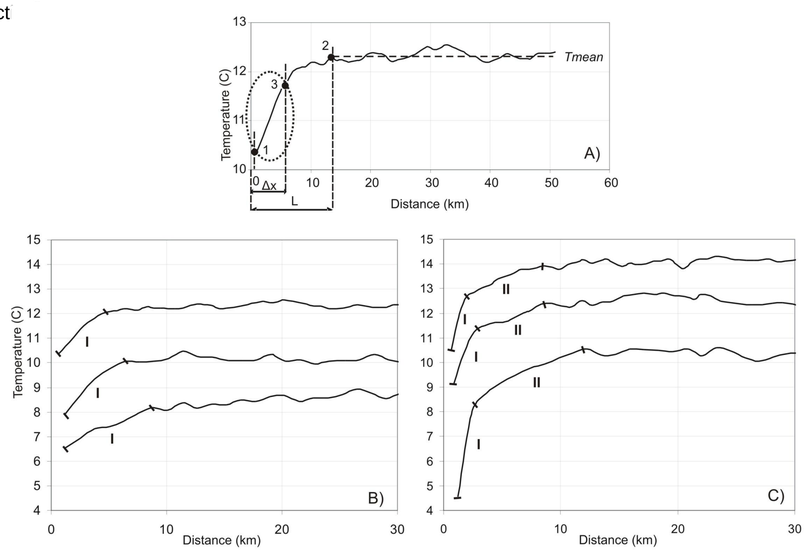

Fig. 5. Schematic shape and typical elements of horizontal SST-profiles **during autumnal cooling** over coastal slope: a) L - the length of the slope; point 1 - the beginning of the slope, point 2 - the end of the slope; Tmean - average SST in the deep-sea part; point 1 - point 3 - section of linear increase of SST. Lower panels: examples of profiles with one (b) and two (I and II) (c) linear parts

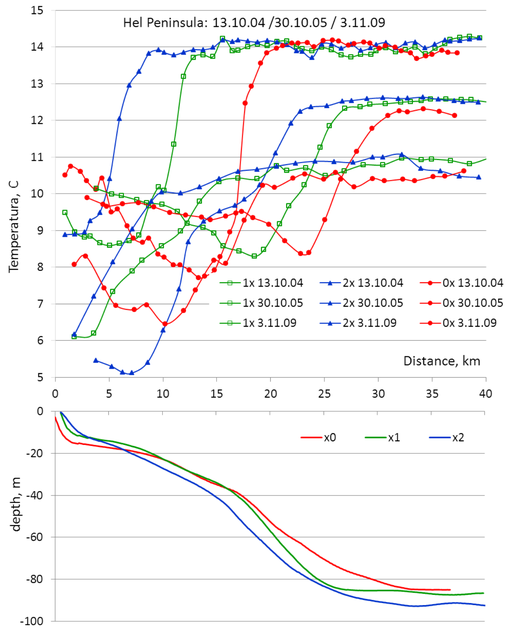

Fig. 6. SST-profiles versus the corresponding bathymetry profiles : 13.10.2004, 30.10.2005, 3.11.2009 - during events of **coastal upwelling** near the Hel Peninsula

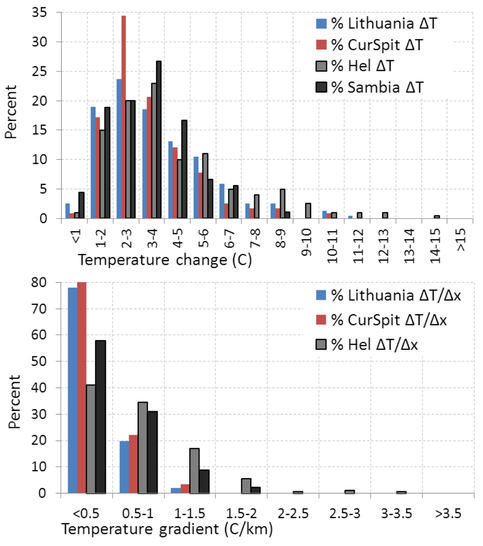

Fig. 7. Histograms of frequency: a - the temperature change between the upwelling zone and adjacent waters (ΔT, C), b - temperature gradient (ΔT/Δx, C/km) - the coastal area near the Lithuania, the Curonian Spit, the Sambian Peninsula, the Hel Peninsula

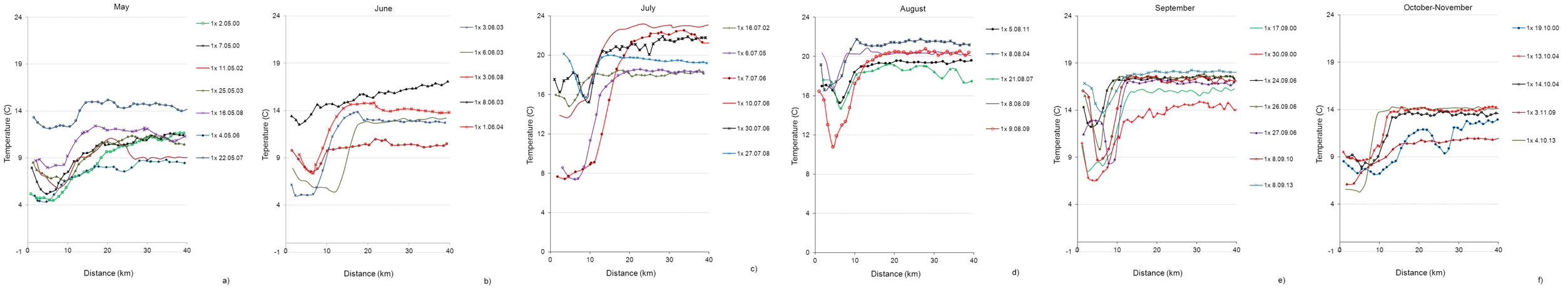

Fig. 8. Set of the SST- profiles above the coastal slope near the Hel Peninsula: (a) - May, (b) - June, (c) - July, (d) - August, (e) - September, (f)- October and November - it is **during events of coastal upwelling** in May-November 2000-2013

Conclusions

Based on a comparison of SST-profiles obtained from data of spectroradiometers MODIS (Aqua, Terra) in May - November 2000-2013 above costal slopes of the Southeast Baltic, our analysis brought the following conclusions.

- Typical coastal-cooling profiles, manifesting the cascading process up to distances of 10-20 km from the coast, allow to allocate the position of the region where the thermocline meets an underwater slope. The shape of the SST-profile is quite conservative, not sensitive to the inclination of the bottom, features of the bathymetry, the intensity of cooling and even to wind conditions, indicating stability of the overall picture of the heat exchange between shelf and the open sea. Decrease of SST to the shore is 2-3 C and it is practically independent of the thickness of the upper mixed layer and steepness of the slope.
- All SST-profiles in the periods of the cascading demonstrate clear drop of water temperature when SST-profile approaches the shore. Remarkably, the shape of the SST-profiles is similar at different times and above different slopes. Practically on any of the profiles one can identify some specific areas: parts with almost linear drop of water temperature as it approaches the shore.
- The basic condition for the emergence of the cascading is intense and prolonged drop of the air temperature.
- SST-profiles within upwelling have characteristic features. Decrease of water temperature always has obvious sudden changes, frontal zones, alternation with the isothermal spots and traces of jets. Characteristic features of SST-profiles are: (i) the core of the upwelling (water with lowest temperature) typically appears at the surface at some distance from the shore, and the development of the upwelling is accompanied by the changes of the position of the core; (ii) often, the strip of warm water separates the core of upwelling from the coastline; (iii) a sharp temperature change (within 1-14 C) is typically observed between the upwelling zone and adjacent deep waters, with large temperature gradient (0.3-3.3 C / km), (iv) characteristic turns and bends, probably primarily due to the bottom topography.
- In contrast to differential coastal cooling, formed along all the coasts at the same time, the upwelling is always limited by certain restricted area.
- Large variability of shapes of the SST-profiles of neighboring cross-sections is indication of upwelling; coastal cooling (and cascading) is characterized by quite conservative self-similar profiles.
- Wind regime is one of the main driving factor for the upwelling, while the cascading is driven by intense atmospheric cooling.

Thus, there are clear features of cascading and upwelling events, which allow exact identification of them using horizontal SST-profiles. This fact increases the number of hydro-physical problems, where one can successfully use an easily accessible remote sensing data.

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