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MODIS-based sea surface temperature of the Baltic Sea Curonian Lagoon

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ABSTRACT

This paper focuses on analysis of sea surface temperature (SST) derived from Terra/Aqua Moderate Imaging Spectrometer (MODIS) infrared imagery between 2000 and 2011 to document the hydrological regime in the Baltic Sea Curonian Lagoon. Records of the daytime SST from MODIS were validated against conventional in situ observations from an oceanographic buoy in the SE Baltic and two coastal hydrographic stations in the Curonian Lagoon. In general a very good agreement between them was found with positive bias (RMSD) not higher than 0.49 °C (1.31 °C) and R^2 not less than 0.78. The MODIS-based SST data set, having a wide spatial coverage and relatively high spatial resolution enables one to study spatial, seasonal and inter-annual SST variations unavailable from sparse in situ measurements in the Curonian Lagoon. In addition satellite SST maps allow monitoring main spatio-temporal characteristics of mesoscale frontal features associated with the Curonian Lagoon coastal plume and coastal upwelling in the SE Baltic influencing coastal and lagoon ecosystems. The satellite infrared measurements and results obtained in near-shore waters in this study are unique and should be useful to researchers of near-shore water dynamics in other coastal regions of the world.

1. Introduction

Shallow coastal lagoons are relatively small water bodies providing essential buffering and filtering functions as mediators between terrestrial ecosystems and the open sea. They also are very sensitive to climate changes especially in the Baltic Sea which is known as one of the most sensitive seas in the world (Leppäranta and Myrberg, 2009). One of the key physical parameters defining the hydrological and ecological states of lagoon waters is the sea surface temperature (SST). SST directly reflects atmospheric and climatological forcing and, in turn, is a driver of regional weather and climate (Crosman and Horel, 2009; Oesch et al., 2005).

The main problem encountered in a variety of water temperature studies is the lack of monitoring stations and buoys that result in both spatial and temporal gaps in SST records. This is particularly true for the Baltic Sea Curonian Lagoon, where the water temperature regime is not well documented, as all previous studies were entirely based on the analysis of annual and monthly averaged SST records derived from historical in situ measurements at several coastal stations (see e.g. Dailidienė et al., 2011a, 2011b). The available scarce amount of in situ data is not enough to understand the full picture of water dynamics and temperature changes in the lagoon. Furthermore, the Curonian Lagoon waters are shared by Lithuania and Russia and each state carries out the monitoring of its corresponding lagoon part independently.

Nowadays the above stated monitoring difficulties can be effectively solved with the help of satellite remote sensing which allows one to obtain spatially detailed, regularly and continuously repeated datasets for the Baltic Sea and its coastal lagoons. Satellite infrared (IR) radiometers provide high resolution and wide spatial coverage records of skin SST (SST_{skin}) uniquely resolving existing difficulties for monitoring the Curonian Lagoon with conventional in situ measurements.

There are many published papers analyzing satellite SST data sets for the Baltic Sea within particular topics on coastal water dynamics (Bychkova and Viktorov, 1987; Gidhagen, 1984; Horstmann, 1983; Kahru et al., 1995; Kozlov and Dailidienė, 2010; Kozlov et al., 2011; Zhurbas et al., 2004), river discharges to the sea (Horstmann et al., 1986; Siegel et al., 1999, 2005), climate change and related issues (Siegel et al, 2006; BACC Author Team, 2008; Lehmann et al., 2011). However, up to now there have been no readily available papers analyzing multi-year satellite SST data sets (for decades and longer) to document the water temperature regime in the Curonian Lagoon.

The aim of our study is to utilize SST records from the Moderate Imaging Spectrometer (MODIS) onboard Terra and Aqua satellites to investigate the water temperature regime of the Curonian Lagoon and to assess spatial, seasonal and interannual water temperature variations, as well as to monitor the interaction between the lagoon and the sea waters. In Section 2 the study site is characterized,

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while the description of the data and the approach used are given in Section 3. Results and discussion of the satellite SST validation and mapping in the Curonian Lagoon are adressed in Section 4 followed by the conclusions in Section 5.

2. Study site

The Curonian Lagoon is the biggest shallow lagoon in the Baltic Sea and all European seas. It is located in the SE Baltic and is separated from the open sea by the relatively narrow sandy Curonian Spit (0.5–3 km wide) and connected to the sea solely through the Klaipėda Strait at the northern end of the lagoon (Fig. 1, a). The lagoon is a terrestrial runoff-dominated system, and its hydrology is strictly related to the discharge from the catchment area. The surface area of the Curonian Lagoon is approximately 1584 km^2 with the longest and shortest axes of 93 km and 46 km correspondingly. The mean water depth of the lagoon is 3.8 m, and the maximum depth is 5.8 m only. The basin of the Curonian Lagoon contains about 6.3 km^3 of water. The volume of fresh water discharge from the Nemunas River and other smaller rivers is on average about 24 $km^3 yr^{-1}$ (Gailiušis et al., 2005). The lagoon water is hypereutrophic (Gasiunaitė et al., 2008) and its quality is controlled mostly by physical factors such as the water balance change, atmospheric dynamics, and water temperature regime.

The Curonian Lagoon has four hydrologically different parts. The first is a narrow, just 230–800 m wide and relatively deep (14–15 m deep) Klaipėda Strait in the northern part connecting the lagoon with the Baltic Sea and serving as the only exchange gate between saline sea and fresh lagoon waters. The second is a relatively shallow (~2 m deep) Northern or transit part with hydrological regime influenced by surface runoff waters passing seawards and inflowing sea water. Next is the Central part where the Nemunas River discharges (land runoff flow rate 24 $km^3 yr^{-1}$). This part is characterized by high water depth variation within the shallow 2–3 m deep Nemunas delta and small-sized dip of 5.8 m depth. The fourth, relatively deep (3–5 m deep) and also the biggest is the Southern part, also called limnological part, because the hydrological regime here is similar to a lake.

Due to its shallowness the Curonian Lagoon is well mixed and the vertical water temperature stratification is weak. The most significant factors affecting the water temperature regime are incoming solar radiation, freshwater and marine water inflows.

Eutrophication is the main problem in the Curonian Lagoon, despite that it has slowed down recently. For several decades there had been continuous attempts to reduce pollution in the lagoon, however, the water temperature rise associated with climate change naturally increases biological contamination and reverses the decline of eutrophication (Razinkovas et al., 2008; Dailidienė et al., 2011b).

3. Data and approach

3.1. Satellite data

In this study sea surface temperature of the Baltic Sea Curonian Lagoon is examined in the period between 2000 and 2011 yr using primarily MODIS Terra imagery. MODIS Aqua data were also used for comparison with oceanographic buoy measurements. MODIS Terra/Aqua Level 2 daytime (MODIS thermal bands 31 (11 μ) and 32 (12 μ) imagery (L2_LAC_SST product) covering the study site with spatial resolution of about 1 km (Brown and Minnett, 1999) were obtained from the NASA OceanColor website (http://oceancolor.gsfc.nasa.gov/). There are typically one to three MODIS Terra observations of the study region occurring between 9 and 12 UTC corresponding to between 11 a.m. and 1 p.m. of local time.

In our case we used a standard MODIS cloud mask encrypted in the Level-2 flags to eliminate cloud-contaminated pixels. Following the recommendations of the MODIS Oceans Science Team and conclusions made in e.g. (Reinart and Reinhold, 2008) the SST quality flags were not used here to define clear water pixels in the study area, as they incorrectly mask most of the lagoon waters and eliminate near-shore marine areas, e.g. during coastal upwelling events, resulting in lack of data coverage and overestimations for monthly means. The application of a cloud mask with additional visual inspection to remove unmasked cloud-covered scenes resulted in 7139 MODIS Terra images out of 8365 between March 2000 and July 2011. Fig. 1(b) shows a relative amount of cloud-free data available for the region of interest over the full study period. It is evident from Fig. 1(b), that average amount of cloud-free data for the open sea (20–22%) is almost twice higher than

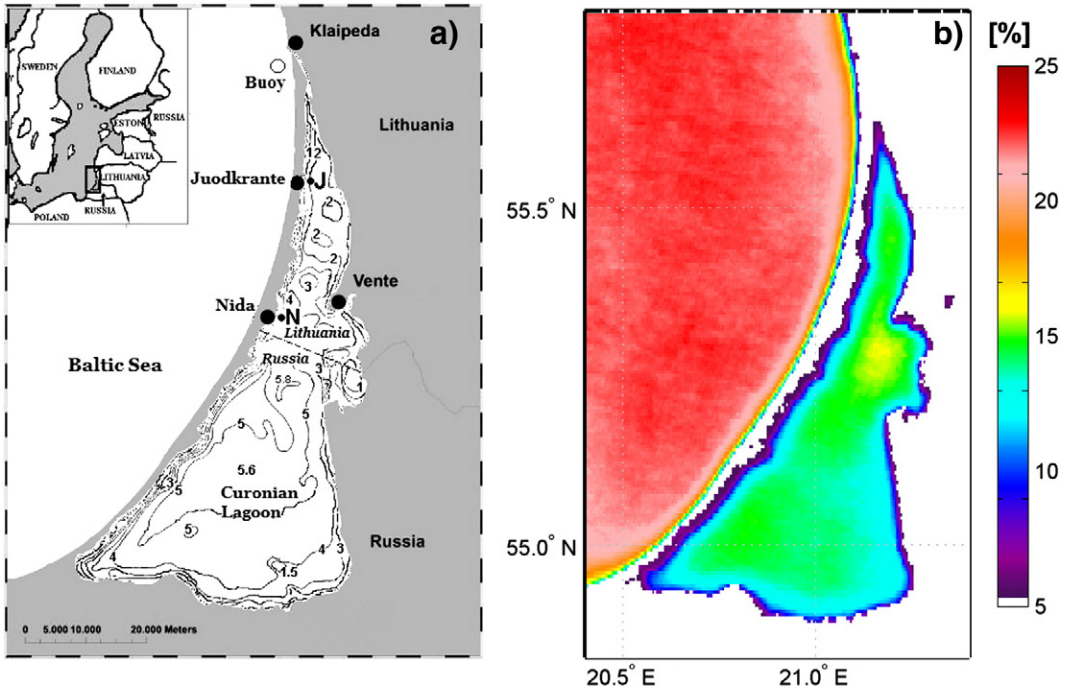

Fig. 1. (a) Map of the Baltic Sea Curonian Lagoon with bathymetry (m), marked locations of coastal stations in Juodkrantė and Nida, bulk temperature sampling points N and J, and oceanographic buoy (open circle). (b) Amount (in percent) of cloud-free SST data over the study area out of all 7191 pre-selected MODIS Terra images between March 2000 and July 2011.