Mapping ice cover dynamics in the Curonian Lagoon using remote sensing and geographic information system

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Abstract

This study aims to utilize remote sensing and a geographic information system (GIS) for mapping ice cover dynamics and the variability of ice cover season duration in shallow estuarine freshwater system – Curonian Lagoon, located in the south-eastern part of the Baltic Sea. High resolution synthetic aperture radar (SAR) images from three Earth observation missions (Envisat ASAR, RADARSAT-2, and Sentinel-1A and 1B) in combination with imagery from Moderate Resolution Imaging Spectroradiometer (MODIS) over the period from 2002 to 2017 were processed by manually digitizing ice polygons using ArcGIS software. Cartographic maps were generated of the ice cover season duration and freezing and melting patterns. Results shows that ice season is tending to get shorter, with eastern and southern sections of the lagoon being covered by ice longer than the northern and western sections of it. In 60 % of the cases ice cover formation properties are observed firstly in the satellite image then at the coastal stations. Ice cover extent corresponds very well with in situ data (R=0.92). The study confirms the importance of coupling remote sensing with GIS for mapping and understanding the dynamical processes of the ice cover.
Keywords: ice, mapping, remote sensing, GIS, Curonian Lagoon.

1 Intorduction

Curonian Lagoon (CL) is located in the south-eastern part of the Baltic Sea (BS), connecting to it by a narrow strait and separated from by a sandy spit. This lagoon is occupying an area of 1586 km^2, making it the largest lagoon in Europe, for which of particular importance is ice phenomenon majorly impacting the ecosystem of the lagoon by altering the hydrodynamical processes, light climate, and gas exchange between water and the atmosphere.

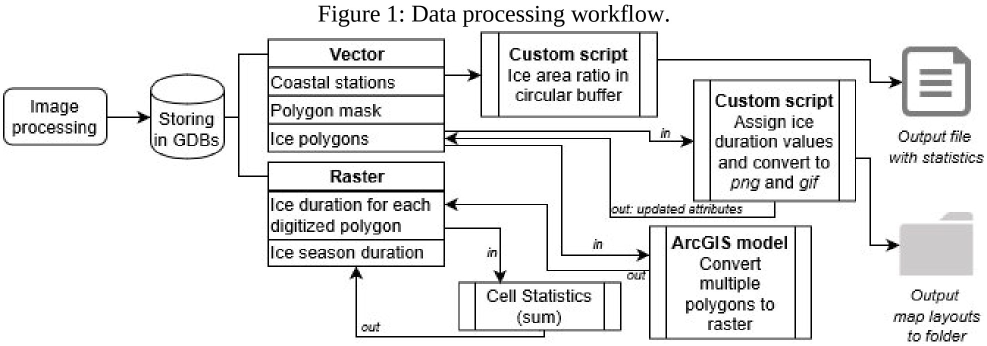
The previous studies of the ice cover in the CL were carried out by analysing only the observational data (Baušys, 1978; Bukantis et al., 2007; Rukšėnienė et al., 2015), which are particularly limited in space and cannot create a general view of what processes occur on the whole lagoon surface. The major objective of the present study is to map ice cover spatio-temporal dynamics and ice season duration variability in the Curonian Lagoon using remote sensing and GIS.

2 Materials and methods

In this study we analysed the 15 winter period from 2002 to 2017 using satellite data derived from SAR measurements from three Earth Observation Missions: Envisat ASAR, RADARSAT-2, Sentinel-1A and 1B, as well as spectroradiometer MODIS on board Terra satellite. A total of 615 satellite images were processed.

The ice edge was manually digitized in polygon feature classes using ArcGIS software, which were saved in file geodatabases (Fig. 1). A fixed spatial extent processing mask was applied to delimit the area of interest (corresponding to the area of the lagoon). A custom Python script tool was created for exporting map layouts of separate ice polygons and converting them to gif files for better visualisation of the spatial distribution and dynamics of the ice cover. For each polygon was assigned its duration value based on the dates between satellite images, converted to raster datasets, and cell statistics function was applied to generate ice cover duration raster datasets for each winter. The point geographic locations

Figure 1: Data processing workflow.



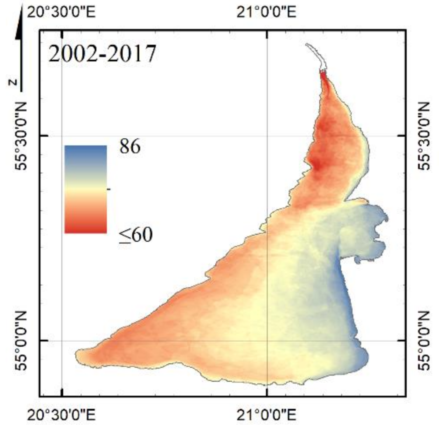
of coastal stations were created for comparison with satellite data by considering ice concentration in circular buffers centered around ground stations. The radius of each buffer was set to the visibility value recorded on each day during the time when the ice observations were taken.

3 Results

CL is fully covered with ice every winter, which formation occurs very quickly (in a matter of days). Satellite data corresponds very well with coastal observations over a long period of negative air temperatures (R=0.92), and most of the discrepancies occur during the melting period, when the ice is drifting. The average ice period in the lagoon is 86 days (the shortest 45, the longest 134 days) and it is showing a tendency to shorten. Upon all ice formation properties: freeze onset (FO), full freezing (FF), melt onset (MO), and last observation of ice (LOI), only MO shows a statistically significant decreasing trend (p=0.02), leading toward an earlier ice break-up along with the overall rise of air temperature.

The GIS analysis showed that ice cover first begins to decay in the northern part of the lagoon (Figure 2), due to the interactions with saline water from the Baltic Sea and the freshwater outflow from the Nemunas River Delta in the central part. Ice usually begins to retreat from the western coast of the lagoon to the eastern, south-eastern coast due to prevailing westerly winds. There were also several episodes where two satellite images were received on the same day (in the morning and in the evening) showing ice floes drifting to the north, with a prevailing speed of 0.003 to 0.14 m/s. Our obtained results of ice regime and trends coincide very well with other ice cover studies in the Gulf of Riga (Siitam et al., 2017) and Vistula Lagoon (Chubarenko et al., 2017).

Figure 2: Yearly-mean ice season duration in the Curonian Lagoon as derived from satellite data in 2002-2017.



Overall, remote sensing has a better performance over coastal ice observation records in defining all 4 stages (FO, FF, MO, and LOI) of ice formation in the CL, having a mean satellite observations success rate of 60%, which means that in more than half of the cases ice cover properties were first observed in satellite images. It has a better performance when defining FF and MO dates (success rate of 62% and 75% respectively) while similar or slightly worse results relative to *in situ* records are obtained for LOI and FO dates (success rate of 55% and 36% respectively). It is evident that increased number of available sensors and their measurement capability over particular region is of great importance for the accuracy of defining the FO, FF, MO, and LOI dates.

4 Conclusions

In this study, we showed how GIS can be used to process and analyse satellite data to investigate ice cover phenology over the entire surface of the CL. The digitized ice polygons and raster datasets show a tendency of decreasing ice cover season with melting starting in the northern part of the lagoon, while remaining the longest in the eastern, south eastern coastline. High frequency of satellite data provided a perfect chance to evaluate the drift speed of ice floes, which were found drifting northward with the velocity of 0.003 to 0.14 m/s.

In 60% of all cases of ice cover formation properties (FO, FF, MO, and LOI) satellite data has an advantage over coastal observations. To increase the ability to identify the timing of these processes a high temporal image resolution is required.

In future research, this digitized ice polygon data converted to grid points will be used for numerical modelling of hydrodynamic and ecological processes affected by ice cover and its duration in the Curonian Lagoon.

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