dr inż. Tomasz Dąbrowski

Galway, Ireland, 04.10.2019

O C E N A

Rozprawy doktorskiej mgr Artura Nowickiego ……..

pt. „Międzyletnia zmienność przybrzeżnego upwellingu w Bałtyku na podstawie modeli numerycznych oraz danych satelitarnych"

„Interannual changes of Baltic coastal upwelling based on numerical models and satellite data"

The coastal upwelling is a phenomenon during which water from deeper layers of the water column is lifted up to the surface. It is driven by a combination of the Coriolis force and a drag caused by the wind. The net transportation of water in the layer of a specific depth is perpendicular to wind direction. It is called the Ekman transport and this layer is the Ekman layer (Ekman 1905). According to Ekman theory, it is directed to the right on the northern hemisphere and to the left on the southern hemisphere. If the wind blows in the right direction, parallel to the coastline and stable conditions exist long enough, the water from the Ekman layer is pushed away from the coast. Waters from deeper layers are transported to the surface. This cooler and usually rich in nutrients deep water replenishes the euphotic zone stimulating the growth of primary producers, often resulting in rapid phytoplankton blooms.

The Baltic Sea is prone to frequent upwelling events due to its relatively small size with irregular and complex coastline. This enables winds blowing from any direction to result in coastal upwelling events. Moreover, the Baltic Sea is strongly stratified throughout summer and autumn and thus upwelling events may result in very significant changes to sea surface temperatures and nutrients and oxygen concentrations. The upwelling events may also be strong drivers of cyanobacteria blooms, which have significant socio-economic impacts and to which the Baltic Sea is particularly prone.

It should be noted that the topic of mgr Artur Nowicki's PhD thesis is very interesting and timely. Mgr Nowicki employed innovative tools in the form of a state-of-the-art numerical model supported further by remotely sensed data in his research. The developed automated method for upwelling detection implemented in the 3D CEMBS model by mgr Nowicki has a great potential to augment further research not only on upwelling events in the Baltic Sea, but on wider eco-hydrodynamics of the Baltic. It will also be a very informative and practical tool for the end users of the 3D CEMBS system.

The presented material, and in particular 4 x peer-reviewed scientific papers indicate a very good knowledge of the subject matter as well as advanced technical skills required to develop the tools that enabled the analysis. The thesis is very well structured and is pleasure to read.

The doctoral dissertation of mgr Artur Nowicki titled „Interannual changes of Baltic coastal upwelling based on numerical models and satellite data" was carried out at the Marine Ecohydrodynamics Laboratory of the Institute of Oceanology of the Polish Academy of Sciences, Sopot, under the supervision of Prof. dr hab. Lidia Dzierzbicka-Głowacka in the OECD field of Earth and related Environmental Sciences – Oceanography.

Presented research was conducted using advanced innovative tools comprising of an existing numerical model of the Baltic Sea, namely the 3D Coupled Ecosystem Model of the Baltic Sea (3D CEMBS), based on the Community Earth System Model (CESM), as well as using the satellite data available from SatBałtyk platform.

Review

The doctoral dissertation of mgr Artur Nowicki comprises of four peer-reviewed journal publications. Three of these publications focus on the description of the data assimilation method implemented by the author to 3D CEMBS system and the resulting improvements to the predictive skill of temperature and salinity in the Baltic Sea. Fourth publication deals directly with the subject matter of the dissertation. The journals are all JCR indexed and have moderate IF in the field, ranging between 1 and 2.

All publications included in the dissertation have been co-authored by other collaborators with **mgr Nowicki** as the lead and **first author** contributing with **c.75%** to the presented work. The co-authors were mostly the scientists working at IOPAN, however, some publications included also oceanographers working at Maritime Institute, Gdansk. The presented research involved the use of all modern tools available nowadays to physical oceanographers, namely, data from in-situ measurements (used for the validation), remotely sensed data (used for both assimilation, validation and upwelling detection) and a numerical model, an advanced mathematical tool that not only can significantly aid research on ocean dynamics, but can also be used as a predictive tool.

The publications comprising mgr Nowicki's dissertation have already been peer-reviewed by experts in the field. I therefore refrain from providing an additional review of same. My review will comprise of an opinion whether the publications comprise a coherent thesis, whether the subject of the dissertation has been addressed and if the dissertation meets the standards required from doctoral dissertations.

The doctoral dissertation submitted by mgr Artur Nowicki comprises of: 1) the list of abbreviations, 2) the English and a Polish abstracts with the following sub-headings:

- Introduction
- Materials and methods
- Results and discussion
- Conclusions

3) the list of references, 4) the list of attached research papers, 5) re-prints of published 4 x peer-reviewed papers, 6) authorship statements and 7) acknowledgements.

The literature review

The introduction section that comprises 2 pages, as well as the introduction to #4 research paper presents the following:

a) The definition of coastal upwelling

b) The characteristic of the Baltic Sea basin that makes it particularly prone to the phenomenon of coastal upwelling

c) Characteristics and previous studies on coastal upwelling in the Baltic Sea

d) Brief of overview of previously published methods of automatic coastal upwelling detection

e) High level overview of implemented methods and materials

One shortcoming that the reviewer can identify and that would make the literature review more comprehensive and also interesting to the reader, is a more in-depth information why we should study the coastal upwelling systems. Also, what the most known coastal upwelling regions in the world oceans are and what typical socio-economic and environmental implications coastal upwelling may lead to. This ideally, should be followed by an overview of typical coastal upwelling locations in the Baltic Sea, e.g. broader presentation of the analysis carried out by previous authors.

Furthermore, in the opinion of the reviewer, this section, although adequate and to the point, calls for more detailed overview of previous research in the area, as detailed in the question below and can be considered a weakest link in otherwise a very solid dissertation. It leaves the reader with an appetite for learning more about various coastal indices and their accuracies that were developed by researchers worldwide.

Aim of the doctoral dissertation

The main aim of this doctoral dissertation is the analysis of „interannual changes of Baltic coastal upwelling based on numerical models and satellite data". Ten areas prone to coastal upwelling were selected for the analysis, 1 area on the Polish coast, 4 areas along the south-eastern coast of Sweden, 2 in the Gulf of Bothnia, 2 in the Gulf of Finland and 1 in the Gulf of Riga. It is nice to see a good geographical spread of the selected areas, which are expected to exhibit coastal upwelling under various wind conditions.

Advanced tools available nowadays to oceanographers were selected in the study. These comprise of:

a) A numerical model 3D CEMBS that is run operationally at IOPAN
b) Satellite SST data available from "SatBaltyk" platform operated by IOPAN
c) Advanced statistical methods
d) Data assimilation to numerical models

Moreover, the candidate included a more historical method of detecting coastal upwelling in his research, based on favourable wind conditions, that according to Ekman theory, are likely to induce coastal upwelling.

Substantial part of the presented PhD research comprised of the development of a data assimilation module for 3D CEMBS. The candidate developed and implemented the satellite SST data assimilation scheme, based on Cressmann method. It is a relatively simple DA scheme, however, the choice of the scheme is largely determined by the efficiency of the computations. Other most commonly used DA methods are listed by the candidate. Three of the attached publications present the implementation of DA to 3D CEMBS and resulting impacts on both the surface and vertical distributions of temperature and salinity. It should be noted that it is an important development leading to an improvement in the prediction of temperature in the region and thus is a prerequisite to successful development (in terms of its accuracy) of the coastal upwelling detection tool.

The number of predicted coastal upwelling tools by 3D CEMBS were then compared against those detected from the satellite SST and several advanced statistical methods were applied by the candidate in order to assess the skill. These were based on the assumption that coastal upwelling can be treated as a binary classification problem. It is an interesting read and the candidate is to be congratulated on the choice of yet another advanced tool applied in the presented research. Good understanding of each of the 6 statistical measures presented is demonstrated and the results are adequately discussed.

Questions to the candidate:

- The aim of the dissertation is to investigate interannual changes in coastal upwelling events. The candidate is asked to elaborate if the time period is sufficient for

discussing interannual changes and what interannual variability in atmospheric conditions were observed in the time period 2010-2016? Does the time period used in the analysis capture the years with prominently different conditions?

- The reviewer did not check the references cited in the dissertation, but it is understood that the presented method of coastal upwelling detection was firstly proposed for the Baltic Sea by Lehmann et al. (2012). Can the candidate explain the origin of the threshold of 2 degrees Celsius – how was this value derived? Is it perhaps arbitrary? Was this proposed by Lehmann et al. (2012) or was it proposed by the candidate? Were there any sensitivity studies carried out using various thresholds either by the author or by other researchers?

Results and discussion

This section of the dissertation can be divided into two distinct parts, namely the results related to the improvement of the 3D CEMBS model thanks to data assimilation and results related to the coastal upwelling analysis, which is the actual main aim of this doctoral dissertation.
In Table 1, p.13, the candidate presents the statistics that are measuring the skill of MODIS satellite SST and 3D CEMBS SST against in-situ measurements downloaded from ICES database. These results are interesting for two reasons. First of all, they clearly show the improvement of the representation of SST in the model following the assimilation of MODIS SST. Some further text on pp. 12-13 also confirms the improvement of SST representation in the model against MODIS, indicating that DA was implemented successfully. The second reason is that it can be noted that, based on the presented values of R, the absolute mean error and the standard deviation, MODIS data appears to have:
- nearly identical value of R compared to the model
- significantly greater absolute mean error
- very similar value of standard deviation
when compared to the model **without data assimilation.**
The above metrics for the model with data assimilation improve further, however, the main reason is that MODIS SST overpredicts SST when compared to in-situ data whereas the model underpredicts and thus after the assimilation the model is brought closer to in-situ.

Question to the candidate: Based on the above, can you comment if MODIS SST was actually a good dataset for the assimilation to 3D CEMBS? Would MODIS SST still be used for assimilation if the statistics presented in Table 1 were computed beforehand?

Further analysis of vertical profiles of salinity and temperature reveal that overall these are represented well by the model, however, some differences exist especially around the locations of sharp gradients. The candidate postulates that an increase in vertical resolution may help to overcome this defficiency.

Question to the candidate: The reviewer notes that the results presented in Fig. 10 and 11 of paper #3 combined with the negative absolute mean error in SST in the model also suggests excessive mixing in the model. Can the candidate comment on this? What is the turbulence mixing scheme used in 3D CEMBS? Is it possible to reparameterize the existing scheme or test another scheme?

Further results presented in the dissertation concern the study of coastal upwelling frequencies and interannual variability. In general, the upwelling regions detected from the model output and from the satellite are in good agreement as well as with the areas reported by previous researchers. The frequencies of upwelling were generally higher than those obtained from the model, though, with average difference of 5.6 percentage points (pp). The highest discrepancies were observed near the Polish coast (12 pp, area 1 on Figure 3). The author then discusses the interannual variability in the frequency of upwellings, breaking down the analysis also to monthly mean frequencies. Geographical distribution of the upwelling frequencies is also discussed. Obtained results indicate some variability in the frequencies with some areas showing more and other less variability.

The candidate also carried out the analysis of upwelling frequencies detected using the wind data obtaining high correlations with the percentage of upwelling frequencies detected from the satellite (Table 1 in paper #4). For most of the locations the obtained percentage is closer to that from the satellite compared to the model.

Can the candidate comment on this result? Did other researchers studying coastal upwelling in the Baltic Sea obtained similarly high success rate using the wind based index only?

An interesting part of the presented results is the application of advanced statistical analysis based on the binary classification method. The presented results indicated that the tool has much higher skill in detecting non-upwelling days than upwelling days (e.g. lower TPR and PPV compared to higher TNR and NPV). An interesting finding is a high value of accuracy (ACC) followed by the report on low value of F1-score. The candidate indicates that the F1-score is much better suited as a metric for assessing the skill of the upwelling detection tool.

Question to the candidate: The reviewer is not a statistician and since the meaning of TPR, TNR, PPV, NPV and ACC can be relatively easily derived from the provided equations, the practical meaning of F1-score is more complex to grasp. The candidate is kindly asked to explain the meaning of the value of F1-score of 0.57 in simple terms to a non-expert user of the coastal upwelling detection tool.

Finally, the developed upwelling detection tool was included on the 3D CEMBS website (www.cembs.pl) allowing the users of the system to generate their own upwelling maps.

Conclusions

Mgr Artur Nowicki submitted a solid doctoral dissertation that presents the method and the tool along with scientific developments in the form of data assimilation that enabled to investigate the interannual variability of coastal upwelling events across various parts of the Baltic Sea.

It has been demonstrated that a simple Cressman assimilation scheme can be an effective method to improve the model skill in terms of predicted SST, which further translates also to better representation of temperature and salinity vertical profiles, which in turn will lead to more accurate representation of water circulation in the Baltic basin, including better representation of coastal upwelling. The presented doctoral dissertation demonstrates successful implementation of the Cressman scheme.

The candidate then used this model, along with the satellite data (and wind data), as a base for the detection of coastal upwelling events. The statistical analysis presented in the dissertation indicate that the tool is capable of detecting upwelling events with satisfactory accuracy. One very useful aspect is that it is an automated tool forming part of an operational forecasting 3D CEMBS system and is available online to the end users.

The interannual variability in upwelling frequencies were discussed as well as some deficiencies of the method, e.g. underperformance along the Polish coast, along with possible reasons, e.g. configuration of the model, vertical levels representation.

Future research was also proposed, namely on fine tuning the method (i.e. adjusting the threshold), reconfiguration and reparameterization of the model. Trends in coastal upwelling frequencies were also analysed, however, as rightly pointed by the candidate the analysed time period 2010-2016 is too short to enable meaningful trend analysis.

Future studies on the improvement of the tool as well as multidecadal trend analysis will, in the opinion of the reviewer, constitute an interesting future research and the candidate laid solid foundations and made significant contribution towards enabling such research.

Summarizing, the scientific achievements of mgr Artur Nowicki are significant and include:

- **4 peer-reviewed publications** in JCR journals with moderate Impact Factor in the field as **the first author**

- **10** further **journal publications** as a **co-author**

- **5** publications in **conference proceedings** as a **co-author**

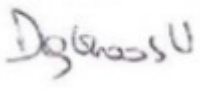
- Successful demonstration of **advanced skills** enabling **research of cross-disciplinary nature**, namely cutting across oceanography, mathematics, programming and IT technology

Final comments and recommendation

Summarizing my review of the presented doctoral dissertation of mgr Artur Nowicki, I am of the opinion that the presented outcomes from the research constitute a significant input to the development of the field of oceanography and the Baltic Sea research and as such meets the requirements of „Ustawa o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki" (Dz.U. z 14 marca 2003 r. Nr 65, poz. 595) and therefore I am submitting my recommendation to the Scientific Council of the Institute of Oceanology of the Polish Academy of Sciences to proceed to the final stages of mgr Nowicki's doctoral study.

Notwithstanding the questions raised in this review that I would like to see addressed by mgr Nowicki, I am of the opinion that the presented doctoral dissertation is of high quality, significantly contributes to the scientific research in oceanography and to the Baltic Sea research and also resulted in the development of a practical tool for end users of 3D CEMBS platform enabling both further research and dissemination of information to variety of end users. The scientific achievements by mgr Nowicki are also impressive with the total of 19 publications in peer-reviewed journals and conference proceedings, with 4 high quality peer-reviewed publications as a first author. In my view, the candidate demonstrated solid theoretical knowledge of the subject as well as the possession of skills necessary to implement research of inter-disciplinary nature and using advanced tools.

I am therefore submitting my recommendation to the Scientific Council of the Institute of Oceanology of the Polish Academy of Sciences **to award a distinction to mgr Artur Nowicki doctoral dissertation.**



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