RadClim BSR – En högupplöst nederbördsklimatologi baserad på Radarmätningar för Östersjöregionen

RadClim BSR – Towards a High-resolution Radar-based Precipitation Climatology for the Baltic Sea Region

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Abstract

Archived radar data has various applications, though it is often underutilised. Nevertheless, this information has the possibility to aid in the development of accurate and relevant climate adaptation tools, inform climate-resilient urban development strategies, and numerous other personal and societal applications. Our work in the RadClim Baltic Sea Region (BSR) project established the potential features, user demand, and feasibility of developing a high-resolution radar-based precipitation climatology (RPC) in the BSR through a user needs survey. This survey was distributed to various user groups in Sweden, Estonia, and Poland in native languages to maximise participation, and revealed that a strong majority of respondents felt their work would benefit from using data provided by an RPC. Consultations with the national weather services in these countries, as well as those in Germany and Finland, the latter two countries representing the current state of the art in this field in Europe, aided in ensuring best practices were adhered to. Ongoing national work related to high-resolution radar-based datasets and tools, and the utility of the existing data across the partner countries and the BSR, in general, were also investigated.

Sammanfattning

Arkiverade databaser med radardata har flera användningsområden, men ännu är dessa underutnyttjade. Dessa databaser har möjlighet att bidra till utvecklingen av korrekta och relevanta verktyg för klimatanpassning, informera om klimattåliga stadsutvecklingsstrategier och många andra tillämpningar för samhället. I vårt projekt RadClim Baltic Sea Region (BSR) undersökte vi användarnas efterfråga och behov av att utveckla en högupplöst radarbaserad nederbördsklimatologi (RPC) i BSR. Undersökningen distribuerades till olika användargrupper i Sverige, Estland och Polen på deras modersmål för att maximera deltagandet, och visade att en stor majoritet av de svarande ansåg att deras arbete skulle gynnas av att använda data som tillhandahålls av en RPC. I samråd med de nationella vädertjänsterna i dessa länder, liksom de i Tyskland och Finland, de två sistnämnda länderna representerar den nuvarande state of the art på detta område i Europa, bidrog till att säkerställa att bästa praxis följdes. Pågående nationellt arbete relaterat till högupplösta radarbaserade dataset och verktyg, och nyttan av befintliga data i partnerländerna och BSR i allmänhet, undersöktes också.

Keywords: Radar-based Precipitation, Climatology, Baltic Sea Region

INTRODUCTION

Baltic Sea Region Information Gap

Spatiotemporally high-resolution radar data capture precipitation information in real-time, being more comprehensive than common datasets using station observations only. Radar data are available in most of Europe, yet the potential for radar-based precipitation climatology (RPC) is hardly exploited in most countries. This especially relates to localised, short-term intense precipitation events typical of the summer season. These events cause a majority of precipitation-related damages and are projected to increase in frequency and intensity with advancing climate change in the Baltic Sea Region (BSR) (Madsen et al., 2014; Olsson et al., 2019; Olsson et al., 2022; Hosseini et al., 2023). Cities are specifically susceptible to flash floods occurring with little warning due to outdated drainage systems and increases in impermeable surfaces.

Recently, archived datasets were processed in some European countries to form radar climatologies. For example, there is now an established operational, partially bias-corrected radar climatology in Germany, updated in real-time, covering more than 20 years of data (Winterrath et al., 2017; 2019; Kreklow et al., 2020). Despite the benefits of such datasets, most countries in the BSR have yet to utilise their existing radar data to produce national or transnational RPCs. When developed, these datasets would have broad utility. They could be applied to disaster management and planning strategies in municipalities to reduce climate risks and be applied in real-time for disaster management purposes - saving lives and properties. The data would also allow for the development of intensity-duration-frequency (IDF) curves even in areas that don't have rain gauge data, which is used extensively in the insurance industry.

Importance of Trans-national Cooperation

A trans-national (and trans-sectoral) approach to developing RPCs will create synergies between the different countries (and actors) and will enable them to learn from each other, foster new collaborations and give the varied perspectives that will be necessary to establish a baseline for stakeholder need, and ultimately improve the final product. Additionally, a transnational approach will allow for building on the knowledge and successes of expert institutions like Deutscher Wetterdienst (DWD), which as noted previously has already developed its own RPC, as well as the Finnish Meteorological Institute (FMI), with its advanced research into constructing realistic IDF curves by utilising radar data.

In the project, institutions from Estonia, Poland and Sweden acted as country coordinators, reaching out to various actors within their respective countries (policy representatives, engineers, and especially key

stakeholders in municipalities) to explore what radar climatology data they need, in which complexity and format, and how they would be able to utilise these data. This trans-national cooperation allowed for the exploration of whether similar actors from different countries had comparable or different needs, and how an optimal product useful for a large range of users located in different countries could be developed. Consulting stakeholders in the BSR countries raised awareness and created interest in radar data use and should allow for the co-development of use strategies, allowing for a wide-spread application of the RPC once developed. This also lays the foundation for later integration of such data into national, regional, and local policy, where it can have a positive societal impact.

Key Players in the Radar Climatology Field in the BSR

The project idea originated from feedback from various actors, mainly working in municipalities across the BSR concerned with city planning, emergency services and disaster prevention, sewage management, climate adaptation, and others (Hoy et al. 2024, submitted). These actors required spatially high-resolution precipitation information to be applied in their field of work, only to find there were often just a few individual datasets (only valid at the exact location of the rain gauge), if any, available in their city, municipality, or region. With increasing intensity and frequency of short-duration extreme precipitation events, often leading to urban flooding, concerns among city officials as well as private and commercial actors are on the rise.

Such concerns and the need for better data availability have previously been flagged by radar experts in BSR countries (EE, SE, PL, FI, DE), e.g., in the frame of the European OPERA radar network (Köck et al., 2000; Holleman et al., 2008). This network currently focuses on real-time provision of radar data, principally for case-study assessments of previous weather events. Yet, radar data biases within the national datasets prevent applying the data from OPERA for use as required by the municipal actors previously noted. Following the lead of DWD in Germany, the project aimed to address these challenges, supporting a future radar climatology relevant to all contexts in the BSR.

Ongoing Developments of Radar Products in Europe

National Scale: Only one publicly available, operational radar climatological dataset exists in the BSR; operated by DWD with data going back to 2001 (DWD, n.d.). It has enhanced understanding of the damage potential and implications of extreme precipitation events to the public and infrastructure, thus supporting city planners and adaptation measures. SMHI in Sweden currently utilises a radar-rain gauge merged product named HIPRAD operationally (Berg et al., 2016), though this product is not publicly available. Polish National Meteorological and Hydrological Service (IMGW) operationally generates multi-source precipitation estimates as 10-min and longer accumulations using RainGRS system (Jurczyk et al., 2020). The products are available publicly. Additionally, the climatological version of the system, named RainGRS Clim, is generating daily and monthly accumulations after reanalyses, consisting mainly of the incorporation of data from high-quality manual rain gauges (Jurczyk et al., 2023), but it is not publicly available yet. The radar-based products of FMI (like other weather services) focus on the nowcasting of severe storms. They developed specific AI-supported products informing their clients of impacts from precipitation events in real-time (Punkka et al., 2023). More recently, they have studied the precipitation microphysics related to dual-pol observations in order to improve the radar retrievals for estimating precipitation rates, which is beneficial for hydrological planning.

International Scale: OPERA, the EUMETNET radar programme, enables radar data exchange and provides European-wide radar composite products, currently every 15 minutes with 2 km spatial resolution. Inside OPERA, radar experts collaborate in operational and scientific topics, including work on a unified data model to share radar data (HDF5 ODIM) (Saltikoff et al., 2019). In the current OPERA phase, the programme focuses on replacing the old data centre, targeting the products to a wider range of

end-users, e.g., providing 5-minute radar composite with 1 km spatial resolution for nowcasting purposes. Another European project, EURADCLIM, aims to overcome some of the shortfalls of OPERA radar composites. For a 7-year historical time frame (2013-2019), sub-daily radar precipitation climatologies were produced, and exploratory work was done on merging rain gauge datasets from the ECA&D dataset with radar composites (Overeem et al., 2023). Finally, the BALTRAD project and its follow-up BALTRAD+ were implemented between 2009 and 2014 under the Interreg Baltic Sea Region (BSR) programme. The main objective of these projects, carried out with the participation of countries within the Baltic Sea basin, was primarily to establish an operational BALTRAD network for real-time radar data exchange (Michelson et al., 2018). The ODIM data model developed under the EUMETNET OPERA programme was applied to the data exchange. In addition, great emphasis was placed on ensuring the highest possible quality of the exchanged data. A toolbox of quality control (QC) tools was developed, which, in addition to being applied to BALTRAD data, is now also used for radar data collected by OPERA as well as by individual national radar networks.

Research Importance in the Scope of International Agreements

The UN Sustainable Development Goals for 2030 strive for actions to achieve a better and more sustainable future for all (UN General Assembly, 2015). RadClim BSR strongly supports goal 13 (Climate Action) by striving to provide essential climatological information regarding precipitation forming the basis for further action. With the envisioned RPC, RadClim BSR specifically aims to 1) help to integrate climate change measures, particularly those pertaining to the flooding risk, into national policies, strategies, and planning and 2) to improve education, awareness-raising, and human and institutional capacity on climate change induced flooding impact reduction and early warning.

The UN published the Sendai Framework for Disaster Risk Reduction in 2015. It outlines four priorities for action to prevent new and reduce existing disaster risks (UN Sendai Framework, 2015). RadClim BSR directly addresses the first priority of understanding disaster risk. In addition, the envisioned RPC will help partners in the BSR have a clear picture of the necessary adaptation measures to build resilience to these precipitation events in their society, contributing to their nationally determined contributions (NDCs).

Establishing use-case for a Baltic Sea Region RPC

The aim of the RadClim BSR project was to establish the use case for a high-resolution radar-based precipitation dataset and tool. Furthermore, it was intended to establish the demand for such a dataset and tool amongst relevant user groups across the BSR and to give a clear picture of the desired details therein, such as data types, temporal resolution and spatial resolution. In order to assess the willingness of relevant user groups within the BSR to utilise an RPC within their sphere of work, we undertook a user needs survey. In the following sections, we will outline how the user needs survey was executed and highlight important results which demonstrate the need for a trans-national RPC within the BSR.

METHODS

Survey Methodology

The user needs survey was developed using the input of all project consortium members. We used the output of a previous project that also used a survey to establish the user needs and demand for a climate tool as a baseline (ClimVis Europe; Hoy et al. 2024, submitted), strongly advancing from there. Once the final survey document in English was agreed to, translation to Swedish, Estonian, and Polish was undertaken to be distributed in Sweden, Estonia, and Poland, respectively (an English language survey was also distributed in Sweden). Attempts were made to bring Latvia and Lithuania into the project in order to have a truly pan-BSR user group, however these attempts were unsuccessful. The translation to native languages was intended to maximise user engagement with the survey. The target group of the survey was similar in all countries and focused on two key user types: individuals who are known to utilise and require precipitation data in their daily work (e.g.

meteorologists, hydrologists, etc.) and decision-makers in various sectors, particularly with links to hydrology or climate adaptation/mitigation topics.

Multiple methods of survey distribution were utilised to reach appropriate user groups of radar information. These included distributing the survey link via email to institutional contact lists, sending the survey to known relevant contacts of project participants in the respective countries, distributing the survey link to municipal or regional government authorities, and posting the survey link on relevant social media platforms.

The survey itself consisted of an assortment of open and closed questions, including several questions with multiple-choice answers. Closed questions were intended to allow for statistical analysis of survey results, while open questions were intended to allow respondents to articulate particular thoughts or perspectives that they had related to the posed question. The survey was made available on Google Forms, and all the results were downloaded via .csv files using MS Excel to filter and analyse the results. The survey was active in each country for a minimum of 6 weeks.

Figure 1. Countries involved in the project in green colours in the Baltic Sea region. Starting from north core partners Sweden, Estonia, and Poland in dark green and affiliated partners Finland and Germany in light green colours.

Data Archiving, Existing Datasets, and Ongoing National Level Radar Work

A clear understanding of the existing datasets and data archiving practices, as well as ongoing work at the national level around the development of radar-based tools or post-processed datasets, was pursued to ensure a clear understanding of the existing landscape in this space. Partners from national meteorological and hydrological service (NMHS) agencies covering much of the BSR were directly involved in assessing these points. Info on these topics was presented by representatives of the NMHSs at in-person meetings and then openly discussed with other participating members in order to identify any gaps in the existing landscape. This knowledge was invaluable in developing a user-needs survey that was relevant to the current radar data situation in the BSR, for example, allowing questions to be developed that could directly be turned into a specification in a future RPC. Coupled with the results of the user needs survey, this will allow for an efficient way forward towards developing the envisioned RPC.

RESULTS AND DISCUSSION

In total, 136 responses were received from the three core partner countries (see Fig. 1). The breakdown of responses by country is as follows: Poland – 84, Estonia – 30, and Sweden – 22. The survey respondents represent a valuable cross-section of users from across the landscape of climate-information users in terms of age, cultural backgrounds, and the type of institutions and sectors represented in the participating countries. Survey results were normalised to ensure consistency across the participating countries, and representative results, and 3-country averages were also calculated.

Key results from the study are indicated below:

- A strong majority of survey respondents indicated their work would benefit from using data

provided by an RPC. Respondents prefer that the information provided by a radar-based precipitation climatology be available as both imagery and numerical datasets.

- Respondents were more likely to indicate they have previously been impacted by short-duration heavy rainfall events than long duration preciptation events. The risk posed by short-duration heavy precipitation and droughts is overwhelmingly viewed by survey respondents as a growing risk.
- There is a slight preference for independent real-time and near real-time data provision (including short-term forecast and recent period accumulation) as opposed to comparing radar-based precipitation climatology to existing precipitation climatology datasets.
- Respondents would see gains from utilising the data from radar-based precipitation climatology in combination with better spatial descriptions, more accurate rainfall information, spatial planning and policies, risk assessments, etc.
- The highest resolution of data possible is desired by survey respondents. CSV is the overwhelmingly preferred technical format and shows that survey respondents continue to work mostly in Excel.

As previously indicated, the aim of the RadClim BSR project was to establish the use case for a high-resolution radar-based precipitation dataset and tool. The results of the user needs survey have provided this information and laid the foundation for proceeding with the future development of a trans-national dataset and tool in the BSR. Results from the survey that are of particular interest are discussed below.

Perceived Impact Areas

We wanted to know about the perceived impacts that would be caused by a heavy precipitation event in the users' region. Two main areas of impact became clear through the survey responses. A majority of respondents in all countries view urban flooding and damage to infrastructure as having an impact on their area. The high resolution of a RPC would be beneficial to users here as it would help better map risk areas related to these impacts. In addition, it is clearly short-duration precipitation events that are perceived to be driving the impacts (urban flooding and infrastructure damage). Of the impacts from long-duration precipitation events, damage to infrastructure

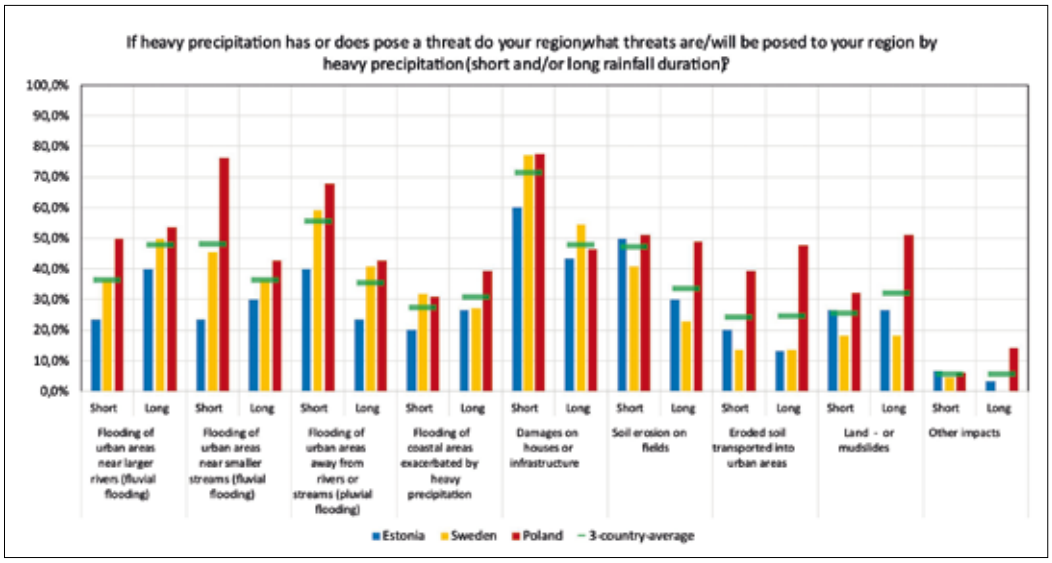

Figure 2. Survey responses to a question of threats that will be posed within users' regions by heavy precipitation from either short or long duration rainfall events.

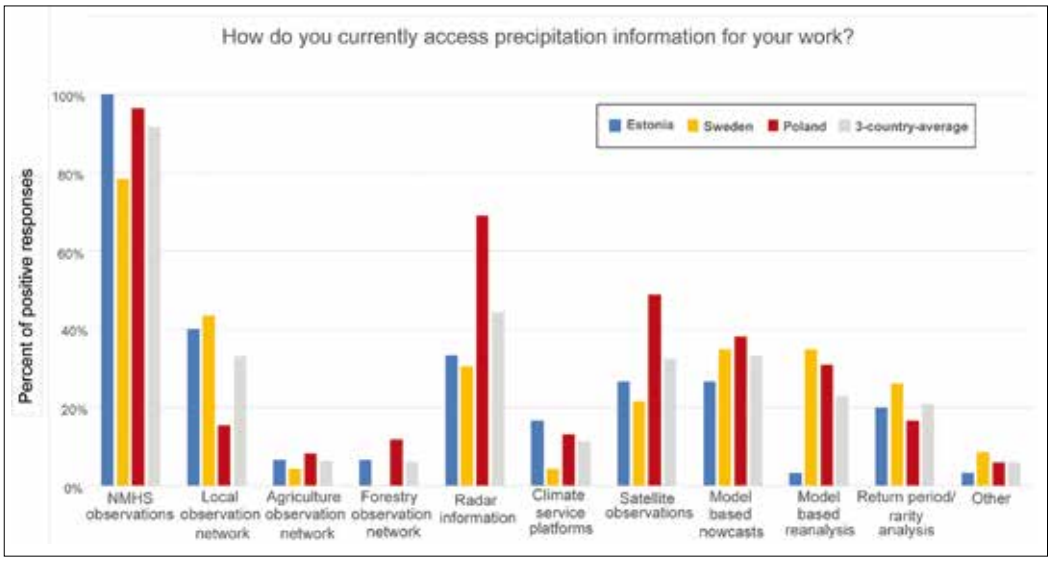

Figure 3. Survey responses to a question about how users currently access precipitation information within their area of work.

and fluvial flooding in urban areas are ranked highest. The takeaway is that the threat to the built environment is considered to be the biggest threat. Of course, this makes sense as water, research and development, and the public sector are often focused on and mandated to protect the built environment from damage. In addition, a separate survey question assessed respondents' views of the expected future occurrence of various types of precipitation events in their region. Here it was indicated that almost 90% of all respondents view that the occurrence of short-duration precipitation events will increase in coming years. Taken together, it is clear where the greatest impact area is anticipated to be.

Establishing a Baseline: Current Data Access

A baseline understanding of how users currently access precipitation data was established through the survey. This made it clear that precipitation observations from NMHSs dominate as the main source of information accessed in each participating country. Radar observations were the next most common source of precipitation information, however. The research team was surprised at how low the indicated use of return period/rarity analysis was. These types of statistical analyses of precipitation data are frequently used by practitioners in the meteorology and hydrology professions (Van den Besselaar et al., 2013; Poschlod et al., 2021), which were well represented among our survey participants. More probing questions would be needed to assess why this is the case, though the project team proposes that there is either a lack of this type of data in the BSR and/or that the data which do exist in this form are not easily accessible. Additionally, it is possible that practitioners have shifted to using different forms of data to provide them with the information they need.

Responsibility for Managing Heavy Precipitation Risk

The view of who is responsible for managing precipitation risk varies by country. In Sweden, the vast majority of respondents indicated that it was local-level administrations (either cities or municipalities) who hold this responsibility. However, in Estonia and Poland, the results show that this responsibility is a matter for the national-level administrations. This result serves as a reminder that bureaucratic structures differ from country to country. As such, firmly identifying at what level this responsibility sits should be addressed in the production of a transnational tool

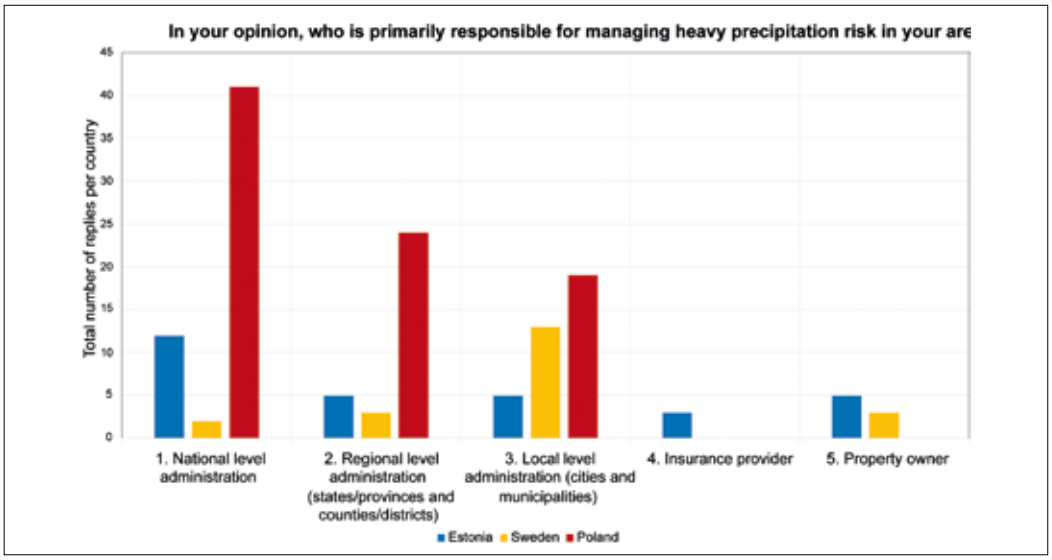

Figure 4. Survey responses to a question aimed at gaining insight into how users in the participating countries viewed primary responsibility related to managing the risk associated with heavy precipitation events in their country.

to ensure it will have utility across all countries in the BSR.

Knowledge of Existing Adaptation Measures to Combat Heavy Precipitation Risk in the BSR

Survey participants were asked to identify their awareness of various types of adaptation measures designed to cope with heavy precipitation events in their region or country. Through this, it was established that many adaptation measures are already in place across the BSR, with all types of adaptation measures inquired about in the survey scoring over 50% awareness in the 3-country average. These adaptation measures are flood barriers, maintaining a natural flood plain, nature-based solutions, improved flood warning systems, changed zoning regulations limiting buildings in flood-prone areas, and updated wastewater and stormwater handling systems. The survey results indicate that the highest awareness of existing adaptation measures of the participating countries is in Estonia, where across almost all of the categories, except for flood barriers (Estonia has no large or rapid response rivers) and improved warning systems, awareness was over 60%. There is still room for improvement regarding the awareness of heavy precipitation adaptation measures in the BSR however, as close to 30% of respondents (from the 3-country average) for each indicated adaptation measure indicated they 'didn't know' whether that particular measure existed in their regions/country or not.

Future Work

Three-country average for identifying what percentage of survey participants are responsible for the management of heavy precipitation observations, impacts, or response in their region was just 50%, though the Polish results are over 70%. This is a key user group for our intended dataset. Thus, future work should focus on ensuring the needs and requirements of this user group are evaluated and considered for the development of a high-resolution RPC.

CONCLUSION

A majority of respondents in the case study countries feel that the information provided by a high-resolution radar-based precipitation climatology would benefit their work. Through the survey, it was determined that both an interactive tool as well as the raw dataset underlying the tool should be accessible to users to aid in their work. Information provided by the

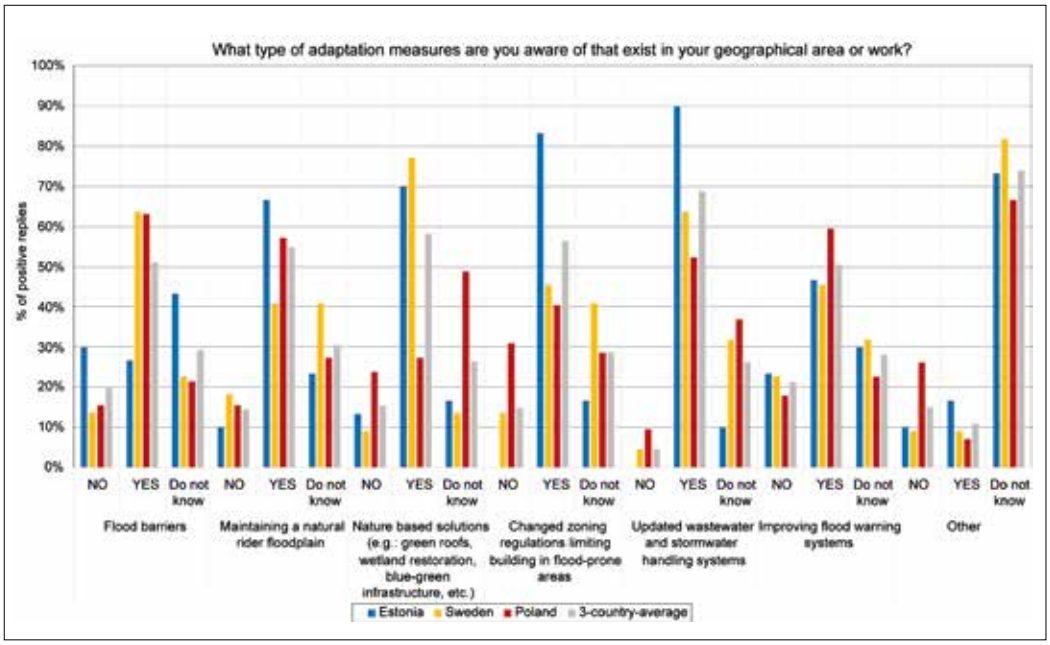

Figure 5. Users' responses to the question of what adaptation measures they are aware of that are currently in use in their country.

RPC should be at the highest temporal and spatial resolution possible in order to allow for assessment of impact from short-duration heavy precipitation events. These types of events were identified as having the highest impact both at the present time and into the future by survey respondents.

Future projects will focus on the full development of a high-resolution radar-based precipitation climatology (datasets and visualisations), which is updated in near-real-time spanning the BSR, relevant for a large range of actors.

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