5th Baltic Earth Conference in Jurmala, Latvia

Session Summaries

This document presents a very brief overview over the presentations in the oral sessions of the conference. Each session is preceded by a short session description, as given in the conference website. For a more in-depth look, refer to the abstracts in the Proceedings book, available vial the conference webpage https://baltic.earth/jurmala2024.

Session A: Biogeochemistry of the Baltic Sea – Linking observations and modelling (summarized by Juris Aigars)

Investigations on the marine and terrestrial carbon, nitrogen and phosphorus cycles and pathways towards an understanding of primary production mechanisms and organic matter transformations in the Baltic Sea; biogeochemical causes and effects of eutrophication, oxygen limitations and trace gas production, including microbiological processes; modelling approaches to explain observations and project future changes.

This session featured 7 oral presentations that tackled eutrophication, acidification, and coastal water light climate issues. The session started with a speech by **Sakari Väkevä** in which the use of Earth observation and modeling potential to assess vernal diatom-dinoflagellate blooms was explored. The session was continued by speech of **Adolf Stips et al.,** addressing the impact of sea ice on eutrophication level of the Baltic Sea. The sessions' eutrophication part was concluded by presentation given by **Lev Naumov et al.** in which response of Baltic Sea oxygen conditions were predictively modeled under Baltic Sea Action Plan Maximum Allowable (BSAP MAI) input scenario as well as half of BSAP MAI scenario.

In the second part of the session **Gregor Rehder et al.** gave an overview of scientific aspects of past and present acidification in the Baltic Sea as well as reviewed existing monitoring possibilities. Thereafter, **Katarzyna Koziorowska-Makuch et al**. presented results of study of seasonal and interannual variability in Vistula river. The following presentation by **Karol Kuliński et al**. explored possible impact of Baltic Sea water acidification on boron concentration in cod otoliths.

In the concluding presentation of the session the **Natalija Suhareva et al**. introduced approach where in-situ observations were combined to remote sensing and modeling results to assess 20-year coastal water darkening trend.

Session B: Natural hazards and extreme events (summarized by Marcus Reckermann)

Observations, analysis and modelling of high impact events in the Baltic Sea region; frequency and strength of storm surges and waves, flooding due to extreme precipitation events or droughts; prediction systems, probabilistic estimates and attribution analyses

Recent extreme water level events in the southwestern Baltic Sea were investigated in a climate Perspective by **Groll et al.** It was shown that the prevailing wind conditions only partly contributed to the extreme coastal water levels, but the pre-filling conditions of the Baltic Sea volume.

Cupiał and Cieślikiewicz investigated the impact of atmospheric low pressure trajectories on extreme wind waves in the southern Baltic region. Four cyclone paths were identified and analysed, of which only two were typical for storm events in the area.

Davydov et al. looked at the effects of extreme storms on coastal erosion in non-tidal seas, here the Baltic, Black and Azov Seas. Major storms and significant storm surges have the highest impact on the coastal zone of non-tidal seas. The major storms and storm surges are relief-forming and determine the further development of the coastal barriers, and do not cause catastrophic consequences within the coastal barriers.

The exceptional storm surge of October 2023 in the Western Baltic Sea was analyzed by **Holfort** from the perspective of an operational forecast and warning service, the German BSH. While the actual warnings were overall considered timely and adequate, potential improvements in communication, warning management and modelling effort were discussed.

Nesteckytė and Kelpšaitė-Rimkienė described the particular situation and challenges regarding extreme storms hitting the port of Klaipėda. The port is notorious for the recurring long waves that enter the port during storms, creating hazardous conditions inside the port to the extent that ships are banned from entering the port during storms or even taken out to sea, as it is safer to be at open sea than in the port. The observed meteorological and oceanographic phenomena during the analyzed storm underscore the complex interplay of atmospheric pressure changes, wind patterns, and coastal geography in shaping localized impacts.

Based upon reanalysis data and climate model simulations, **Meier et al.** present trends in past and future climates in sea surface and bottom marine heatwaves**.** Since the 1980s, marine heatwaves during both summer and winter have become more frequent and longer, and the marine heatwave annual maximum extent at the seabed of shallow coastal waters has increased. Projections of future climate until the end of the century suggest a further increase in frequency and duration of marine heatwaves at a rate depending on the global warming level.

Session C: Sea level dynamics, sediment dynamics, coastal processes and impacts on coasts

(summarized by Kevin Parnell and Ralf Weisse)

Variability and change of mean and extreme sea level; waves, storm surges, currents, seiches, variations in wind and sea level pressure, river runoff, effects of sea ice, inflows, thermosteric effects, land uplift/subsidence and their effects on sea level/sediment transport/coastal changes; projections of future sea level rise, observed and projected long-term trends and multi-decadal variations

The presentations in this session were related to the BEAR report: Weisse, R.; Dailidienė, I.; Hünicke, B.; Kahma, K.; Madsen, K.; Omstedt, A.; Parnell, K.; Schöne, T.; Soomere, T.; Zhang, W.; Zorita, E.: Sea level dynamics and coastal erosion in the Baltic Sea region. Earth System Dynamics. 2021. vol. 12, no. 3, 871-898. DOI: 10.5194/esd-12-871-2021, and will contribute to a work package in the next Baltic Earth Science Plan "Sea level and coastal change in the Baltic Sea".

Wave and current-induced sediment resuspension in the understudied Bothnian Sea was reviewed by **Tuomi et al**, noting difficulties in its assessment with the common mixed sediments and the need for better integration of wave and current Other process-orientated related talks discussed the dynamics of Daugavgriva Island beach in Latvia (**Viška et al.**), changes to the directional forcing of sediment transport (**Eelsalu and Soomere**) particularly with respect to the decreased importance of NW winds., coastal changes due to different hydrodynamic conditions (**Bugajny**), and the unintended impacts of the construction of alongshore breakwaters (**Bojan**).

The impact of sea level rise on the Estonian coast, noting its variability due to continued isostatic adjustment (Kapsi) was discussed. **Viigand et al.** (presented by **Soomere**) showed that there are implications of periods of extreme low sea levels (as well as extreme high sea levels), but that the problem is not likely to get worse in the future. A method for classifying soft cliffs using remote sensing and data mining was presented by **Tanwari** (**Terefenko et al.**)

Data sources, methodologies and modelling dominated the posters presented in this session. **Frishfelds et al.** presented a coastal modelling tool for the NorthSea and Baltic Sea. Data sets and modelled data relating to river discharge (**Mischel et al.**), wave properties (**Giudici et al**.) and wave driven sediment transport (**Soomere et al.**, presented by **Jankowski**). **Wolski et al.** provided sea level insights from the ~220 tide gauges in the Baltic Sea. A method for collecting data from the water profile (Salvador et al.) using bird-mounted sensors provided an interesting new perspective.
A longer-term perspective on coastal evolution was presented in a single contribution by **Bitinas and Damušytė.**

In the session open discussion, participants were asked their opinions on two questions:

- What is, from your perspective, the most important driver of coastal change in the Baltic Sea?
- Which outcomes of climate change in the Baltic Sea are most certain?

Among the 58 participants, a majority stated that other anthropogenic drivers have a greater overall impact on the Baltic Sea system than climate change. Natural climate variability was considered as equally important as anthropogenic climate change. Apart from temperature changes, changing extreme water levels including mean sea level changes, changes in wave climate, and increasing coastal erosion were considered as the most certain effects of climate change. Some discussion evolved regarding a possible increase in future storm activity. Consensus emerged that public (media) perception differs from the scientific perspective where available evidence was considered to be weak by the majority of those actively participating in the discussion.

At the end of the session participants were invited to participate in the working group established in the new science plan.

Session D: Human impacts, interactions and management options (summarized by Marcus Reckermann)
Interactions between anthropogenic forcings like eutrophication, pollution, fisheries, aquaculture, shipping, offshore installations, hydrographic engineering, coastal management, agricultural and forestry practices and land cover change with natual forcings; analysis and application of coupled Earth system models capturing interactions between atmospheric, marine and land compartments/processes, as well as responses to anthropogenic forcings; regional detection and attribution efforts. How to cope with the various human and evironmental impacts described above and climate change, including geoengineering options.

Morhmann et al. investigated the extent and potential impact of the forced NordStream2 gas leakage of 26 September 2022. From glider observations, dissolved methane was found predominantly in intermediate depths, above a local halocline and below the seasonal mixed layer, spreading predominantly by advection. Increased dissolved CH4 levels were found in 23 MPAs, varying by factors of 2 to 100 times of natural levels Dissolved methane initially observed below the autumn mixed layer was later entrained into the deeper winter-time mixed layer and released into the atmosphere. No immediate impact on the environment could be observed.

Zielinski gave an overview over the relatively new research focus on marine light pollution. Coastal regions are experiencing brighter nighttime environments due to urbanization and industrial activities, which leads to a potential impacts on the coastal marine environments, connected to other changes like changes in runoff, increased nutrients, rising temperatures and melting ice.

Marine traffic is a strong human impact on the marine environment. Using satellite images and a deep learning-based object detection method, **Mäyrä et al.** have tried to follow the abundance and distribution of small vessel along the Finnish coastline. These mostly recreational boats are not obliged to have active AIS signals, and can sail into much shallower areas with potential direct impacts on the environment. Vessels could be detected down to 10m., with some limitations (spatial resolution, clouds), but their large spatial coverages and dense temporal resolutions and operationality make them a cost-effective solution for marine traffic monitoring.

In the Finnish archipelago, **Hyytiäinen et al.** tried to approach the question in how far local communities and regions can manage the eutrophication status of their adjacent coastal ecosystems and how much coastal water conditions depend on pollution levels and mitigation efforts in other areas. It was concluded that both local water protection measures and measures conducted elsewhere are necessary to achieve improvements in local water quality, even in a relative closed Archipelago Sea.

Srėbalienė et al. reviewed the data on alien species spreading through ballast water. They assessed their distribution trends and countries of origin. Over the last 20 years, non-indigenous species from the Ponto – Caspian region were dominating. 33% had either the Black or Caspian Seas as their native region. The second dominating origin was the NW Atlantic (24%), NW Pacific (19%), while the NE Atlantic constituted only 6% of the non-indigenous species origin. For some species, the origin was unknown (11%) and other origin regions accounted for by 5%.

Incomplete combustion products released from ship exhausts already undergo fast physical and chemical changes and potentially accumulate at the atmosphere-seawater interface. The distribution of these organic compounds was investigated by **Serafim et al.** The results indicate a high spatial heterogeneity, with higher levels in the Pomeranian Bight attributed to the influence of the Oder River. Concentrations were similar along the Kadetrinne shipping lane but likely originated from different sources, including fossil fuel combustion on land. The study shows the complexity of pollutant distribution in the land-locked sea and emphasizes the role of local factors, such as riverine input and wind conditions.

Coastal vulnerability due to extreme water levels is an important aspect of coastal management. **Soomere et al.** explore the potential of quantities that reflecting features of local water level variations to characterise the contribution of water level into estimates of coastal vulnerability.

The search for prospective quantities of water level variations with certain prognostic value has not yielded a perfect quantity of this kind. The scale parameter of the exponential distribution of local storm surge heights follows accurately the geometry of the coast but does not take into account variations in the background water level. The shape parameter of the GEV distribution eventually has a larger prognostic merit but its values are noisy and contain substantial uncertainties depending on the particular method of their evaluation.

Miettunen and Virtanen aim to demonstrate how ecological connectivity between different habitats could be accounted for in a complex coastal area, using the Archipelago Sea in the northern Baltic Sea as an example region. Using a Lagrangian particle tracking model, connectivity between selected areas in the Archipelago Sea was simulated. The project aims to assess how well the present Finnish MPA network connects ecologically important sites, and to identify where MPAs should be placed to maximize ecological connectivity.

Brodziński et al. present a method for optimizing the location of measurement stations that minimizes the error in determining the average value of the parameter under study for a given area. The method can be used both to test the representativeness of measurement stations in the

case of an existing monitoring network (by identification of the most important and redundant ones), and to determine the optimal network of measurement stations.

Air pollution by shipping can cause problems when ports are close to cities. **Šilas and Rapalis** have used Artificial Neural Networks as a tool for port pollution control and evaluating pollution from ships. As shown in this study, neural networks can be trained based on real ship operation and pollutant concentration data to develop a model for online prediction of air pollutant plumes from ships in ports based only on data that is already available for port operators.

Session E: Modeling past and future climate changes and teleconnections (summarized by Marcus Reckermann)

Recent and projected changes in regional climate variables like temperature, precipitation, etc., as well as impacts on the atmosphere, hydrosphere, oceanography, and biosphere of the Baltic Sea region; recent progress in the understanding of regional climate variability with special focus on coupled effects between sea, atmosphere, land and anthroposphere. Identification of critical regions with teleconnections to the Baltic Sea; assessment of potential change of atmospheric mass and energy flow over Europe; assessment of dynamically driven climate variability (e.g. jet stream) with its origin far outside the Baltic Sea and its propagation into the Baltic Sea region

By comparing long hindcast simulations of three regional ocean models, **Barghorn et al.** identified a shift in saltwater inflow seasonality during the 20th century. It was the main driver of the exceptional warming in the Bornholm Basin, which deteriorated the oxygen conditions.

Börgel et al. explored the influence of multidecadal sea surface temperature (SST) fluctuations in the North Atlantic Ocean, known as the Atlantic Multidecadal Variability on Northern European temperature, particularly in the Baltic Sea region. The study suggests that oceanic inertia, coupled with reduced ice/snow albedo, amplifies the warming effect in the North Atlantic and Baltic Sea.

Spatially and temporally high-resolution wind fields over the Baltic Sea were described by **Dreier et al.** using an innovative extended delta approach based on high-resolution reanalysis wind data and detailed analyses of large sub-ensembles of regional climate projections. Until the middle of the century, projections did not show clear trends, but towards the end of the century, they did.

Jakobson et al. analysed the climate conditions in Estonia as a function of the Global Warming Level (GWL). They found that in winter, the Estonian average temperature is warming 1.7 times faster than the global average. For other seasons, the warming is about 1.4 times faster.

Lehmann and Post analysed the changing impact of large-scale atmospheric circulation variability on the water mass exchange and circulation, focussing on the link between changes/shifts in large-scale atmospheric conditions and their impact on regional scale variability over the Baltic Sea area from 1950 to 2022.

Using the new multi-variate information flow concept, **Stips et al.** were able to confirm the inherent one-way causality between human activities and global warming, as during the last 150 years the increasing anthropogenic radiative forcing is driving the increasing global temperature, a result that cannot be inferred from traditional time delayed correlation or ordinary least square regression analysis.

Stendel et al. presented the Danish project ROPEWALK, in which weather observations in ship journals and logbooks, stored in the Danish National Archive, are digitized to be used to supplement observational data back to the 17th century as input for reanalysis and other research projects. A

huge amount of data (more than 750 shelf meters) is stored in the archive, beginning as early as the 1680s.

Session F: Small scale processes not yet resolved and their impact on the large-scale dynamics and patterns (summarized by Marcus Reckermann)
State-of-the-art knowledge of submesoscale dynamics in the Baltic Sea and similar coastal and/or marginal sea environments based upon observations and modelling and the role of submesoscale in multiscale interactions, e.g. energy transfer, mixing, development of stratification, coastal-offshore exchanges, fluxes of substances, including through the air-sea interface, etc.

Using Ago floats deployed in the Gdansk Basin, **Walczowski et al.** (presentend by D. Rak) observed deep mixing events in the winter of 2023. They demonstrated the usefulness of autonomous research devices: Independent instruments placed on buoys, moorings with profiling instruments, and gliders have been used for a long time in the Baltic Sea, but Argo floats in particular, perform exceptionally well in the conditions of the Baltic Sea despite being designed for the deep ocean.

Liblik et al. present first results of the Central Baltic Sea Circulation Experiment, an international project designed to address knowledge gaps regarding the prevailing subsurface circulation patterns in the Central and Northern Baltic Proper, and to validate numerical modeling. Moorings and gliders were deployed at various locations carriying acoustic Doppler profilers.

Bulczak et al. examine the seasonal variability and long-term winter shoaling of the upper mixed layer in the southern Baltic Sea. The results reveal a significant winter shoaling of the mixed layer by 4 meters per decade, driven by the increased stratification due to rising temperatures and salinity. These changes could have significant impacts on the dynamics and productivity of marine ecosystems

Using a high-resolution hydrodynamic model CEMBS-PolSea, **Dybowski et al.** tried to identify mesoscale features such as eddies in the southern Baltic Sea. Preliminary results indicate the successful automatic identification and tracking of marine eddies. The tool not only determines the expected location of the eddie but also provides information on its size and duration.

Janecki et al. presented a tool to help understand the the vertical startification (thermo-, halo-pyclocline) in the Polish waters of the southern Baltic Sea. It offers significant advancements in understanding and predicting the dynamics of water mixing in the Baltic Sea, contributing immensely to various aspects of maritime operations and research.

Session G: Comparing marginal seas worldwide (summarized by Jan Harff and Joanna Dudzińska-Nowak)
How do climatic, geological and human impacts in different polar, moderate and other marginal seas compare with conditions in the Baltic Sea? Can we establish a systematic scheme (classification), describing cause-effect relations for marginal seas with regard to the human-environment relationship?
As highly sensitive parts of the ocean, marginal seas are particularly exposed to the pressures of climate change but also to anthropogenic impacts due to the increased economic use of the seas and their coasts and drainage areas. This makes it all the more important to protect these fragile ecosystems and habitats, while ensuring the sustainable use of the valuable marine resources. Hereby the goals are described by the UN's Decade of Ocean Science for Sustainable Development (2021 - 2030) program. These goals require new holistic approaches that comprehensively describe a controlled functioning of intensively used coastal and marine areas. To support the search for those holistic approaches under the roof of a Baltic Earth conference already the second time a topical

session for the comparison of marginal seas was convened. Ten authors from Europe, Asia, Africa, and America presented and discussed a wide range of descriptive data and task-related classification methods as basic prerequisites for mastering the diversity of marginal seas. Three main topics have been addressed in lectures and discussions:

Data

In particular, for sustainable approaches, the need for data was expressed describing the human-nature relationship on integrated time scales and to be provided through new interdisciplinary cooperation chains. These chains include real-time and longer series of monitoring data including satellite observations as well as historical data derived from transfer functions - the interpretation of proxies. In order to compare marginal seas and their coasts, it is essential that monitoring plans are designed in a uniform manner. This applies to both the spatial arrangement of the observations and the temporal sequence. For the southern Baltic Sea, **Dudzinska-Nowak and Jankowski** gave related examples for the considerable temporal and spatial variability as well as for high decadal dynamics of coastal changes to reduce substantially bias the forecast. An open classification method presented by **Dudzinska-Nowak** allows the comparison of data for any non-tidal marginal sea. Discussing the recent requirement to handle the increasing flood of research data the participants agreed with **Arlinghaus et al.** who proposed to apply methods of Artificial Intelligence (AI) and Machine Learning (ML) for the classification of coastlines in the Baltic Sea and the North Sea using multispectral satellite images (Sentinel-2).

Diversity of marginal seas

Geo-, ecosystem, climate and the interrelations with socioeconomic system have been considered to express the diversity of marginal seas. Highlighting the geosystem as classification scales as one of the driving forces of coastal dynamics **Parnell and Soomere** introduced for the comparison of marginal seas tidal range and characteristic wave periods. Comparing South China Sea, North Sea and Baltic Sea the authors presented a review for the variables to classify marginal seas in terms of erosional processes to be considered for the protection of coasts. River mouth systems play an extraordinary role for the assessment of the land – sea interfaces. In addition to the geosystem - including geological structure and tectonics of coasts and drainage areas - the climate plays a critical role in the formation of the river mouths' structures. **Ghatak et al.** introduced Ganges-Brahmaputra-Meghna (GBM) – the worldwide largest river delta located at the northern apex of the Bay of Bengal – ruled by the tropical monsoon climate. In so far this delta forms a prototype as one end member on a scale of geosystem/climate parameters suitable for a classification of river mouth systems. **Zhang et al.** used this scale to compare the mouth systems of the Pearl River merging the tropical northern South China Sea and the Oder River dewatering to the southern Baltic Sea in the temperate climate zone. Regarding the Oder River, in addition to the current climate also its history plays an important role because of climate-induced Glacio-Isostatic Adjustment (GIA) . A recent example of diverse Arctic marine ecosystems determined by freshwater runoff from melting glaciers and icebergs to coastal waters was presented by **Krawczyk**. The author described the hydrographic complexity and fragile ecosystem of Disko Bay on the West Greenland Shelf as a key study area.

Marginal seas and humans

The interaction between the development of the environment and human society and thus the need for effective management strategies is particularly evident in relation to the marine environment for marginal seas. **Cawthra and Fisher** describe this interaction in an impressive way based on the interpretation of proxy data of the Late Quaternary for the South African shelf. The data mirrors the impact of marine transgression and regression on regional prehistoric migration events. For regional planning, this data is used to identify risk-zones of different hazards as a result of sea-level scenarios. Risks and impacts from compound (high sea levels and river discharges) events have been analyzed by **Weisse et al.** for western European coasts. Results imply that compounding high sea levels and river discharges may pose a substantial threat along westward-facing coasts in Europe - a risk to be considered in particular for future coastal zone management. **Greene and Delaney** generalized the

concept of “Urban Seas” as a tool not only to optimize the relation between human impact and environment of industrialized river mouth systems. They proposed the concept also as an instrument to manage the discharge of harmful substances from these river mouth systems as point sources to the world ocean.
Summarizing it was concluded that a general knowledge gap exists between society's demand for management strategies on the one side and cause-effect relationships of (controlling) drivers and environmental (tunable) marginal seas’ parameters on the other side. This gap can be closed not only by considering solutions for individual marginal seas but rather by generalization of individual seas' diversity leading finally to a taxonomy of marginal seas. This task requires an inter- to transdisciplinary communication platform that Baltic Earth provides an ideal frame for. Therefore, it was proposed to establish a Baltic Earth Working Group “Marginal Seas – Humans and Environment” to promote the development of a marginal sea taxonomy.

It was suggested to focus the first work phase to the academic year 2024-2025 with the main task to jointly prepare a white paper on the topic of "Marginal Seas - challenges and chances". At the end of the first year of work, an evaluation of the work results will precede further planning. This working group is not only open to the Baltic Earth community, but young scientists and students are particularly invited to participate.

Session H: Philosophical aspects of Baltic Sea Earth System (summarized by Anders Omstedt)
Dichotomous thinking and the need for broader, integrative perspectives; complex systems with multiple drivers; ‚external‘ social dynamics in ‚internal‘ scientific modeling; what is the basis of the public authority of scientific knowledge? What is the knowledge market for the Baltic Sea region? What is the boundary between science and activism?

Anders Omstedt and Jüri Elken chaired the session. **Marie Heidenreich** started the session by giving insights into science policy dialogues and ideas about building trust between scientists and policy people. Questions were raised about dealing with climate-skeptical persons in the dialog, and Marie agreed that it is difficult to deal with them.

Jüri Elken introduced the mechanical energy balance in the Baltic Sea. As the BALTEX/ Baltic Earth program focuses on the water and energy cycle, the estimations of the mechanical energy balance are still unknown, particularly regarding human activities. This interesting presentation opened up the need for further dialogs with, e.g., the Baltic Earth Working Group on Small-Scale Processes.
Two posters from the Working Group of Philosophy were given during the poster speed talk and presentation. One is about the Baltic Sea Geography, and the other is about Marine protected areas and the field station Seili in the Åbo archipelago.

On Friday, **Anders Omstedt** gave two presentations on the philosophical aspects of marginal seas and climate and environmental sciences. The former was with **Rasmus Winther**, and the second was with **Inga Dailidiene, Rasmus Winther,** and **Hans von Storch**—the presentations aimed to introduce philosophical thinking to the Baltic Earth community.

The topic was open for discussion with good inputs, such as understanding how the scientific views had changed during the BALTEX/Baltic Earth period and discussions on what we mean by philosophy.