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EDITORIAL FOREWORD

Earth system changes in marginal seas

The Baltic Sea is one of the best-studied marginal seas in the world. Due to the long history of research and human impact in the region, interactions between natural and anthropogenic drivers affecting oceanographic and biogeochemical processes can be exemplarily studied and used as case studies for similar regions around the world. Coastal erosion caused by sea-level rise and extreme meteorological events, changes in the marine environment caused by climate change, as well as the consequences of industrialization and extensive agriculture are major fields of current research. The development of management strategies to keep the balance between the protection of the environment and the economic use of resources represents a challenge for human society in the catchment area and the coastal zone of marginal seas such as the Baltic Sea.

Baltic Earth is an international network of researchers and institutions, dedicated to an improved Earth System understanding of the Baltic Sea region in the face of climatic, environmental and human impact in the region. The research is aligned along Grand Challenges, which range from natural and human-driven dynamics of sea level, coasts and salinity, land-sea biogeochemical linkages, hazards and extreme events, to multiple drivers and human impacts. Baltic Earth organizes workshops, conferences, summer and winter schools as well as publication projects such as the BACC and BEAR reports. Every two years, the international and interdisciplinary Baltic Earth Conference brings together the research communities of the Baltic Sea and beyond to discuss issues related to the Baltic Sea Grand Challenges.

The threats to the coasts and marine environments of the Baltic Sea are similar in other marginal seas, so a coordinated research approach should be considered in order to jointly search for generalized management strategies. Hence, the Baltic Sea can be regarded as a key area to study the continuum of the catchment area and the receiving marginal sea basin. The need to compare marginal seas around the world in a comprehensive view is reflected by the establishment of the **Task Group "Marginal Seas"** within the frame of the Deep-time Digital Earth (DDE) Big Science Program of the "International Union of Geological Sciences (IUGS)". This Task Group acts as a core of an international and interdisciplinary network of scientists with the general mission to implement methodologies for the integration of global marginal seas evolution data and the sharing of international knowledge concerning three basic research topics: (1) paleo-geographic, -oceanographic, and -environmental evolution of marginal seas of the Last Glacial Cycle, (2) future expectations for the development of marginal seas and their coastal zones, facing the challenge of climate change and increasing human impact on the environment for this century, (3) best strategies for sustainable development of the marine and coastal realm that can help to keep a balance between the protection of the environment and the economic use of marginal seas' resources.

Considering the joint challenges of Baltic Earth and the DDE Marginal Seas Task Group, this Special Issue combines the results of two conferences with a similar scope: the 3rd Baltic Earth Conference "Earth system changes and Baltic Sea coasts", held online on 2 and 3 June 2020, and the International Conference "Marginal Seas — Past and Future", also held online on 16 and 17 December 2020. The conferences are strongly interrelated in terms of content as well as organization, so it was decided to exploit the synergies for this collection of papers: the marginal seas concept can be applied to the Baltic Sea region, and the Baltic Earth concept can be relevant in marginal seas worldwide. Contributions from both conferences have a common relevance and can be mutually fruitful.

Contributions came from the Baltic Sea, the China Seas, the Mediterranean, the Salish Sea (in NW America) and the South African continental shelf; some contributions described overarching issues. Although both conferences have their own sets of topics and research foci, there are large overlaps. In the following, we briefly give an overview of the contents of the Special Issue. Most papers in this Special Issue describe physical or biogeochemical aspects of the regional Earth systems, using modeling, observation, mapping and data management for historical reconstructions and future projections.

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Earth system changes on different time scales

This includes the description of processes of the geo-, eco-, and climatic systems and the links between them as complex cause-effect relationships, and their changes on different time scales. Comparative studies from marginal seas around the world characterize the roles of the respective climatic and hydrographic systems, including present and past sea-level dynamics.

Stattegger and Leszczyńska present a new interpretation of data explaining the relative sea-level change during the general most important phase of the younger Baltic Sea history: The Littorina Transgression as the start of the current permanent brackish-marine phase of the Baltic Sea history. This new data allows a more precise correlation of the post-glacial sea-level rise events in marginal seas. Zhang et al. have studied marine transgression and regression during the Holocene by the fossil diatom assemblages and grain size distributions of a sediment core from the middle of the Beibu Gulf at the Northern shelf of the South China Sea. The authors interpret the rapid increase in sea level as meltwater events pulse-1B and pulse-1C. These meltwater pulses are regarded as key events for the correlation of the South China Sea with other marginal seas such as the Baltic Sea. Groh and Harff report on the application of the Sea-Level Equation (SLE) to describe the adaption of the relative sea level (RSL) to changes in continental ice masses and the resulting interaction of crustal deformations and changes of the Earth's gravity field. The Baltic Sea served as a study area, the representative for formerly glaciated regions and their surroundings (near-field), where RSL is dominated by crustal deformations induced by changing glacial loads. As a second test site, the South China Sea and the Beibu Gulf are considered. Wolski and Wiśniewski have studied the connection between sea level variability in the Baltic Sea and the North Atlantic and Arctic Oscillation (NAO, AO) periodicities, indicating these regional climate systems to be drivers of the extreme water levels in the Baltic Sea.

Analysis of coastal morphodynamics requires relating the temporal periodicity of driving meteorological events to spatial patterns of coastal landforms. Janušaitė et al. have studied the sandbar switching episodes and the dynamic state of the beach-foredune system along the Curonian Spit coast, Baltic Sea, using decadal satellite-derived and beach levelling data. Compared to a small accretion rate outside the sandbar switching zones, a moderate average rate of erosion was observed within switching zones at an interannual storm-related time scale.

Hagemann and Stacke made the effort to combine high-resolution regional climate change observational and re-analysis datasets with high-resolution river discharge datasets. The experimental setup is useful to generate high-resolution river runoff analyses, consistent with the meteorological forcing for historical periods and future scenarios from any climate model data instead of having to rely on observed time series for the European region. Observational datasets were also used by Mačiulytė et al. to investigate the potential impact of changing precipitation patterns on agricultural success in the Baltic region. They found that since 1950, overall precipitation in the eastern Baltic Sea region has increased significantly, and also shifted seasonally, with potential negative impacts on agriculture. Similarly,Klimavičius et al. looked at the impact of meteorological conditions on vegetation development in the Eastern Baltic Sea region. They used the "Normalized Difference Vegetation Index" (NDVI) to evaluate changes in growing season indicators in relation to meteorological conditions over the past roughly 40 years. They found that the growing season has extended into the spring and autumn and increased in duration, with air temperatures being the most important determining factor.

The oxygen budget in the Baltic Sea is an important characteristic for the biogeochemical state of the Baltic Sea, with consequences for higher trophic levels up to fish. Sub-and anoxic deep water plumes are a permanent feature in the Baltic proper, and they have increased in volume. Golenko et al. have found low oxygen plumes in intermediate water layers, with uncertain origin. Hypotheses about the origin of these plumes were tested using numerical hydrodynamic modelling, indicating the region of formation and subsequent pathways.

Wave properties are important indicators for erosion processes in the soft coasts of the southern Baltic Sea as well as for the quantification of sediment transport. Soomere et al. describe the available third-generation spectral wave models to simulate the regional wave climate of the Baltic Sea. The models replicate all main features of the Baltic Sea wave climate but reconstructions of wave properties in the nearshore, archipelago areas, and in narrow subbasins require finer spatial resolution and possibly advancements in wave physics. Progress in these fields is important for coastal management.

The aspect of how marginal seas are modified by human activities and how the present and past societies have been affected by Earth system changes is covered by another set of papers.

Marginal seas and society

Based on the archaeological record, Bailey and Cawthra highlight the impact of sea-level change on key developments in human history during the late Pleistocene and the early Holocene. Before modern sea levels became established roughly 7000 years ago, most paleo-shorelines and large areas of the coastal hinterland were exposed as habitable land and then drowned again by the rising sea level. Examples of paleo-landscape reconstruction through multi-disciplinary collaboration between archaeology and marine science in the North Sea, the Red Sea and the Cape Coast of South Africa are used to discuss evidence of past human responses to sea-level change.

Liu investigated the Huanghe estuary (Yellow River) and the adjacent Bohai Sea, with a special focus on the ecosystem and social responses to stressors like eutrophication, pollution, changing freshwater input and course shifts, massive and intensive aquaculture, overfishing,

excess land reclamation, and land use change in the region. It is explained how ecosystems and society interact and how these drivers have a disproportionally large impact on the Bohai Sea and its marine ecosystems. The described biogeochemistry-ecosystem-human interactions in the Huanghe estuary and the Bohai Sea can be scaled to similar marginal seas in order to help mitigate impacts. Martyanov et al. assess the transport and distribution of microplastics in the eastern part of the Gulf of Finland by means of numerical modeling. The riverine sources as well as transport and sedimentation patterns were accounted for, including biofouling and ingestion by zooplankton. The results of the modelling efforts can be used to assess microplastic pollution in the eastern Gulf of Finland, and help to develop monitoring strategies. Human conglomerations also in other coastal regions like the Pearl River Estuary (PRE) in China exert strong impacts on the coastal seas through the release of harmful anthropogenic substances into the sea. Deich et al. continue an issue that has been discussed for the Baltic Sea, namely how endocrine-disrupting compounds and in particular estrogenic substances interact with the hormone system of organisms. Natural and synthetic estrogens as well as estrogen-like substances derived from plants and fungi have been measured in the highly populated coastal zones around the PRE and at the adjacent northern shelf of the South China Sea, and regular monitoring is advised. The assessment of the trophic status plays an important role in determining management strategies to improve polluted marine environmental conditions. Boniewicz-Szmyt et al. have investigated the role of biofilms on solid surfaces in the Gulf of Gdansk, Baltic Sea as indicators of the trophic state including the water quality and environmental stress of the shallow marine environments.

Porz et al. have investigated the morphological evolution of two mud depocenters in the southwestern Baltic Sea by comparison of numerical model results to geological and oceanographic data. A favorable comparison of model results to published current speed observations indicates that the mesoscale dynamics of each individual inflow event are deterministic in the sense that water flow is guided by bathymetry. The results indicate that episodic events with high bottom current velocities as well as bottom-trawling-induced resuspension are responsible for the present-day and future morphological configuration of the mud depocenters in the southwestern Baltic Sea.

Greene et al. give an example of complex data acquisition for marine benthic habitat mapping in the Salish Sea in British Columbia (Canada) and Washington (USA), a key region of increasing commercial intensification such as shipping, fishing, recreation, and tourism, all of which have the potential to affect marine benthic habitats. In an attempt to understand the marine benthic habitats' dynamics, utility, and susceptibility to alterations, a major seafloor mapping project has been conducted, based on the geologic and geomorphologic interpretations of marine geophysical, geological, and biological data.

Finally, two manuscripts are devoted to the perception of human societies on the marine environment of marginal seas. Von Storch reports about a series of ad-hoc surveys at different academic institutions in the Baltic Sea region where students and young scientists were asked their opinion on the environmental problems of the Baltic Sea and on responsibility for the marine environment. Overfishing, climate change and waste disposal were seen as the most important factors. Respondents believe the European Union or the respective national governments are responsible for the management of the Baltic Sea. Remarkably, it was not the generation of scientific knowledge about climate dynamics that was seen as the primary task of scientists, but rather the support of climate activism. Omstedt considers the large gap between scientific knowledge and the treatment of the sea, illustrating a weak coupling between facts and values. A discussion of how to improve the human relationship with the sea should be initiated. Research into the UN 2030 Agenda with its ambition to transform our world into a sustainable and healthy physical and mental environment creates an opportunity to deepen our understanding of human behaviour and values and how they impinge on the physical world. Together with improved communication and transdisciplinary initiatives, these efforts could help to better understand the marginal sea system and generate a new relationship with the ocean.

Modeling and data management

The contributions to both conferences showed the increasing importance of data exploration and modeling for describing the interrelation between the marginal seas' system components of climate on the one hand and the geo- and bio- and anthroposphere on the other. In several of the contributions to this Special Issue, sophisticated numerical models are parameterized on the short (up to decadal) scales using observational data, and on the longer (geological) time scales by proxy-data interpretations. One of the preconditions for the systematic application of modeling procedures is the standardization of data. The problem of how to make the best use of the many and diverse environmental data that are collected by various institutions around the world was approached by Foglini and Grande. They describe the FAIRness (FAIR: Findable, Interoperable, accessible and researchable) principles to enable efficient data integration in order to overcome challenges in data heterogeneity and fragmentation. The authors use the landlocked Adriatic Sea to exemplify the FAIR concept. A 'Spatial Relational Database Management System' (RDBMS: Geodatabase) was created for the Adriatic Sea, linked with a WebGIS (i.e. a web-based version of a geographical information system) and a metadata catalogue that follows FAIR data principles. The integration and harmonization of heterogeneous data sources is the key to further developing interoperability with European marine data management infrastructures for handling and exchanging a high variety of multidisciplinary data.

This Special Issue is a contribution to the currently developing field of marginal sea research, with the Baltic Sea as a "model" region. One focus is the change in natural environmental systems, particularly due to anthropogenic impacts. The modeling of marginal sea processes will allow us to generate future scenarios for managing coastal and marginal seas. This Special Issue is intended to represent a step to-

wards this goal. We sincerely thank the contributors at both conferences for providing an impetus for further research activities in this field.

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