Marginal Seas – Past and Future

International Online Conference, 16/17 December 2020

Summary

Preface

The online conference was the first initiative of a 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 international and interdisciplinary network of scientists with the general mission to prepare computer-based methodologies for the integration of global marginal seas evolution data and the sharing of international knowledge to answer three basic questions:

- How did marginal seas of different climatic zones and tectonic settings change their **paleo-geography, -oceanography, and -environment** during the natural climate and environmental variation of the Last Glacial Cycle (last 130 kyr)?
- What are the **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?
- What **strategies for sustainable development** of the marine and coastal realm can help to keep a balance between the protection of the environment and the economic use of marginal seas' resources?

The conference aimed to identify tracks for planning the activities of the Task Group for the next three years. The online meeting was organized by the Institute of Marine and Environmental Sciences, University of Szczecin, Poland, and co-organized by the International Baltic Earth Secretariat at Helmholtz-Zentrum Geesthacht, Guangzhou Marine Geological Survey, China, and Polish Academy of Sciences, Committee of Marine Sciences.

The conference was structured into three Topical Sessions. The first one focusses on the interdisciplinary description of interaction between climate, geo- and ecosphere, the second one covers the interaction of marginal seas and society, and the presentations of the third session deal with data management and visualization (mapping) to build the bridge to the next step on the roadmap of the DDE Marginal Seas Task Group: generating scenarios of the geological past and future developments by the application of numerical models. Despite that the scope of the conference was not regionally limited, special attention was paid to the Baltic Sea, which, as a natural laboratory, plays a key role in understanding basic processes in marginal seas.

Session 1: Geo-, Eco- and Climate Systems

Lectures and discussions were held on the one hand to explain the links between processes of the geo-, eco-, and climate system as complex cause-effect relationships, on the other hand, interdisciplinary approaches have been discussed to describe these relationships using models. In terms of geological time periods, one focus of the studies was on the Last Glacial Cycle (LGC) and in particular the Holocene and the Anthropocene, the climatic variation of which mainly dominate today's marginal seas. Comparative studies from marginal seas in different geographic positions explained the role of the ruling climate and hydrographic systems. The lectures can be assigned to four subtopics

Geo-system and sea-level

For environmental studies of marginal seas on the annual to millennial time scale, sea-level change is of fundamental importance. It is ruled by an interrelation of climate-induced eustatic change, tectonics, isostatic dynamics and other effects. **Andreas Groh and Jan Harff** reported about the application of the Sea-Level Equation (SLE) to describe the adaption of the relative sea level (RSL) to changes in continental ice masses the resulting interaction of crustal deformations and changes of the Earth's gravity field. The Baltic Sea served as a study area, 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 in particular are considered. In regions far away from the former centers of glaciation (far-field), load-induced changes of the Earth's gravity field are the major contributors to RSL changes. Also the load of sediments accumulated during the last glacial period have been investigated for estimating sea-level scenarios.

For the reconstruction of the sea level change, either proxy-data can be deciphered or complex models can be used to derive seal-level scenarios. **Karl Stattegger** used for his reconstruction of global sea-level change during the LGC a method combining geological proxy-data and glacio-isostatic models. He compared the South China Sea and the Baltic Seas, focusing on the deglaciation during the Late Pleistocene and Holocene, whereby he paid special attention to phases of high acceleration of sea-level rise. These phases allowed the correlation between the South China Sea high-stands and Baltic Seas flooding phases.

Climate modeling and data analyses

Eduardo Zorita reviewed the possibilities of climate modeling to display the interrelation between climate, geosphere and biosphere of marginal seas for the geological past of the Last Glacial Cycle (LGC) as well as for the future within the current century. He pointed particularly at Complex Earth System Models (ESM), regarding possibilities and limitations, to simulate both future climate and the LGC. Main limitations for model applications to marginal seas is often the spatial resolution of the which are too coarse to reflect regional to local effects, requiring spatial generalizations and downscaling. Hope gives the currently ongoing Palmod project that aims at simulating the climate of the last 130 kyears with a comprehensive ESM, with an interactive global carbon cycle and interactive ice-sheets.

Important for the model evaluation are sensitive tests using measured data and current trend-analyses. **Bing Wang** analyzed long-term climate changes in three South China areas (Guangdong-Hong Kong-Macao Greater Bay) and compared them with five European stations, representing the areas of Stockholm, Milan, Vienna, Bologna and Praha. Based on Ensemble Empirical Mode Decomposition (EEMD) and Mann-Kendall methods, this study is focused on multi-scale temperature fluctuation and mutation point extraction in the past. The multi-scale analysis shows that there are 4 time-scale changes in both Guangdong-Hong Kong-Macao Greater Bay and the European area. The author discovered that trends on inter-annual, inter-decadal and centennial scales are comparable, but the fluctuation periods are different in both regions, especially on the interdecadal and century scales.

Ecosystems

The Baltic Sea serves as an excellent key area to study the complex effects of meteorological forces, steric sea-level change and vertical crustal displacement on the dynamics of water exchange between an semi-enclosed basin and the open sea. The inflow of marine water and thus the oxygen dynamics in the marginal sea basins are controlled via the oceanographic dynamics of these gates. Reduced oxygenation leads to the formation of hypoxia that has spread worldwide in marginal seas' basins in the near past. To disentangle the various drivers of hypoxia, **Markus Meier** et al. developed a modelling approach based on historical reconstructions and dynamical downscaling to investigate bottom oxygen concentrations in past and future climates. The Baltic Sea is the marginal sea with the currently largest man-made hypoxic area in the world. The drivers of hypoxia in the Baltic Sea have been used to compare it with the northern Gulf of Mexico, Chesapeake Bay, the Gulf of St. Lawrence, the

northwestern Black Sea, the northern Adriatic Sea and the East China Sea, aiming to upscale results. The oxygenation is one of the key parameters determining the ecodynamics of marginal seas that has also been reflected in **Corinna Schrum's** presentation who used a mathematical model of nutrient cycles to compare the Baltic Sea and the Barent Sea. In general, marginal seas belong to the most dynamic ecosystems worldwide. In addition to natural pressures acting on large spatial and temporal scales, such as for instance sea-level variations, anthropogenic drivers have to be increasingly considered since industrial times. **Teresa Radziejewska and Andrzej Witkowski** have mentioned in particular the importance of exact timing of processes and the reconstructions of the paleoenvironment by proxy-variables and transfer functions, using sedimentological and paleontological studies of sediment cores. **Helge Arz et al.** demonstrated exemplarily paleoenvironmental studies, based on radiocarbon and paleomagnetical analyses conducted for sediment records from the Black Sea and the Red Sea. The results confirm the exceptional sensitivity of such marginal sea systems to changes in sea-level and regional climate during the last glacial cycle. Most prominent are the environmental shifts during glacial-interglacial transitions, accompanied by major hydrological imbalances in the basins in response to global sea-level, local/regional evaporation/precipitation changes, and e.g., melt water input. Even more prominent are the abrupt millennial-scale changes that occurred during the overall unstable climate of the last ice age, the so-called Dansgaard-Oeschger cycles. Climate simulations and several chronostratigraphic approaches are tested to overcome the problem of lacking detailed and reliable age control of these multi-proxy records.

Marginal seas and climate zones

Investigating marginal seas systems beyond the geological and tectonic setting, the position within the controlling climate sub-subsystem plays the dominant role. For the East Asian Monsoon system, **Peter D. Clift** explained the primary control of the strength of the monsoon over rates of erosion and chemical weathering and sediment transport in East Asian river systems. Cycles of the Asian summer monsoon during the last glacial period, but in particular in Late Pleistocene to Holocene, either rule the accumulation of weathering products of the Himalaya in river valleys and terraces, or the transport to the shelf and deeper marine basins. These cycles are superposed with the development of agriculture, responsible for exacerbating the recycling of sediment into the deep water as a result of the spread of agriculture breaking up the shallow sediment surface and liberating material into the rivers. To describe those processes on spatially adequate to marginal seas scales, global to transregional models have to be regionalized and calibrated using proxy-sediment records. **Jinpeng Zhang and Chixin Chen** described the formation of a sedimentary sequences down-core at selected sites in the Pearl River Estuary (PRE) - an area directly influenced by the East Asian monsoon dynamics. Paleontological investigation of sediment cores within the estuary allow to specify the regional to local effects of monsoon dynamics on the Pearl River mouth system. Together with the identification of phases of marine transgression and regressions, the results contribute to the comparative studies of paleoclimate and sea-level dynamics with other marginal seas such as the Baltic Sea. In this respect, however, we have to consider that comparative marginal seas studies need to refer to one and the same model approach. For the description of polar marginal seas and their comparison with other climatic zones, specific models and parameters need still to be developed, and related studies are just in the starting phase. **Daria Ryabchuk et al.** gave an overview about geological conditions and coastal processes of Eurasian arctic marginal seas which are characterized by extreme variety of bedrock and Quaternary geology, tectonic, high potential of mineral resources, and numerous unsolved problems of geological history. Fundamental problems from different Quaternary Ice Sheets extensions, time and mechanism of deglaciation, Holocene sea-level change in different Arctic Marginal Seas – to questions of local paleogeographical reconstructions and different submerged glacial and postglacial seabed forms genesis are still far from being solved yet. Despite the fact of extensive data collection and mapping programs, there is a large demand of models that help to mitigate the threats of coastal

geological hazards considered to be climate-dependent. Model results could help for a sustainable development of the Arctic coasts.

Session 2: Marginal Seas and Society

The focus of this topic is on the relationship between geo-, eco, climate system and the anthroposphere in terms of protection and exploitation of the marginal seas' natural resources, including the environment. The change in the role of human societies from the passive adaptation of survival strategies during the late Pleistocene to the active role of changing the natural environment in the Anthropocene marks a principle shift in socio-economic history. A key to understanding this active role is exploring the perception that societies have had of the environment as an opportunity or a threat, depending on the state of societal development along its temporal and regional variation. Three subtopics can be separated from lectures and discussion.

Adaption of societies to the change of the natural environment

Geoff Bailey and Hayley Cawthra described the change of the coastal environments on the continental shelves and their marginal seas from the geological and archaeological point of view, as an effect of climatically controlled sea-level change of more the 130 m during the Last Glacial Cycle. The effect of coastline shifts on continental shelves since the Last Glacial Maximum was closely connected to human history, including the beginnings of seafaring, intensification in the exploitation of marine resources, colonization of deglaciated regions and new continents, and very likely population growth and increasingly sedentary settlements, all well before the advent of agriculture. Modeling approaches of plaeo-landscapes that are submerged today because of the postglacial sea-level rise can help to answer fundamental questions of Meso- to Neolithic archaeology. Investigations motivated by archaeological questions may in turn contribute new information to sea-level and climatic modelling, and more generally to an understanding of the threats to both the underwater and on-land cultural heritage posed by present and future sea-level rise. Since early phases of prehistoric and historical development of mankind, societal processes have not only been adjusted passively to changing natural environments – including in particular climate and coastline migrations – but also did act as drivers of the environmental changes. This anthropogenic impact became a challenge with the industrial age and has required targeted planning for sustainable development already decades ago. Various stages on this path from just recording to planning were described with lectures from comparative regions of the Chinese marginal seas and the Baltic Sea.

Anthropogenic impacts on natural environments

Sumei Liu investigated the Huanghe estuary (Yellow River) and adjacent Bohai Sea as an example to address the response of biogeochemical variations and change to drivers such as eutrophication, pollution, and changing freshwater input and course shifts, massive and intensive aquaculture, over-fishing, excess land reclamation, and land use change. It is explained to what extent these drivers have a disproportional large impact on the Bohai Sea and its marine ecosystems, whereby the author intends to extrapolate biogeochemistry-ecosystem-human interactions in the Huanghe estuary and Bohai Sea globally to predict and prevent similar marginal seas from experiencing major societal and ecosystem disbalancing.

Joanna J. Waniek et al. highlighted hotspots of chemical degradation processes as well as redox reactions in the sediments (e.g. denitrification, reduction of trace metals), impacting the C, N, P and Fe cycles in the vicinity of metropolitan areas on the northern shelf of the South China Sea. The authors present first examples for the Pearl River Estuary and the northern shelf of South China Sea regarding organic pollutants, and trace metals from the Saigon-Dongnai river estuary crossing the conglomeration of Ho Chi Minh City. In this respect, it is discussed to what extent "fingerprints" of the megacities in marginal seas are mapped in shelf sediments and what the function of the sediments is

with respect to anthropogenic pressure, in particular the introduced pollutants (e.g. trace metals, microplastics, UV filters, personal care products).

Marcus Reckermann et al. reported about an advanced step for understanding the cause-and-effect relation in the complex regional Earth system (e.g. the atmosphere, land surfaces, water bodies, biosphere, biogeochemistry, geology and anthroposhere) for the Baltic Sea area. The Baltic Sea shall serve here as a model area so that the findings may be transferred to similar marginal sea regions. The authors presented an inventory of drivers and their effects on the marine ecosystem and anthroposphere including feedbacks between climatic and non-climatic factors and politically motivated management decisions, which have no or little natural scientific groundings. The impacts of the latter ones may be stronger than natural ones and may be even more unpredictable than those. In another approach **Sampo Pihlainen et al.,** based on numerical modeling, studied the relative importance of societal drivers and changing climate on anthropogenic nutrient inputs of the Baltic Sea. The authors used socioeconomic and climate scenarios as inputs for spatially and temporally detailed models for population and land use change, and their subsequent impact on nutrient loading. In general, societal drivers outweigh the impacts of changing climate on nutrient loading. Food demand is the most impactful driver, strongly affecting land use and nutrient loads from agricultural lands in the long run. In order to reach the good environmental status of the Baltic Sea, additional nutrient abatement efforts should focus on phosphorus rather than nitrogen. Agriculture is regarded the most important sector to be addressed for a sustainable management of the Baltic Sea's environment.

Societies' perception of the environment

To advance from modeling of the marginal seas natural environment including anthropogenic activities as what-if scenarios, to management requires a high level of understanding and accepting of natural sciences findings and their implications by stakeholders. Three presentation were devoted to the connection between natural-, socio-economical and human sciences and culture. **Anders Omstedt** includes the emotional aspect that has to be considered in particular for coastal protection activities into the discussion. Compared to natural sciences, human sciences (the arts and humanities) describe the deep emotional and social connection to the sea, albeit a weak coupling between facts and feelings. To bridge these gaps, the author recommends among other topics: 1) a stronger (natural) science integration into the societal discussion, 2) supporting ocean-observation systems, 3) improved science-policy interfaces (science diplomacy and communication) and 4) a new ocean-climate financing system. In terms of an optimal coastal management plans, **Kevin E. Parnell** expects decisions to be based on quality science incorporating solid theory and empirical evidence, modified by socio-economic imperatives, and interpreted by competent practitioners with a goal of sustainability. But he also claims that history, culture, tradition, tenure systems, indigenous knowledge, and other less tangible factors play a part in the coastal management process but have not been well established yet. Decisions by coastal management practitioners involve different sorts of knowledge, but face difficulties in determining its validity and in its integration. The author claims that scientific (including social science) investigation, the reporting of results and their use in management processes, is well established and understood, but traditional or indigenous knowledge and its use is less well established. The author is discussing the possibility of mixed coastal management systems, integrating indigenous knowledge into traditional management concepts. **Jan-Marcin Węsławski et al**. are approaching similar questions. The authors are testing the hypothesis that similar groups in terms of age, economic interests level of education across contrasting communities in countries like Japan, Indonesia, Poland and Germany, assign special - and partly contradictory - socio-economic and cultural value to the sea and its environment. The authors assume, that some parts of society will behave in a similar way regardless the country of origin – e.g. the young, educated, middle class use to be liberal and environmentally concerned, and react alike to the new international regulations. Their relations to the sea is mainly socio-cultural. Fisherman and those of traditional jobs linked to the sea, are similar in their conservative approach, while the class of governmental professional employees represent the current policy of their respective countries. The authors conclude that wide spread marine education

– ocean literacy is a main tool to solve the potential conflicts and obtain the positive response to modern international regulations for the conservation, restoration, protection, but also the use of the natural marine environment.

Session 3: Scaling / Mapping / Data-Management

For comparative studies of marginal seas (from mapping to process modeling) which allow both historical reconstruction and future projection, a harmonization of multidisciplinary data and their international accessibility is required. The two subtopics of Session 3 are:

- the introduction of exemplarily general principles of data harmonization and structuring, and
- the application of data bases for mapping and process modeling.

Principles and examples of international research data bases

Federica Foglini and Valentina Grande explained 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 land-locked 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. Research objects provide the basis for the development of e-infrastructures for preserving, sharing and reusing scientific data and knowledge within and across communities. The integration and harmonization of these heterogeneous data sources is also the key to further develop interoperability with European marine data management infrastructures for handling and exchanging high variety of multidisciplinary data (e.g. EMODnet, SeaDataNet). The European Marine Observation and Data Network (EMODnet) was established by the European Commission in 2007, in particular for the harmonization of marine scientific datasets of different disciplines. Exemplified for geological data (EMODnet Geologiy) **Kristine Asch** described the mapping concept of the European seas. The data compilation is based on the data from the EMODnet Geology partners (mainly geological survey organizations) and is derived from offshore geophysical surveys (e.g. echo soundings or seismic profilers) and sampling (drilling or dredging). The major challenges for harmonization are the heterogeneity of the data provided, with respect to the semantics of geological descriptions, and spatial resolution of profiling and mapping. In order to ensure data interoperability and to present the resulting digital maps in a homogeneous way, the information requires standardizations. Thus, within the project standard feature types, vocabularies and map keys are defined, underpinned by existing standards such as the data specification of the EU Directive INSPIRE.

A global data base of ocean sediment Data (dbSEABED Project), available as input to models of the seafloor environment - whether they are process-numerical or machine-learning in style - was described by **Chris J. Jenkins.** dbSEABED has steadily amassed geological, compositional and physical properties data for over 6 million seafloor sites from shore to abyss, in all parts of the oceans. The research field of the project is sedimentology / stratigraphy / ecology, applying advanced heterogeneous data integration, using computer and mathematical methods. The database outputs include multiparameter point-wise, vector and gridded data. They have been used by collaborators in fields as diverse as global carbon budgets, marine groundwater chemistries, global deep-sea carbonate dissolution, underwater acoustics, fish ecology, study of hurricane impacts on continental shelves and slopes, deep-sea coral ecology, and fate of man-made objects at the seabed. The database deals with sub-bottom stratigraphy of the seabed, a feature which could assist with proposed Marginal Seas modelling.

Mapping and Process modeling using interdisciplinary data sources

H. Gary Greene gave 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 impact marine benthic habitats. In an attempt to understand the Salish Sea, marine benthic habitats' dynamics, utility, and susceptibility to alterations a major seafloor mapping project is being conducted, based on the geologic and geomorphologic interpretations of marine geophysical, geological, and biological data. From sedimentological, geophysical and biological data, detailed marine benthic habitat maps have been constructed that are being used to evaluate the presence and health of the Salish Sea's flora and fauna. Understanding the dynamics of the benthic environment is essential in forecasting alteration or destruction of natural features, including changes that may be brought about by sea level rise and impacts from seafloor infrastructure developments or sinkable oil spills. In addition to mapping and describing the status of the marine environment, dynamic modeling of processes such as morphodynamics of the coastal zones allows, via the generation of future what-if-scenarios, an assessment of the effect of engineering measures for the protection of a coast being in danger to be destructed. **Joanna Dudzinska-Nowak and Wenyan Zhang** presented an example of morphogenetic modeling (presented before in the **Wenyan Zhang's et al**. presentation in session 1) of coastal processes of the southern Baltic Sea. These processes are determined by a complex interplay of the geological setting, eustatic sea-level change, glacio-isostatic adjustment, wave-driven sediment dynamics, storm surges, and aeolian processes acting on different time scales. Besides the inputs of hydro-meteorological data, the accuracy of high resolution morphometry within the coastal zone rules the quality of modeling results. This information can be obtained with high precision based on remote sensing data like airborne photographs and airborne laser scanning technology (ALS; LiDAR- Light Detection and Ranging), or with lower precision based on satellite data. These methods are especially useful for quick data registration for large areas where access can be difficult e.g. because of the narrow beach and cliff height, and traditional survey and photogrammetric methods are not feasible. Not less important than the observation site location is also the selection of time periods for the analyses. Inaccurate measurements, an accidental location, and a too-short period of observations, not accounting for hydro-meteorological variability, may substantially bias the forecast and pose a potential threat for the infrastructure planned to be deployed at such sites.

Conclusions

Marginal seas play an important role globally as zones of transition between land and ocean. These marginal seas, crossing all types of climate zones, formed under most various tectonic and geological conditions, play a crucial role for providing people with habitat, food, trade ways, and facilitated socio-economic networking. However, marginal seas are increasingly threatened - depending on their location - by rising sea-level, floods, storms, tsunamis, coastal erosion and environmental hazards that endanger livelihoods. These threats have become even more visible in recent times in the face of climate change and anthropogenic impact on the natural environment. The interrelation between the system-components climate, geo- and ecosystem can be described by sophisticated numerical models parameterized on the short (up to decadal) scales using observational data, and on the longer (geological) time scales by proxy-data interpretations. These models allow on the one hand the reconstruction of the geologic history of the study areas and on the other hand the generation of future projections.

Due to the complexity of natural marine environments, modeling has to be considered a multidisciplinary task with regard to the overlapping themes of the geosphere, bio(eco)sphere, anthroposphere and climate. Teams operating in this field should be embedded into an **interdisciplinary worldwide network** of natural, environmental and social scientists (including historians and socio-economists), civil engineers and IT specialists. As the first step of a marginal seas research team, the network for scientific discussion and exchange of concepts and methods should be

made available by using existing network structures to be adjusted to new specific tasks. Considering the complexity of marginal seas' systems, it is impossible to apply a single model to realistically simulate the diversity of natural environments. This diversity has to be analyzed first in order to determine entities representing types of geologic, hydrographic, dynamic and climatic conditions, requiring individual model approaches. **Key areas** should be selected serving as natural laboratories for types of marginal seas so that research results can finally be generalized and extrapolated. The selection (respective development) of the appropriate numerical models and their parametrization are supported by analyses of data sources. Therefore, the status of available data plays an important role when selecting key areas. An **inventory of data bases** (data mining) and rules of **standardization and harmonization** of research data should be the first steps in regional research.

From the perspective of sequence stratigraphy, the Last Glacial Cycle (~130 kyr) represents an appropriate geological *time frame* to be reconstructed. Data for model validation are available on different time scales from short term (monitoring data) to long term (represented by proxy-data). For future scenarios, climate model data are available on the centennial time scale. Regarding the *spatial scale*, main limitations are the too coarse resolution of climate models (ESM) to reflect regional to local effects of marginal seas. Methods of downscaling have to be considered.

Special **research projects** should be launched as **feasibility studies** for special model approaches on the road to a general understanding of marginal seas processes. Comparative studies of the Baltic Sea and Chinese marginal seas, representing different types of marginal seas in terms of climate zones, geological/tectonic sites and oceanographic conditions, have been conducted successfully and should be continued. Separate studies of marginal seas of special climate zones, such as polar regions, should be considered as next steps on the roadmap.

Marginal Seas projects should be **application-oriented**. The acceptance by stakeholders of strategies suggested for a sustainable development may serve as the project´s quality measure. To maximize a positive effect in this sense, it is suggested to establish an **advisory board** at the beginning of a project that stakeholder representatives are invited to join.

The UN Decade of Ocean Sciences for Sustainable Development provides excellent tracks to balance society's demands and research targets in marginal seas research projects. Special attention has to be paid to financing. Multi-source project funding is recommended including the interest of stakeholders.

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