WP3: Proxy development and innovation: the baseline for progress in palaeoclimate research (Jelle Bijma, Sabine Kasten)

We improve the understanding and readability of the geological and climate archives

Objectives and challenges

To reconstruct past climate variability and the interrelation of different processes for times prior to the instrumental era and anthropogenic influence, marine researchers have to rely on indirect evidence – on information provided by "proxies", which stand as surrogates for particular climate and environmental variables. The analysis of particular marine sediment and ice core properties, water and air samples offers the potential to reconstruct an array of parameters (e.g. temperature, salinity, sea ice cover, global ice volume, nutrients, transport pathways, marine biological productivity, etc.), which allow to reconstruct regional and global changes in the climate system. Much of the success and progress in palaeoclimate research is based on proxy innovation, validation, and the application of multi-proxy approaches to reconstruct climate variability, processes and biogeochemical cycles. Hence, the development and calibration of proxies plays a critical role in climate research. We therefore identify the following major challenges:

- Development of new analytical techniques and methods in order to discover new processes, pathways or mechanisms leading to the observed distributions in established proxies and Identification of possible new proxies (e.g., measurement of trace elements in aerosols stored in ice cores to provide information about transport pathways and source locations).
- Quantification of post-depositional signal modulation through transport and reaction processes in sediments (e.g., to quantify the lateral redistribution of sediments, its sources and timescales).
- Optimising the link between models and data by implementing proxy parameterizations into climate models in order to simulate proxy generation and burial in all available archives ("simulated marine-, lacustrine-, and ice cores"). This challenge will be tackled in close cooperation with T4-WP2.

Implementation

Most proxy calibrations are *empirical* relationships based on observations in recent systems that cover only part of the total variability through time. Ideally, proxy relationships should be based on an understanding of the mechanisms (biological, chemical, physical) by which proxies are linked to their environmental target parameters. With regard to microfossil shells and biomarkers, such a mechanistic understanding includes a detailed knowledge of the actual shell formation process (how are proxies incorporated?) and of the life cycle of the organism (when and where are proxies incorporated?). Because this primary signal is modulated we also need to investigate transport processes (water column/ sediment), bioturbation and preservation (degradation/dissolution and additional diagenetic processes). Similarly, it should be asked how the primary signals preserved in ice cores are modulated by transport, firnification ("lock-in") and ice-flow. Within this WP we will work with different "proxy groups", ranging from micro-fossils, over biomarkers and radionuclides to minerals and elements, which are preserved in ice and sediment records. Some of these can be combined to deconvolve additional environment parameters, others provide information on the same environmental target parameters and allow to cross-calibrate proxy records. In addition to proxies considering salinity and water temperature as well as nutrient cycling, particulate, dissolved and gaseous components of sediments and ice cores will be investigated with respect to their potential use as proxies for biogeochemical cycles. These materials include biomarkers, trace elements, mineral precipitation and dissolution, and natural radionuclides, which are related to the productivity of the surface ocean, the export to the seafloor, and the diagenetic "overprint" that occurs in the sediments.

The expertise and results generated in our WP will form the basis for several "numerical modules" needed in T4-WP2, notably a module on proxy incorporation, on bioturbation and on diagenesis. Vice versa, will the array of simulated proxies produced under T4-WP2 improve our understanding of the mechanisms behind the generation and modification of the primary signal (e.g., production, export, dissolution of different sedimentary/biological components). In addition, reservoir effects and kinetic constraints cause time lags between changes in environmental factors and their imprint in the (different) geological archives. Hence, we will learn about 1) leads and lags of different proxies in the same archive and 2) leads and lags of the same proxies in different archives. A process of iteration allows to better constraint proxy relationships.

This WP brings together a multidisciplinary consortium (geologists, biologists, chemists, physicists, mathematicians, mineralogists and paleoceanographers) that follows an integrated approach by combining laboratory experiments, field studies and numerical modelling. The ultimate goal of this WP is to develop new techniques and a process based understanding of relationships between different proxy groups and their respective target parameters in all available archives, in order to make past climate reconstructions and future climate predictions more reliable.

Milestones

- Multi-element characterisation by GC-TOF-ICP-MS (Gas Chromatography - Time of flight - Inductively coupled Plasma - Mass Spectrometer) and development of new analytical opportunities by using a femtosecond laser for sample ablation in combination with a multicollector ICP-MS-OES (Multicollector Inductively coupled Plasma - Mass Spectrometer and Optical Emission Spectrometer) (years 1-2).
- Development of conceptual models of proxy generation, transport and secondary modification, which will be translated into numerical modules to be implemented in Earth System Models that generate “simulated proxy records versus time” (close cooperation with T4WP2) (years 2-5).
- Better interpretation of leads and lags of proxies (e.g. $\delta^{18}O$) between different archives. Both real and “simulated” records will be used to match them internally in order to create a common time frame. This is a prerequisite to understand action and reaction in the climate system explaining leads and lags.

Deliverables

- Development of a process-based understanding of proxy generation (production, seasonality, incorporation) and transport (export, deposition), which includes:
  - Incorporation of (trace) elements into foraminiferal tests, coccolithophorids and other biogenic materials and development of compound specific δD as an independent proxy for seawater salinity.
  - Improve the opal-based isotopic proxies ($\delta^{30}Si$, $\delta^{15}N$) of nutrient cycling and develop Selenium as a proxy for biological productivity (aerosols, ice cores).
  - Quantify particle fluxes, source and transport processes in marine sediment (Th, Pa, ^{210}Pb, etc.) and ice cores records (trace elements contained in aerosols).
  - Reconstruct regime shifts in pelagic and benthic systems during the past century, based on nutrients, radio nuclides, macroorganism bioarchives and biomarkers in the sediment (regime shifts as a consequence of climate change and human pressure).
- Assessment of postdepositional signal modulation (bioturbation, dissolution, lock-in depth, diagenetic overprint), e.g., development of improved indices describing organic matter preservation, carbonate-dissolution and opal-preservation and redox conditions in the bottom water and the sediment at the time of deposition.
- Development of numerical modules (considering proxy incorporation, bioturbation, diagenesis, etc.) to be implemented in the “simulated cores” experiment.

2.3.3 Expected results, milestones

We expect to significantly improve our understanding about polar climate sensitivity, the forcing mechanisms and feedbacks that drive climate variability and the rates of change.
Combining our results from analytical studies with integrating studies using numerical models will broadly enhance our knowledge about the interaction and interference of climate variability that operated on different spatial and time scales (decades to millions of years). The development of new and improved paleoproxies, their application for reconstructing climate variability as well as their implementation in models to simulate proxy generation and burial in

different archives promise to yield valuable additional information from the various compartments of the earth system. From this, we also expect a better understanding of the primary processes involved in the incorporation of the environmental signals as well of the secondary processes masking the primary signal in marine archives and ice cores. In this context we expect to achieve major breakthroughs by the development of innovative analytical techniques, based on multi-element characterisation by GC-TOF-ICP-MS (Gas Chromatography - Time of flight - Inductively coupled Plasma-Mass Spectrometer). The improvement of the library of proxies for climate reconstructions along with our interdisciplinary investigations at a large variety of temporal scales will contribute to a more comprehensive mechanistic understanding of the Earth's climate system. This will augment our capacity to generate reliable estimations of future climate and sea level development under different anthropogenic impact scenarios. In close cooperation with T1 and T4, this may provide also ways towards most effective mitigation procedures and technology. In this respect, our investigations on time periods that are marked by warmer than present conditions promise to hold important clues for understanding certain aspects of future climate change. The joint studies will allow the successful submission of "ready to drill" proposals in the framework of IODP (polar South and North Pacific) and the identification of sites in the ice covered Arctic Ocean to be drilled during expected cruises of the ice-breaking research vessel *Aurora Borealis*. Such drilling will allow new discoveries on the ice-ocean development during the Cenozoic from yet little explored ocean basins that are crucial for the documentation and understanding of Earth's climate and tectonic development.

2.3.4 Cooperations

Our outlined visions require cooperation with national and international research institutions and universities to gain from complementary expertise. Our cooperative efforts include the share of research vessels, drilling platforms and investigating technology, as well as data exchange and joint projects that are embedded in international research programs like ICDP/IODP, EPICA-MIS, IPY (PLATES & GATES, BIPOMAC), PAGES, ANDRILL, SCAR/ACE, IBCSO, Inkaba yeAfrica, CLICOPEN, ANTPAS, IBCSO, and others. The following table summarizes some of the most important partners for our research topic.

<u>National Partners:</u>

University (Department of Geosciences, MARUM)	Bremen
University (IFG, IFM-GEOMAR)	Kiel
Federal Institute for Geosciences and Natural Resources (BGR)	Hannover
University (Inst. for Chemistry and Biology of the Mar. Environment)	Oldenburg
GeoForschungsZentrum	Potsdam
University (Inst. for Geosciences)	Tübingen

International Partners:

British Antarctic Survey	Cambridge	UK
University Bergen (Dept. of Earth Science), Geological Survey of Norway (NGU)	Bergen, Trondheim	Norway
Lamont-Doherty Earth Observatory Institute, Universities of California	Palisades, Davis, Santa Cruz	USA
State University Moscow, All-Russia Res. Institute for Geology and Mineral Resources (VNIIOkeangeologia)	Moscow, St. Petersburg	Russia
Weizmann Institute of Sciences	Rehovot	Israel
Laboratoire de Glaciologie et de Geophysique de l'Environment (CNRS/CEA)	Gif-sur-Yvette	France
University of Bern (Physics Institute), ETH	Bern, Zurich	Switzerland
Geoscience Australia, Australien Antarctic Division-CRC	Canberra, Hobart	Australia
University of Utrecht, Netherlands Institute for Sea Research (NIOZ)	Utrecht, Texel	Netherlands
University (Centre for Ice and Climate)	Copenhagen	Denmark