WP 4: Antarctic Circumpolar Climate and Ecosystem Study (Volker Strass, Christine Klaas, Reiner Schlitzer)

We will carry out long-term observations of the physical, chemical and biological changes that are currently underway in the Southern Ocean and we will perform multi-disciplinary process studies focused at the possible controls and feedback mechanisms between the Southern Ocean and the global climate, with the aim to enable reliable predictions of future developments.

Objectives and Challenges

The Southern Ocean plays a critical role in the earth's climate system. Its major feature is the broad ring of cold water - the Antarctic Circumpolar Current (ACC) - that isolates the Antarctic continent while connecting all the other oceans. It harbours a series of unique and distinct ecosystems along zonal bands that displace each other with changing climate regimes. Superimposed on the major zonal currents is a meridional circulation that *inter alia* involves the northward spreading of intermediate and bottom waters and accounts for the up-welling of macronutrients in the Antarctic Divergence. Because of these unique features, the ACC plays a major role in the ocean-wide heat transport and the global biogeochemical cycles. Furthermore, the ACC could potentially sustain a stronger biological pump of carbon if primary production were not limited by lack of the trace nutrient iron, as demonstrated during the previous programme period (see Annex). While the Southern Ocean plays an important role in the global climate system, it is *vice versa* likely affected by anthropogenic impacts such as global warming and ocean acidification. Complex physical, chemical and biological feedback mechanisms are at work, which need to be investigated at specific levels but in perspective of the global system.

Combining measurements, experiments and models, our work package is aimed to meet the following objectives:

- Documentation of the changes that are currently underway in the Southern Ocean and identification of the driving processes that needs to be represented in models for predicting future changes.
- Assessment of the impacts of large-scale iron input and ocean acidification on the pelagic ecosystem and the cycling of elements.
- Development of proxies that reveal spatial and temporal changes in elemental cycling and thus are instrumental for an improved interpretation of the paleo-record stored in sediments.

Implementation

Changes in properties and circulation of key water masses, with an emphasis on the Circumpolar Deep Water in the eastern Weddell Sea inflow, will be observed by an under-ice profiling float system and by moorings with upward looking sonar, profiling CTDs and ADCPs. Changes associated with newly formed deep and bottom water will be monitored by repeating transects in the Atlantic Sector of the Southern Ocean and by moored instruments in the Weddell outflow continuing a time series that was begun in the late 1980's. Observations of the ACC fluctuations off South Africa will be documented by pressure inverted echo sounders. Optical measurements of phytoplankton parameters and acoustic sounding as well as net-catches of zooplankton including krill will be used for biological surveys. The new data will be interpreted in the context of historical hydrographic data sets, including 25 years of *Polarstern* cruises. Assimilation and inversion of *in situ* and remote sensing data in models will be employed to quantify nutrient and carbon fluxes and to study element cycles of trace elements and isotopes. Data collected during the IPY by *Polarstern* expeditions contributing to CASO, GEOTRACES, SCACE and ANDEEP-SYSTCO will allow assessments of the status quo, thus providing baselines for subsequent studies. These studies will consider the variation of trace elements and (radio-) isotopes in space, time and with particle type, fluxes in the water column and at the seafloor, and the contribution of microbes to carbon remineralisation and respiration within the bottom water and surface sediments. Trace element distributions, such as $^{231}Pa/^{230}Th$, will be simulated in cooperation with TOPIC 3 with models to test their value as a proxies of past changes.

In order to distinguish natural from anthropogenic variations of water mass characteristics and circulation patterns, the use of a coupled atmosphere-sea ice-ocean modelling with eddy resolution in the Atlantic sector is planned that will be up-scaled in TOPIC 4. Process-oriented field studies in cooperation with WP 3 will be conducted on the control of primary production and the biological pump by physical forcing and relationships in the plankton community structure. Laboratory experiments and modelling will be directed at a quantitative description of

physiological/ecological processes of carbon uptake and utilization in the plankton. The CO_2 uptake and transport in the Southern Ocean will be quantified and separated into natural and anthropogenic contributions by combining *in-situ* measurements and process-modelling. Island effects on micronutrient (iron) transports and its effect on productivity will be studied by high resolution modelling with realistic topography. Development of new biogeochemical general circulation models (BOGCMs) will feed into activities of TOPIC 4 in order to simulate major ecological/biogeochemical processes (distribution of tracers, air-sea gas exchange) on the larger to global scale.

Gaps in existing knowledge and understanding of the role of iron in regulating the biological pump of carbon shall be identified through synthesis analysis of iron fertilization experiments conducted by RV Polarstern (see ANNEX) and by other ships as available from data archives. As possible reasons for differences in carbon export between experiments will be considered (i) the duration of the experiment, (ii) the vertical and horizontal mixing regimes, (iii) macronutrient background concentrations, (iv) phytoplankton and zooplankton assemblages, and (v) food web interactions. For an assessment of the feasibility and risks of iron-fertilization as a geo-engineering option to mitigate the greenhouse gas problem the BOGCMs mentioned above will be employed. Laboratory experiments and mechanistic modelling at the organism level are planned for testing hypotheses about the influence of ocean acidification and related changes on nutrient and trace metal speciation and on autotrophic processes and calcifying organisms.

In close cooperation with TOPIC 3, organisms that have been proposed as producers of proxies will be collected from the marine environment. Experiments with proxy organisms mimicking different processes that can influence proxy values will be run under laboratory conditions. Further development of models on the scale of single organisms, aimed at a process-based understanding of proxies is planned.

Milestones

- Development of a high-resolution circulation model suitable for an assessment of islands and shallow shelf sediments as sources of micronutrients for enhanced surface primary productivity by the end of the programme.
- Development of automated techniques for the identification and counting of organisms (colour from space, microscopy, flow cytometry, FISH (Fluorescent In-Situ Hybridization), genetic chips) and of better methods to estimate export fluxes (particle counters, free-drifting sediment traps) throughout the programme.
- Assessment of $^{231}Pa/^{230}Th$ as a tracer of paleo-circulation after half the programme period.

Deliverables

- Description of the inter-annual to decadal variability in physical, chemical and biological properties and determination of the regional circulation and of biogeochemical fluxes by assimilation and inversion of *in-situ* and remote sensing data.
- Description of physical control mechanisms of primary production and of key organisms in the food web such as krill, for which a multi-parameter description of likely changes under scenarios of climatic variability is intended.
- Quantification and understanding of the influence of ocean acidification and related changes on nutrient and trace metal speciation and on the pelagic ecosystem.
- Assessment of the impacts of large-scale iron input on global climate and of the feasibility and risks of employing iron-fertilization as a geo-engineering option to mitigate the greenhouse gas problem.
- Description of the variability of proxy organisms with environmental conditions and its impact on the isotopic composition of biogenic materials in the surface ocean and sediments.