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HELMHOLTZ GEMEINSCHAFT

Role of Ice Sheets in the Earth System

We investigate the role of polar ice sheets for sea level change, as an archive of past climatic conditions and as a limiting edge for life in extreme environments.

Objectives and Challenges

Polar ice sheets are a crucial component in the hydrological cycle. They store more than two third of the global freshwater, which is equivalent to up to 70 m in terms of sea level change, and are the largest reservoir of potable water. Based on results obtained during the MARCOPOLI programme, we state that dynamics in polar ice sheets contribute ~15% to the present global sea level rise. The uncertainty for Antarctica's input is of the same order as the total estimated polar contributions, mainly due to the unknown mass balance of the ice sheet. Additional uncertainty arises from potential disintegration of ice shelves in a warmer climate, which may strongly influence ice stream dynamics. An improved mass balance requires a thorough investigation of the fluxes from the atmosphere, across the grounding line and finally into the ocean.

The physical and chemical processes in the atmosphere, at the snow surface and in the firn body control the atmosphere - ice sheet interaction and proxy signal formation for further ice core studies. Basal melting and re-freezing influences ice sheet and ice shelf dynamics. Iceberg calving and decay impacts the ocean, and leaves morphological and biodiversity imprints on the sea floor. Paleo-climatic interpretation of ice cores relies on the knowledge of the internal structure and dynamics of the ice sheet. The role of the sub-glacial hydrological system for ice sheet dynamics needs to be assessed, and sub-glacial lakes represent a so far unknown isolated habitat for ancient microbes.
Therefore, we address the following challenges:

- Reducing the uncertainty of the polar contribution to sea level rise by improving our knowledge of ice-sheet mass balance, that will require a better understanding of the stability of the ice sheet and the ice shelves
- Quantification of recoverable water resources in the cryosphere to mitigate global shortages in fresh water
- Assessment of the impact of ice shelf disintegration on Southern Ocean water mass characteristics and macro-benthic systems
- Quest for the oldest ice-core record in Antarctica by providing high resolution data of ice sheet geometry, internal structure, net surface mass balance, and interaction with atmosphere and the sub-glacial environment
- Description of life forms and understanding of the processes in the sub-glacial environments by means of modelling, direct measurements and sampling

Implementation

The state of the polar ice sheets, including geometry, dynamics, internal structure, and interfacial exchanges at the surface and base will be assessed by combined modelling and observational efforts. The observational component comprises remote sensing, ice core drilling, in-situ measurements, and repeated oceanographic surveys in cooperation with WP 2, 3 and 4. It also includes the evolution of ice-shelves, the fate of icebergs as they drift in the ocean, and the impact of both on benthic communities, which will be investigated by marine biology field experiments linked to activities in WP 6.

AWI's Polar 5 aircraft will serve as platform for ice and snow penetrating radar and laser altimetry. It will also logistically support ice core drilling for ground-truth and surface mass-balance and signal proxy formation studies in the interior of East Antarctica based on support by TOPICS 5 and 6. Long-term records of meteorological parameters will be continued on board of RV Polarstern and at the polar stations, complemented by selected airborne surveys of air temperature, trace gases, aerosols, and meteorological base parameters. Precipitation above the ice sheet, trace element and stable isotope deposition, and the radiation balance are the key atmosphere-ice interaction processes, which will be investigated. The measurements will serve as input for and validation of numerical models derived during the MARCOPOLI programme (see ANNEX) with various complexities. Namely, high-resolution 3-dimensional time evolution (4-d) models of ice sheet, ocean, and atmosphere, with the ultimate purpose of providing a coupled ice sheet, ocean, sea-ice, and atmosphere model that eventually will feed into TOPIC

4 activities. The application of a separate ocean model to sub-glacial lakes will foster our understanding of the circulation in the sub-glacial environment and its mass fluxes across the ice/lake boundary. The causes for recent regional and global sea level changes will be addressed by ocean modelling using the four-dimensional variation analysis (4d-var) assimilating data from oceanography, geodesy, and glaciology. Improvements to the digital and topographic database - International Bathymetric Chart of the Southern Ocean (IBCSO) - will allow to model morphological remnants of paleo ice-sheet extensions in cooperation with TOPIC 3. Polarstern will be sent to the western Weddell Sea (Larsen Ice Shelf) to monitor the dynamics of macro-benthic systems in an un/disturbed environment and to characterize and quantify dense shelf water sources, important for the formation of deep and bottom waters.

Refrozen water, unexpectedly discovered in the EDML (EPICA Dronning Maud Land) borehole, will be analysed for dissolved and particulate trace elements as well as gases to determine the origin and history of the sub-glacial water. Procedures for biological studies in sub-glacial lakes will be tested on existing ice cores (e.g. EDML) to record their biological history. In addition, we will work on methods for sterile penetration into the pristine sub-glacial environment to study its microbiological constituents.

Milestones

- Availability of a coupled ocean-ice sheet model based on unstructured grids to study the behaviour of the polar ice mass in a changing climate (year 5)
- Improved assessment of the mass loss of the Antarctic ice sheet draining into the Weddell Sea and its impact on hydrography (year 3)
- Field surveys for mapping bathymetry, ice thickness, internal structure, snow accumulation and snow-pack variability (year 5)
- Contribution to the development of new sampling methods for entering the pristine sub-glacial environment (year 3)

Deliverables

- Determination and quantification of physical and chemical processes controlling interaction and signal transfer between atmosphere, snow, and firn
- Analysis of life beneath Antarctic ice shelves, in ice sheets and in the sub-glacial hydrological system in relation to its ecological constraints; description and modelling of circulation, tracer distribution and mass fluxes in the sub-glacial hydrological system
- Prediction of sea level rise in a warming climate by considering the ice sheet mass balance and the steric expansion of seawater based on the understanding of the observed changes
- Prototype of a coupled ocean-ice sheet numerical model (based on unstructured grids) for Antarctica
- Assessment of the Weddell Sea focused on an iceberg census to quantify the amount of available freshwater and on the relation between various shelf water sources and deep and bottom water variability
- Higher resolved maps of ocean bathymetry and Antarctic ice sheet thickness, internal structure, accumulation and snow-pack variability