WP1: Current and Future Changes of the Earth System (Klaus Dethloff, Jens Schröter)

Quantify the impacts of high latitude feedbacks for climate variations of the Earth on decadal to centennial time scales.

In the framework of PACES we will focus on consequences of Arctic warming (the shrinking of summer sea ice, changes in atmospheric circulation patterns, cloud cover and water vapour changes, melting of permafrost, changes in ice transport in response to atmospheric wind and ocean currents, stratospheric ozone reduction), the ocean-shelf-ice interaction (including deep water formation, stability of shelf-ices, sea level, changes in ocean heat transports), and the ecology and biogeochemistry in the Southern Ocean (changing of circulation and mixing in a warming climate, changes of oceanic CO_2 uptake, impacts of large scale iron fertilizations) because of their importance for global climate.

Objectives and challenges

The observed strong Arctic warming over the last few decades has been attributed to increased greenhouse gas concentrations and the strong natural variability in the coupled ice-ocean-atmosphere system. Arctic summer sea ice cover is expected to almost disappear in the second half of the 21st century. Projected changes of sea ice in the Southern Hemisphere are less drastic, but other major changes (e.g. ocean temperature, water mass formation rates) are expected. Qualitative and quantitative consequences of these changes for ocean, atmosphere, and ecosystems are obvious and impacts on global climate are unavoidable. Warming will lead to melting of permafrost and thus to further release of methane and to changes of atmosphere and ocean circulation that may affect the uptake of CO_2 by the Southern Ocean. The ocean-shelf-ice interactions in a warming world, the release of freshwater and its impact on ocean circulation and mixing with consequences for marine ecosystems are of particular importance. The understanding of the polar climate system is still incomplete due to its complex atmosphere-land-cryosphere-ocean-ecosystem interactions involving a variety of distinctive feedbacks. In particular clouds, aerosols and ozone, planetary boundary layer processes, sea ice, and marine ecosystems are not well represented in climate models (IPCC, 2007). On annual and decadal timescales the various earth system components interact mainly via the atmosphere and the upper ocean dynamics (circulation, waves, mixing), greenhouse gases (H_2O, CO_2, CH_4) and energy and moisture fluxes.

The major research aim within WP1 is to describe the most important physical and chemical mechanisms that control the atmospheric and oceanic circulation patterns in polar regions and on the global scale and their consequences for decadal scale climate variability as a result of the nonlinear dynamics of the coupled atmosphere-ocean-sea-ice-ecosystem under the influence of external forcing factors.

Sea ice plays a crucial and central role in the climate system due to the impact on ice-albedo feedback mechanism, exchange of heat, water and momentum, freshwater transport, and the influence on the lower stratosphere. Improved descriptions are needed for atmosphere-ocean-sea-ice feedbacks, aerosol and cloud-water vapour feedbacks in the troposphere and ozone feedbacks in the stratosphere, to be synthesized with Topic 1 (WP2).

One of the major findings documented in the recent IPCC report is that we are now pretty confident that the effects of climate change on the global carbon cycle will lead to a further increase in atmospheric CO_2 content, i.e. a positive feedback to climate change, where the Southern Ocean and the land biosphere contribute most to this feedback.

Recent and ongoing changes in sea-ice and land-ice volume, sea level and other oceanic properties are analyzed and put into a global context. To this end we will integrate detailed modelling and measurement studies carried out in PACES.

Implementation

An ESM will be set up with state-of-the-art coupled modules for the atmosphere, ocean, land and ocean biosphere and newly developed or improved modules of polar components. Global simulations with this ESM including substantially improved representations of polar processes will be analyzed in order to study the impact of processes in Polar Regions via atmospheric and oceanic teleconnections with other regions and within the global climate system.

Sensitivity studies will be carried out including the initial simulated sea-ice state, ocean circulation, cloud conditions, water and accumulation cycle, natural variability in the modelled system, interplay between natural variability modes and external forcing factors. These tie in strongly to the strength and characteristics of the ice-albedo and other polar feedback parameterizations and anomalous ocean heat transports. There is a high uncertainty regarding the time span when a seasonally ice free Arctic ocean will be realized, how the coupled system will reach that state, and what would be the impacts of this new state on the Arctic system and the rest of the globe. A main goal is to include the key dynamical-radiative-chemical interactions in the tropo- and stratosphere and to clarify the interactions between high latitudes and the global system.

A global sea-ice-ocean model with varying resolution will be coupled to models of the regional atmosphere as well as ice sheets. Processes of ice-shelf dynamics in conjunction with the oceanic circulation below the floating ice shelf will be addressed. Of special interest is the possible instability of the West Antarctic Ice Sheet. Here data analysis of past oceanic change together with climate scenarios provide a basis for investigating observed ice sheet and ice-shelf variability and their possible future. Inverse modelling allows to attribute observed change to different causes such as shift in oceanic circulation regimes, variations in local forcing or water mass formation processes in more remote locations.

The global oceanic teleconnections of local change in key regions at high latitudes are represented in a global model that specifically simulates the local processes under consideration in a seamless way by varying spatial resolution. The quality of the earth system model will be assessed by inverse modelling. The earth system model will be supported by data analysis and inverse modelling.

The uptake of CO2 in the Southern Ocean is given by the imbalance between outgassing of upwelling water, uptake by cooling southward headed surface flows, and uptake by biological production and export. This imbalance varies with sea ice cover and severe limitation of biological production by iron and light and vertical motion. Climate variations can change temperature, circulation, mixing, nutrient and iron supply (dust) and thus the current sink for atmospheric CO2. Simulation of the variations in the Southern Ocean is challenging because of the small scale vertical motion induced by rough bottom topography and eddy dynamics, the interaction with sea and land ice, and the complexity and patchiness of pelagic ecosystems including the cycling of iron. Model components for the sea and shelf ice and for the pelagic ecosystem are already available, and will be coupled to the finite element ocean model (FEM) of varying resolution to adequately resolve all scales of interest, in order to quantify Southern Ocean feedbacks in the global carbon cycle.

<u>Milestones</u>
Set up of an ESM that includes substantially improved coupled modules for circulation, stratospheric chemistry, sea ice, marine biogeochemistry, permafrost (year 2)
Sensitivity, coupling and validation studies with improved polar process parameterizations (year 3).
Coupling of adaptive model components with unstructured grids (year 3).

<u>Deliverables</u>
- Improved process description of regional Arctic climate feedbacks concerning aerosols, water vapour and stratospheric ozone and their global impact.
- Scenarios of Arctic sea ice cover changes.
- Quantification of Southern Ocean carbon cycle feedbacks.
- Analysis of oceanic variability in observations and scenarios with special attention on the possible instability of the West Antarctic Ice Shield.
- Contributions to the 5th IPCC Assessment Report (2011).