WP 5: The role of degrading permafrost and carbon turnover in the coastal, shelf and deep sea environment (Hans-Wolfgang Hubberten, Julia Boike)

We describe and quantify effects of climate change on terrestrial, coastal and sub-sea permafrost and unfrozen marine deep-sea sediments in the Arctic that significantly alter the energy, water and carbon budget on land and in the ocean.

<u>Objectives and challenges</u>

Carbon fixation or mobilizations due to environmental changes in the Arctic are crucial for the carbon balance in the ocean-land-atmosphere system and for the release of greenhouse gases to the atmosphere (see recently published results in ANNEX). Humanity's socio-economic interest lies in predicting how the carbon, energy and water balance of complex northern ecosystems will respond to ongoing climate warming. The aim of this WP is to observe, quantify and model the occurring processes and their impact on the atmosphere and climate system.

Considerable amounts of methane are stored in permafrost and sediments of the Arctic coastal margin. Gas hydrates in landside and offshore permafrost as well as pockmarks, seeps, mud volcanoes or gas hydrates at the Barents Sea margin and around Svalbard highlight the reservoirs and dynamics of the Arctic methane cycles. Expected environmental changes and global warming will influence the dynamics cycle of methane, trace gases, and fluids. Until now, impacts forced by temperature changes, sea level rise, degradation of permafrost or altered slope stability on the release and fate of methane are essentially unknown. Extremely high ground ice contents, the highest river input of any ocean and broad shallow shelves render the Arctic coastline particularly sensitive to change. Ground ice content remains the primary geo-morphological determinant of coastal retreat rates. Submarine permafrost degradation is sensitive to the coastal retreat rate, and to seawater salinity and temperature, which vary with sea ice dynamics.

Global warming will have important implications for the water, energy and carbon budgets and for the functional diversity of microbial communities in these systems. It is likely that temperature increases in high latitudes will also stimulate microbial activity and thus, carbon decomposition and thereby accelerate climate change through the increase of trace gas (CH_4, CO_2) release.

Marine dissolved organic matter (DOM) was shown during MARCOPOLI to represent an enormous organic carbon pool on a global scale, important to global carbon fluxes, secondary production and climate change. Modification processes are largely unknown; transport routes are unclear due to limited information of on-shelf ocean circulation. Terrigeneous DOM in permafrost regions may be released and transported by rivers to the ocean in short time span. Using satellite imagery to measure dissolved and suspended carbon fluxes in the circum-Arctic coastal zone is a potentially powerful method for assessing carbon fluxes at large spatial scales.

Therefore the major challenges in the workpackage are …

- to understand the processes leading to the release of methane or to an instability of gas hydrates due to temperature changes
- to understand the consequences of warming permafrost for Arctic coastal erosion, mass flux, landscape formation, and gas release
- to elucidate the cycles of carbon, water and heat as well as the relevant microbial processes and communities in the complex Arctic landscape at scales from meters to kilometres
- to understand the central processes and to quantify the amount of transported carbon (DOM) by applying new instrumental techniques

<u>Implementation</u>

Gas hydrates in permafrost and deeper marine sediments:

The coastal zone and shelf areas of the Laptev and East Siberian Seas, the continental margin of Svalbard as well as mud volcanoes and pockmarks in the Barents and Norwegian Seas are our study areas... The field studies include water column and sediment investigation of methane, carbon dioxide, pore water and sediment composition, stable isotopes, radon and tracers for sediment-water exchange. New techniques, including in situ mass spectrometers and a mobile underwater vehicle from TOPIC 5 and 6 are used. Long-term benthic observatories, deployed off Svalbard in WP 3, provide information on temporal variations. Observational evidence to test models of the evolution of northern, continuous permafrost since the beginning of the glacial/interglacial cycles is needed. The application of state of the art geophysical sounding techniques provided by TOPIC 3 in regions where historical data are available will give an indication both of the current state and the rate of change of permafrost.

Carbon, energy and water fluxes in permafrost landscapes:
The main objective is to elucidate the cycles of carbon, water and heat fluxes and the related microbial processes and communities in the complex Arctic landscapes at scales from metres to kilometres. The integrated research strategy combines flux measurements (carbon, water, heat), characterization of permafrost environments (vegetation, soil, micro-morphology) and microbial communities (structure, function, stability). The application of multi-scale remote sensing techniques allow closing the gap between the understanding of small-scale pattern and the large scale processes accessible to satellite-borne remote sensing.

Change in the Arctic coastal zone:
To understand Arctic coastal change within a framework of standardized, co-ordinated pan-Arctic research that link our activities to those in TOPIC 2, the trajectory, rate and environmental controls of coastline position change in the Arctic and the key climate-dependent geo-morphological and surface changes in periglacial landscapes will be studied. This includes changes to ground ice volume, which controls the rate of erosion, sediment delivery to the ocean, the surface mass balance, carbon release and the position of the ground surface. Methods include the derivation of distributed surface parameters from satellite data, and the assessment of mass fluxes using satellite-derived digital elevation models. The indication of characteristic plant associations and spectral signatures leads to the detection of changing surface patterns. Ground truth requires field data on permafrost, botany, spectrophotometry, morphometry and coastal geo-morphodynamic characteristics.

Production, transportation and fate of organic matter:
Organic matter is initially formed during primary production in the surface ocean or rivers, or mobilized in soils, then modified via biotic and abiotic processes to particulate or dissolved form and transported into the deep ocean by thermohaline circulation. Modification and transport processes are uncertain but influenced by the predicted global changes. Permafrost regions are probably extremely sensitive because enormous amounts of dissolved organic matter may be released and transported to the oceans. New techniques such as high-resolution mass spectrometry will allow detailed molecular characterisation of organic matter, a prerequisite for all process studies, and radiocarbon analysis. Residence times, transport rates, and erosion of previously permafrost-stabilized organic matter will be studied from source to sink in projects with WP 3. Newly collected data on the Arctic coastal under-water light field and coloured dissolved organic matter will enable the parameterization of Ocean Colour satellite data for spatial extrapolation.

<u>Milestones</u>

- Methane, trace gases and dissolved carbon fluxes from sediments into the water column and from terrestrial permafrost to the atmosphere will be quantified (3 to 5 years).
- Insights into the function and stability of microbial communities involved in the carbon turnover and the response of micro-organisms to warming (5 years)
- Numerical models of transport and reaction processes in biogeochemical cycles, including methane release and gas hydrate stability (5 years)

- Circum-Arctic and regional coloured maps of coastline position changes, dissolved organic matter, dissolved organic carbon and suspended particulate matter will be provided (3 and 5 years, respectively)

Deliverables

- Quantification of methane, trace gases and dissolved carbon fluxes from sediments into the water column and from terrestrial permafrost to the atmosphere.
- Quantification of gas hydrates occurring in shallow coastal and offshore permafrost and potential methane liberation due to permafrost degradation
- Functional diversity assessments of micro-organisms involved in the Arctic carbon cycle and the response of microbial communities to warming
- Identification of spatial and temporal linkages between fluxes at the plot and landscape scales and from land to ocean of different permafrost affected ecosystems
- Quantification of the trajectory and rate of and environmental controls on coastline position change in the Arctic
- Production of circum-Arctic and regional coloured maps of dissolved organic matter, dissolved organic carbon and suspended particulate matter