Annual Meeting 2017: Modelling Coupled Earth and Human Systems – The Dynamic Duo
Boulder, Colorado, USA
May 23-25, 2017

Michael Angelopoulos[1,2], Pier Paul Overduin[1], Mikhail Grigoriev[3], Sebastian Westermann[4], Guido Grosse[1,2]

[1]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Institute of Earth and Environmental Sciences, University of Potsdam, Potsdam, Germany
[3]Permafrost Institute, Siberian Branch of the Russian Academy of Sciences, Yakutsk, Russia
[4]Department of Geosciences, University of Oslo, Oslo, Norway

The effects of changing boundary conditions on modelled heat and salt diffusion in subaquatic permafrost offshore of Muostakh Island, Siberia

INTRODUCTION

Geophysical datasets, thermal modelling, and drilling data suggest that a large portion of Arctic shelves are underlain by submarine permafrost due to their exposure during the glacial low water stands. The degradation of subsea permafrost depends on the duration of inundation, warming rate, the varying degree of coupling of the seabed to the atmosphere through changing water column and sea ice conditions, and brine injections into the seabed. This study evaluates the effects of changing upper boundary conditions on subaquatic permafrost thaw rates using CRYOGRID, a one-dimensional heat diffusion model, which was extended to include coupled dissolved salt diffusion. More specifically, the impacts of using a seasonally varying seabed temperature function compared to a mean annual seabed temperature for both freshwater and saline water bodies were assessed. Daily observations of seabed temperature and electrical conductivity from 01-09-2008 to 31-08-2009 offshore of Muostakh Island (71.67153°N, 129.99611°E) in Siberia were used to set up the upper boundary conditions for the base case model runs. For saline water bodies, sensitivity analyses for mean annual salt concentrations and seabed sediment type were also performed.

MODEL GOALS

1. Assess the impact of using seasonally varying seabed temperatures compared to a mean annual seabed temperature for freshwater and saltwater (constant salinity) on talik growth and permafrost warming rates.

2. Assess the impact of using both seasonally varying seabed temperatures and salinity on talik growth in a marine setting.

MODEL RESULTS

1. Freshwater Case: The mean annual seabed temperature (MAST) model produces a 3m thick talik after 60 years of inundation, because grounded ice conditions do not occur as in the seasonally varying seabed temperature (SVST) models.

2. Saltwater (Constant Salinity Case): For high seawater salt levels (i.e. 420 moles NaCl/m³), the MAST and SVST show very similar results, because dissolved salts below the seabed depress the pore water freezing point sufficiently to prevent ice formation in the near-surface sediment.

3. Saltwater (Seasonally Varying Salinity Case): For the daily seawater salinity and temperature input model at Muostakh Island, a seabed active layer slows talik growth. This occurs, because seawater salinity decreases in summer due to lower salinity bottom water in coastal regions, which leads to diffusion of salt from the seabed in the summer.

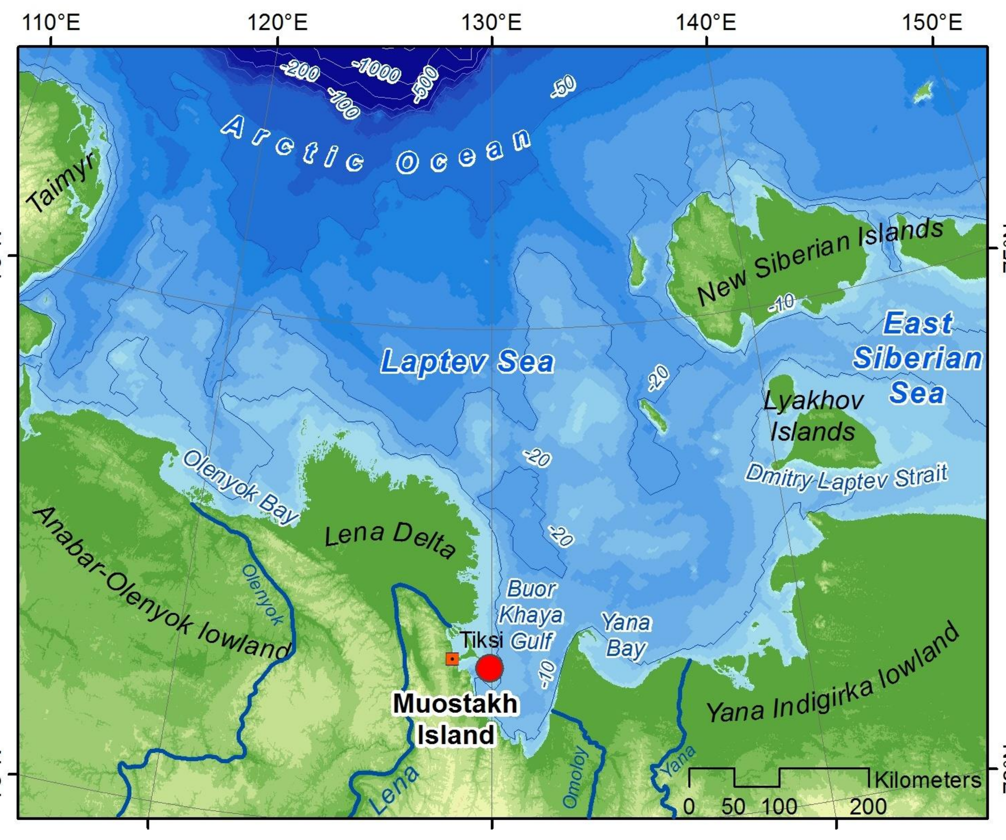
IMPLICATIONS

Given the current trend of freshening in the Arctic Ocean, we expect seasonal freezing of the seabed to be more common for newly submerged permafrost caused by coastal erosion, and thus potentially leading to slower permafrost table degradation rates.

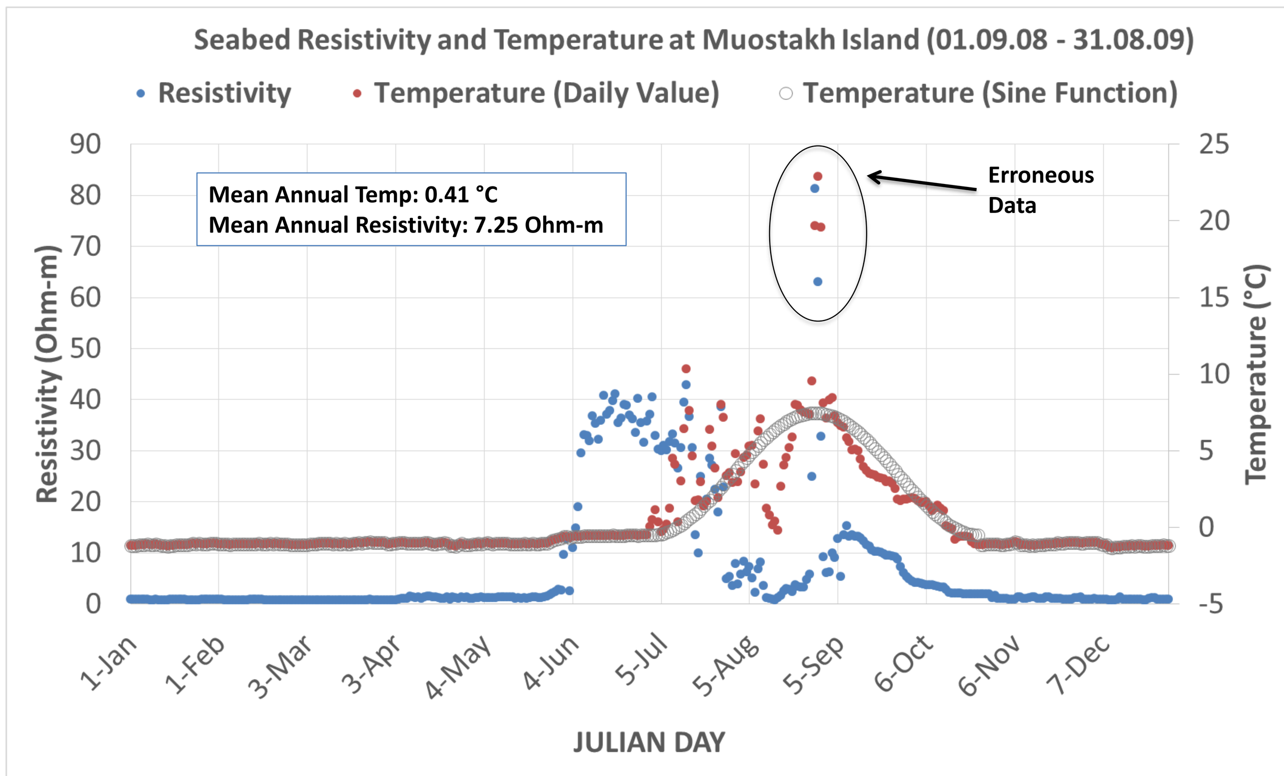
MODEL ASSUMPTIONS

- All the models were run with daily time steps
- All the models started on September 1st
- The upper boundary condition transition from a terrestrial to marine setting is defined by a linear function over a time of 365 days.
- The lower boundary condition is a geothermal heat flux of $50x10^{-3}$ W/m² (4.3 KJ/m²/day)
- The initial undisturbed temperature regime of permafrost was defined using a steady-state condition (ground surface temperature of -10 °C and a geothermal heat flux of $50x10^{-3}$ W/m²)
- The initial salt concentrations were set to 0 moles NaCl/m³ everywhere in the model domain.
- Model grid configuration: logspace(1,log10(6010),500)'-10
- Model depth of 6km
- The porosity of the silt is 0.4 and the porosity of the clay is 0.5.
- For models with salt diffusion, the salt diffusion coefficient is the same in all models.
- For models with salt diffusion, the tortuosity is the same in all models.
- The mineral particle conductivity of the silt is 3.0 W/m*K and 2.0 W/m*K for clay.
- The Van Genuchten parameters of the silt are 1.67 (n) and $6.5*10^{-4}$ mm^{-1} (α). Refer to Dall'Amico et al. (2011) for additional information.
- The Van Genuchten parameters of the clay are 1.25 (n) and $1.49*10^{-3}$ mm^{-1} (α). Refer to Dall'Amico et al. (2011) for additional information.

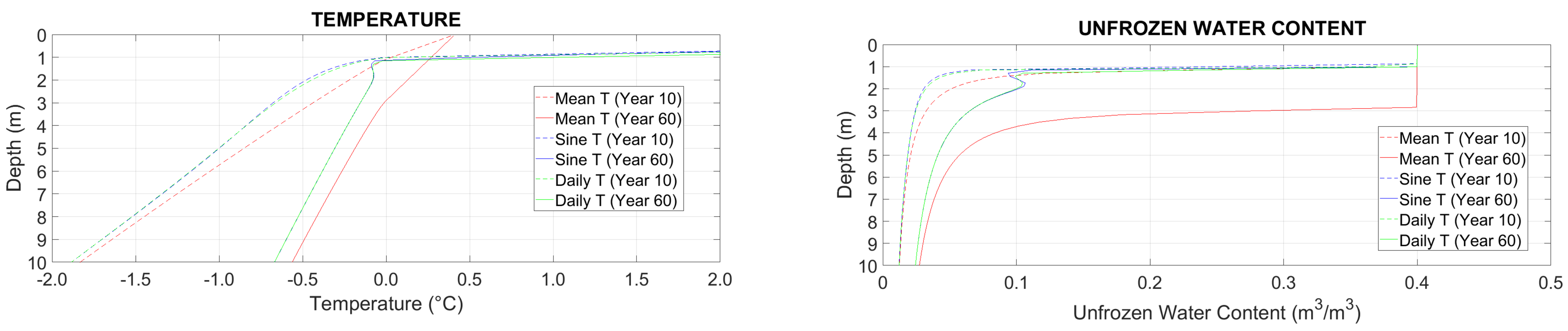
The location of Muostakh Island in the Siberian Arctic



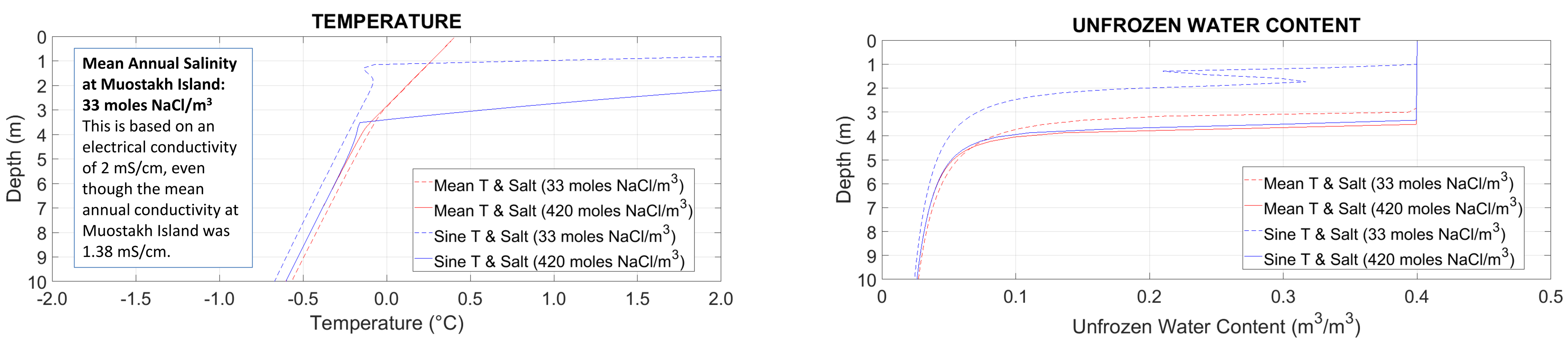
Types of Upper Boundary Conditions for Thermal Modelling

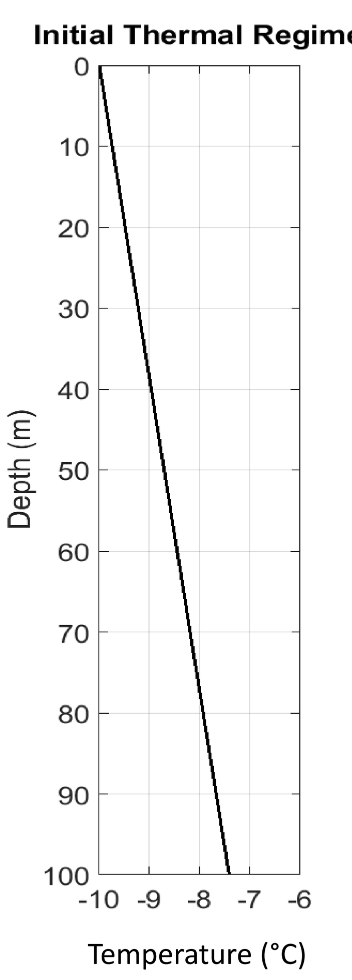


SUBAQUATIC PERMAFROST EVOLUTION BELOW FRESHWATER (10 AND 60 YEARS AFTER INUNDATION ON SEPTEMBER 1)

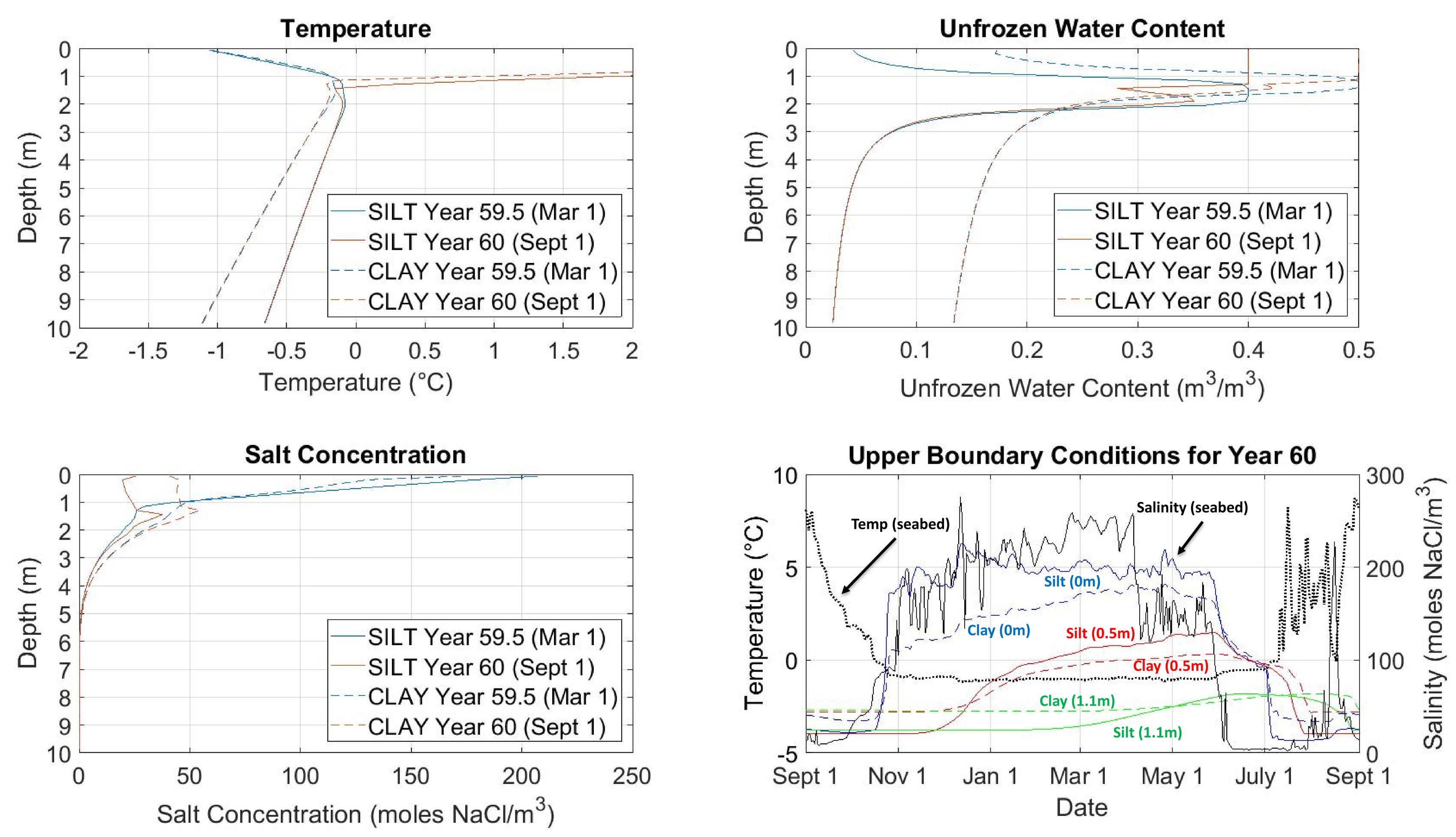


SUBAQUATIC PERMAFROST EVOLUTION BELOW SALTWATER WITH CONSTANT SALINITY FOR MEAN ANNUAL MUOSTAKH ISLAND SALINITY AND TYPICAL SEAWATER SALINITY (60 YEARS AFTER INUNDATION ON SEPTEMBER 1)





SUBAQUATIC PERMAFROST EVOLUTION OF SILT AND CLAY PERMAFROST WITH DAILY TEMPERATURE AND SALINITY INPUTS FROM MUOSTAKH ISLAND



References

Dall'Amico, M., Endrizzi, S., Gruber, S., & Rigon, R. (2011). A robust and energy-conserving model of freezing variably-saturated soil. *The Cryosphere*, *5*(2), 469.

Overduin, P, P., Westernmann, S., Yoshikawa, K., Haberlau, T., Romanovsky, V., and Wetterich, S. (2012) Geoelectric observations of the degradation of nearshore submarine permafrost at Barrow (Alaskan Beaufort Sea). *Journal of Geophysical Research* 117, F02004, doi:10.1029/2011JF002088.

Romanovskii, N. N., Hubberten, H. W., Gavrilov, A. V., Tumskoy, V. E., & Kholodov, A. L. (2004). Permafrost of the east Siberian Arctic shelf and coastal lowlands. *Quaternary Science Reviews*, *23*(11), 1359-1369.

Westermann, S., Schuler, T. V., Gisnås, K., & Etzelmüller, B. (2013). Transient thermal modeling of permafrost conditions in Southern Norway. *The Cryosphere*, *7*(2), 719.

European Research Council

POTSDAM
Telegrafenberg A43
14473 Potsdam
+49 331 288-2173
michael.angelopoulos@awi.de
www.awi.de