Teaching plan of permafrost course by Prof. Oleg Anisimov (9-12 March 2009), University of Helsinki.

Monday 9.03.2009, (room A114)

10:00 – 12:00 (2 hours) Lecture 1 *"Introduction to permafrost observations and modeling"*

- permafrost as part of the periglacial environment;
- history of permafrost exploration in the 19th – early 20th century;
- early permafrost observations and first models;
- modern permafrost observations in the context of the global climate and environmental changes (CALM and GTNP programs).
- Regional study: permafrost degradation near Abisko research station, Northern Sweden.
- Case study: palsa mires in Northern Fennoscandia under changing climatic conditions.

Recommended reading: (key papers are available as pdf files, ask the lecturer**)**

Brown, J., Hinkel, K.M., and Nelson, F.E., 2000: The Circumpolar Active Layer Monitoring (CALM) program: historical perspectives and initial results. Polar Geography 24(3): 165-258.

Fronzek S, Luoto M, Carter TR, 2006. Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia. Climate Research 32:1-12

Fronzek, S., Timothy R. Carter, Jouni Räisänen, Leena Ruokolainen and Miska Luoto, 2009. Applying probabilistic projections of climate change with impact models: a case study for sub-arctic palsa mires in Fennoscandia. Climatic Change (in press).

Lemke, P. et al., 2007: Observations: Changes in Snow, Ice and Frozen Ground. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Luoto, M., Fronzek, S., and F.S. Zuidhoff, 2004. Spatial modelling of palsa mires in relation to climate in northern Europe. Earth Surface Processes and Landforms, 29: 1373-1387.

Nelson, F.E., Shiklomanov, N.I., Hinkel, K.M., and Christiansen, H.H., 2004a: Introduction: The Circumpolar Active Layer Monitoring (CALM) Workshop and the CALM II Program. Polar Geography, 28(4), 253-266.

Romanovsky, V.E., A.L. Kholodov, S.S. Marchenko, N.G. Oberman, D.S. Drozdov, G.V. Malkova, N.G. Moskalenko, A.A. Vasiliev, D.O. Sergeev, and M.N. Zheleznyak, 2008. Thermal state and fate of

permafrost in Russia: First results of IPY. Proceedings of the 9th International Conference on Permafrost, Institute of Northern Engineering, University of Alaska, Fairbanks, 1511-1518.

Shiklomanov, N.I., 2005. From Exploration to Systematic Investigation: Development of Geocryology in 19th- and Early–20th-Century Russia. Physical Geography, 26 (4): 249-263.

Streletskiy D.A, Shiklomanov N.I, Nelson F.E, and Klene A.E. 2008: 13 Years of Observations at Alaskan CALM Sites: Long-term Active Layer and Ground Surface Temperature Trends. Proceedings of the 9th International Conference on Permafrost, Institute of Northern Engineering, University of Alaska, Fairbanks, 2, 1727-1732.

Vasiliev, A.A., Leibman, M.O., and Moskalenko, N.G. 2008. Active Layer Monitoring in West Siberia under the CALM II Program. Proceedings of the 9th International Conference on Permafrost, Institute of Northern Engineering, University of Alaska, Fairbanks, 2, 1815-1821.

Zhang, T., Heginbottom, J. A., Barry, R. G., and Brown, J., 2000: Further statistics of the distribution of permafrost and ground ice in the Northern Hemisphere. Polar Geography, 24(2): 126-131.

13:00 – 15:00 (2 hours) Exercises *"Mapping spatial and temporal variability of active-layer thickness (ALT)"*

- each student will download data (in *Excel* format) with long records from 2 selected CALM sites representing different environmental conditions, i.e. Arctic coastal plain, Arctic foothills, etc., Data are available at **www.udel.edu/Geography/calm**;
- plot time series of the mean ALT and standard deviation using *EXCEL*.
- Using IDRISI, plot spatial distributions of the active-layer thickness over each site (121 point measurements in regular spatial grid) for consecutive years for which data are available. Compare observations for "coldest" and "warmest" years. Analyze changes (if any) in the spatial pattern over the observational period.
- Analyze the distribution of minimums and maximums on the ALT plots in different years. Using *Excel* rank observations at 121 nodes (organize in increasing order) and select 5 nodes with minimum and 5 nodes with maximum ALT at each site for every year, identify location of these nodes on the plots and analyze the changes in spatial distribution of minimums and maximums in time, if any.
- Evaluate the effect of non-climatic factors on ALT variability by comparing spatial statistics with temporal changes.

Sites with grid measurements at **www.udel.edu/Geography/calm**;

R1 Nadum

R2 Ayach-Yaha

R3 Marre-Sale

R5 Vaskiny Dachi – data contain gaps and comments

R9 Cape Rogozny

R11 Cape Rogozny

R17 Akhmelo

R18 Mt. Rodinka

R23 Talnik

R24 Bolvanskyi

+ USA sites

U1 Barrow

U5 West Dock – data contain gaps and comments (W)

U7A Betty Pingo – data contain gaps and comments (W)

U11 Imnavait creek – data contain gaps and comments (g)

U12A Toolik – data contain gaps and comments (g, w)

Tuesday, 10.03.2009, (meeting room)

10:00 – 12:00 (2 hours) Lecture 2 *"Predictive permafrost modeling"*

- N-factor models and their validation;
- equilibrium permafrost models;
- dynamical permafrost models;
- stochastic permafrost models and their application in risk analysis;
- evaluation of the environmental and climatic data bases for permafrost modeling.

Recommended reading:

Anisimov, O.A., Lobanov, V.A., Reneva, S.A., Shiklomanov, N.I., Zhang, T., 2007. Uncertainties in gridded air temperature fields and their effect on predictive active layer modeling. Journal of Geophysical Research, 112 (F02S14): doi:10.1029/2006JF000593.

Anisimov, O.A., Shiklomanov, N.I., Nelson, F.E., 2002. Variability of seasonal thaw depth in permafrost regions: a stochastic modeling approach. Ecological Modelling, 153 (3): 217-227.

Klene, A.E., Nelson, F.E., Shiklomanov, N.I., 2001. The n-factor as a tool in geocryological mapping: Seasonal thaw in the Kuparuk River basin, Alaska. Physical Geography, 22 : 449-466.

Lawrence, D.M., Slater, A.G. A projection of severe nearsurface permafrost degradation during the 21st century. Geophysical Research Letters, 2005, vol. 32, No L24401, doi:10.1029/2005GL025080,

Lawrence, D.M., A.G Slater, V.E. Romanovsky, and D.J. Nicolsky, 2008. Sensitivity of a model projection of near-surface permafrost degradation to soil column depth and representation of soil organic matter, J Geophys Res, 113, F02011, doi:10.1029/2007JF000883.

Mitchell, T. D., and P. D. Jones (2005), An improved method of constructing a database of monthly climate observations and associated high resolution grids, Int. J. Clim., 25(6), 693– 712, doi:10.1002/joc.1181.

Nicolsky, D.J., V.E. Romanovsky, V.A. Alexeev, and. D.M. Lawrence, 2007. Improved modeling of permafrost dynamics in a GCM land-surface scheme, Geophys. Res. Lett. 34, L08501, doi:10.1029/2007GL029525.

Riseborough D, Shiklomanov NI., Etselmuller B., Gruber S. 2008, Recent Advances in Permafrost Modeling. Permafrost and Pereglacial Processes, 19: 137–156

Saito, K., Kimoto, M., Zhang, T., Takata, K. and Emori, S. 2007. Evaluating a high-resolution climate model: Simulated hydrothermal regimes in frozen ground regions and their change under the global warming scenario. J. Geophys. Res. 112: F02S11.

Sazonova, T.S., Romanovsky, V.E. A model for regional-scale estimation of temporal and spatial variability of active-layer thickness and mean annual ground temperatures. Permafrost and Periglacial Processes, 2003, vol. 14, No 2, p. 125- 140.

Sazonova, T.S., Romanovsky, V.E., Walsh, J.E., Sergueev, D.O. Permafrost dynamics in the 20th and 21st centuries along the East Siberian transect. Journal of Geophysical Research-Atmospheres, 2004, vol. 109, No D1.

Stendel, M., Christensen, J.H. Impact of global warming on permafrost conditions in a coupled GCM. Geophysical Research Letters, 2002, vol. 29, No 13, p. 10-1 - 10-4.

Sushama, L., R. Laprise, and M. Allard. 2006. Modeled current and future soil thermal regime for northeast Canada, J. Geophys. Res., 111, D18111, doi:10.1029/2005JD007027.

Zhang, Y., W. Chen, and D.W. Riseborough, 2008a. Disequilibrium response of permafrost thaw to climate warming in Canada over 1850–2100. Geophys. Res. Lett. 35, L02502, doi:10.1029/ 2007GL032117.

Zhang, Y., W. Chen, and D.W. Riseborough, 2008b. Transient projections of permafrost distribution in Canada during the 21st century under scenarios of climate change. Global and Planetary Change 60: 443-456, doi:10.1016/j.gloplacha.2007.05.003.

Zhou, F., R. Li, A. Zhang, and L. Zhu, 2008. Surface-coupled three-dimensional geothermal model for study of permafrost geothermal regime in a building environment. J. Geophys. Res., 113. D19102, doi:10.1029/2008JD009827.

Wednesday, 11.03.2009, (room A114)

9:00 – 10:00 (1 hour) Lecture 3 *"Climate- and ecosystem-driven changes in permafrost and their modeling"*

- role of non-climatic (ecosystem) factors in permafrost variability;
- comprehensive permafrost scenarios in a changing world.

Recommended reading:

Duchesne, C., J.F. Wright, and M. Ednie. 2008. High-resolution numerical modeling of climate change impacts to permafrost in the vicinities of Inuvik, Norman Wells, and Fort Simpson, NT, Canada. Proceedings of the 9th International Conference on Permafrost, Institute of Northern Engineering, University of Alaska, Fairbanks, 385-390p.

Shiklomanov, N.I., Anisimov, O.A., Zhang, T., Marchenko, S., Nelson, F.E., Oelke, C., 2007. Analysis of model-produced permafrost active layer fields: results for northern Alaska. Journal of Geophysical Research, Earth Surface, 112 (F02S14).

Sturm, M., Racine, C., and Tape, K., 2001: Climate change: increasing shrub abundance in the Arctic. Nature, 411: 546-547.

Zhang, Y., W. Chen, and D.W. Riseborough, 2008c. Modeling long-term dynamics of snow and their impacts on permafrost in Canada. NICOP, 2055-2060p.

10:00 – 12:00 (2 hours) Exercises *"Hemispheric-scale mapping of permafrost dynamics under changing climatic and environmental conditions"*

- each student will construct hemispheric-scale maps of permafrost distribution (based on surface frost index data, SFI) and ALT for the baseline climatic conditions and one of the GCM-based projections for 2025 and 2050 (each student will use different climatic projection); Requires appropriate GIS, like *IDRISI*
- perform spatial analysis, i.e. calculate changes in the area of near-surface permafrost distribution, changes in the total volume of the seasonally thawing layer.

Thursday, 12.03.2009, (room A114)

14:00 – 15:30 (1.5 hours) Lecture 4 *"Predictive modeling of permafrost in a changing world: impacts on the natural environment, human structures, and the feedback to global climate system"*

- key geomorphological impacts and their modeling;
- potential impacts of permafrost on northern infrastructure and predictive risk assessment;
- emission of greenhouse gases from thawing permafrost and evaluation of potential impacts on the global climate;

Recommended reading:

Anisimov, O.A., Reneva, S.A., 2006. Permafrost and changing climate: the Russian perspective. Ambio, 35 (4): 169-175.

Christensen, T.R., Ekberg, A., Strom, L., Mastepanov, M., Panikov, N., Mats, O., Svensson, B.H., Nykanen, H., Martikainen, P.J., Oskarsson, H., 2003. Factors controlling large scale variations in methane emissions from wetlands. Geophysical Research Letters, 30 (7).

Christensen, T.R., T. Johansson, N. Malmer, J. Åkerman, T. Friborg, P. Crill, M. Mastepanov, and B. Svensson. 2004. Thawing sub-arctic permafrost: Effects on vegetation and methane emissions, Geophysical Research Letters, VOL. 31, L04501, doi:10.1029/2003GL018680.

Christensen, T.R., T. Johansson, M. Olsrud, L. Ström, A. Lindroth, M. Mastepanov, N. Malmer, T. Friborg, P. Crill and T.V. Callaghan. 2007. A catchment-scale carbon and greenhouse gas budget of a subarctic landscape Phil. Trans. R. Soc. A. 365, 1643–1656 doi:10.1098/rsta.2007.2035

Corradi C., O.K., K. Walter, S. A. Zimov, E.-D. Schulze,, 2005. Carbon dioxide and methane exchange of a north-east Siberian tussock tundra. Global Change Biology, 11 (11): 1910-1925.

Friborg, T., Soegaard, H., Christensen, T.R., Lloyd, C.R., Panikov, N.S., 2003. Siberian Wetlands: Where a sink is a source. Geophysical Research Letters, 30 (21): 2129.

Khvorostyanov D. V., P. Ciais, M. Heimann, S. A. Zimov, 2008. Vulnerability of permafrost carbon to global warming. Part I: model description and role of heat generated by organic matter decomposition. Tellus B, 60 (2): 250-264.

Khvorostyanov D. V., G. Krinner, S. A. Zimov, Ch. Corradi, G. Guggenberger, 2008. Vulnerability of permafrost carbon to global warming. Part II: sensitivity of permafrost carbon stock to global warming. Tellus B, 60 (2): 265-275.

Mastepanov M., C. Sigsgaard, E. J. Dlugokencky, S. Houweling, L. Strom, M. P. Tamstorf & T. R. Christensen. 2008. Large tundra methane burst during onset of freezing. Nature, 456: 628-631.

Nelson, F.E., Anisimov, O.A., Shiklomanov, N.I., 2001. Subsidence risk from thawing permafrost. Nature (410): 889-890.

Nelson, F.E., Anisimov, O.A., Shiklomanov, N.I., 2002. Climate change and hazard zonation in the circum-Arctic permafrost regions. Natural Hazards, 26 (3): 203-225.

Rivkina E., Kestas Laurinavichius, Lada Petrovskaya, Kirill Krivushin, Gleb Kraev, Svetlana Pecheritsina, David Gilichinsky, 2007. Biogeochemistry of methane and methanogenic archaea in permafrost. FEMS Microbiology Ecology, 61 (1): 1-15.

Wagner D., A. Embacher, Eva-Maria Pfeiffer, Michael Schloter, A. Lipski, 2007. Methanogenic activity and biomass in Holocene permafrost deposits of the Lena Delta, Siberian Arctic and its implication for the global methane budget. Global Change Biology, 13 (5): 1089-1099.

Wille C., L.K., Torsten Sachs, Dirk Wagner, Eva-Maria Pfeiffer, 2008. Methane emission from Siberian arctic polygonal tundra: eddy covariance measurements and modeling. Global Change Biology, 14 (6): 1395-1408.

Zimov, S.A., E. A. G. Schuur, F. S. Chapin III. 2006a. Permafrost and the Global Carbon Budget. Science, 312: 1612-1613.

15:30 – 17:00 (1.5 hours) Exercises *"Hemispheric-scale mapping of risks to infrastructure in permafrost regions and GIS analysis of carbon emission from thawing permafrost"*. All maps are plotted using IDRISI.

- each student will construct the map of geocryological hazard index using ALT data for baseline climate and scenario-specific data for the future (from the previous exercise), overlaid by the data on ground ice content;
- each student will construct the map illustrating the potential increase in greenhouse gas emission using ALT and soil temperature data for baseline climate and scenario-specific data for the future (from the previous exercise) overlaid by the mask of frozen peatlands, combined with the parameterization, reflecting the flux dependence on ALT and soil temperature.