ISSN 0149-1776

GLACIOLOGICAL DATA

PERMAFROST AND CLIMATIC CHANGE
AN ANNOTATED BIBLIOGRAPHY

World Data Center A
for
Glaciology
[Snow and Ice]

INTERNATIONAL PERMAFROST ASSOCIATION

WDC operated for:
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Boulder, Colorado 80303 U.S.A.

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and Geomagnetism
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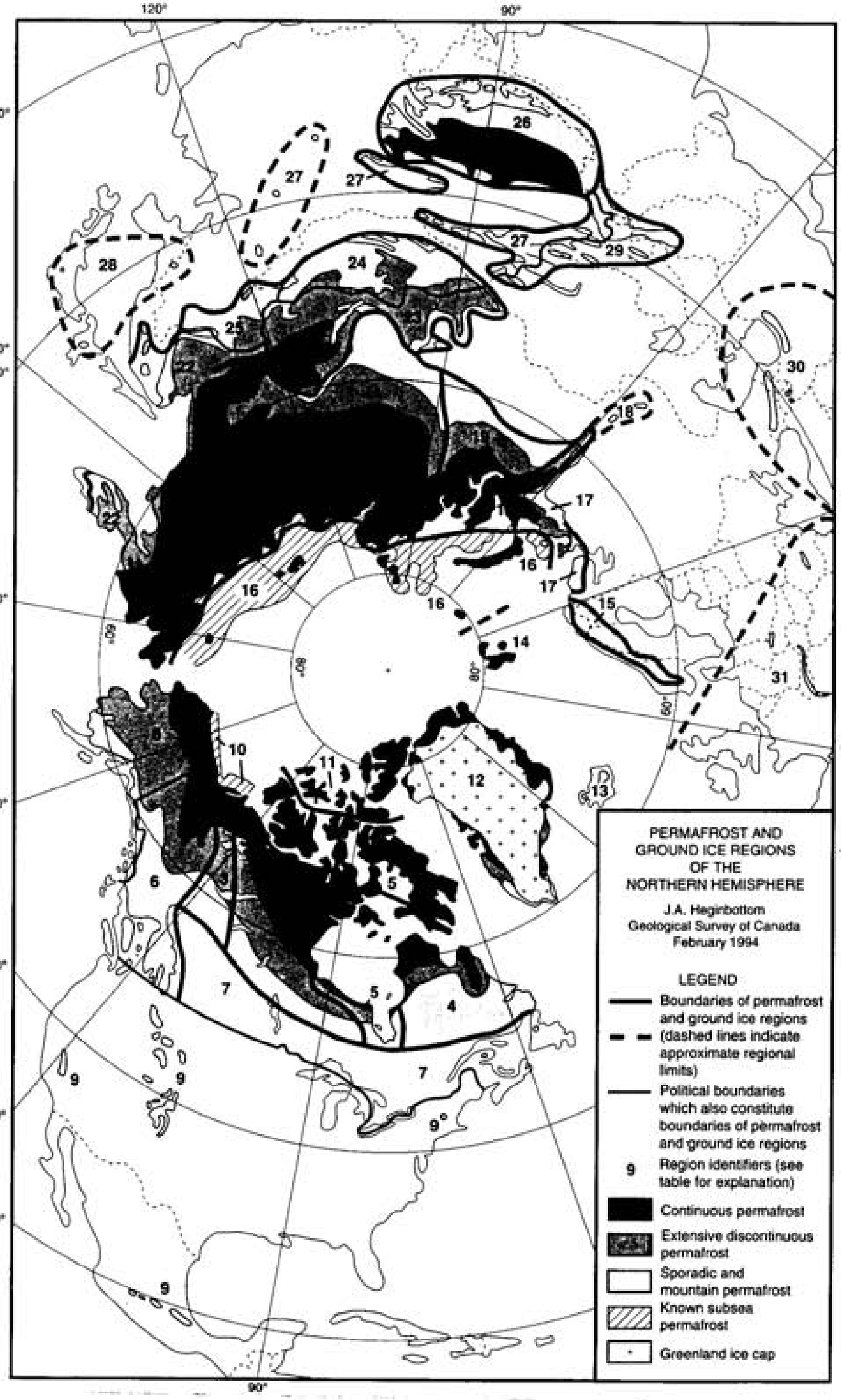
PERMAFROST AND CLIMATIC CHANGE
AN ANNOTATED BIBLIOGRAPHY



KEY TO PERMAFROST AND GROUND ICE REGIONS

NORTH AMERICA
Canada

1 Queen Elizabeth Islands
2 Western Arctic Lowlands
3 Interior Plains
4 Eastern Arctic and Canadian Shield
5 Basins within Canadian Shield
6 Cordillera
7 Areas outside the permafrost region

USA
8 Alaska
9 Conterminous USA and Mexico

Subsea Permafrost
10 Beaufort Sea Continental Shelf
11 Arctic Archipelago

NORTH ATLANTIC
12 Greenland
13 Iceland
14 Svalbard
15 Fennoscandia

ASIA

Russia
16 Arctic Islands and Arctic Ocean Continental Shelf
17 European North
18 Urals
19 West Siberia
20 East Siberia
21 Northeast Siberia
22 Far East
23 Southern Siberia and Trans-Baikalia

24 Mongolia

China
25 Northeast China
26 Tibet Plateau
27 West China and other Mountain Permafrost Areas
28 Japan and Korea
29 Central Asia
30 Southwestern Asia

EUROPE
31 Central and Southern Europe

GLACIOLOGICAL DATA

REPORT GD-27

PERMAFROST AND CLIMATIC CHANGE AN ANNOTATED BIBLIOGRAPHY

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WDC operated for:
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Boulder, Colorado 80303 U.S.A.

Prepared In Cooperation with:

International Permafrost Association
and its
Working Group on Present Global Change and Permafrost

June 1994

DESCRIPTION OF THE WORLD DATA CENTER SYSTEM[1]

The World Data Centers (WDCs) were established in 1957 to provide archives for the observational data resulting from the International Geophysical Year (IGY). In 1958 the WDCs were invoked to deal with the data resulting from the International Geophysical Cooperation 1959, the one-year extension of the IGY. In 1960, the International Council of Scientific Unions (ICSU) Comite International de Geophysique (CIG) invited the scientific community to continue to send to the WDCs similar kinds of data from observations in 1960 and following years, and undertook to provide a revised *Guide to International Data Exchange* for that purpose. In parallel the CIG inquired of the IGY WDCs whether they were willing to treat the post-IGY data; with few exceptions, the WDCs agreed to do so. Thus the WDCs have been serving the scientific community continuously since the IGY, and many of them archive data for earlier periods.

In November 1987 the International Council of Scientific Unions (ICSU) Panel on World Data Centers prepared a new version of the *Guide to International Data Exchange*, originally published in 1957, and revised in 1963, 1973 and 1979. The new publication, *Guide to the World Data Center System, Part 1, The World Data Centers (General Principles, Locations and Services)*, was issued by the Secretariat of the ICSU Panel on World Data Centers. This new version of the *Guide* contains descriptions of each of the twenty-seven currently operating disciplinary centers, with address, telephone, telex, and contact persons listed. The reader is referred to the new *Guide* for descriptions of the responsibilities of the WDCs, the exchange of data between them, contribution of data to WDCs, and the dissemination of data by them. The WDCs for Glaciology are listed below.

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Director:	Professor Xie Zichu

The following organization provides international data services including data analyses and preparation of specialized data products. It merges the previous activity of the Permanent Service on the Fluctuations of Glaciers and the Temporary Technical Secretariat for World Glacier Inventory. These activities are not part of the WDC system but the center cooperates with WDCs in the discipline. Users wishing assistance in seeking data or services from this group may contact an appropriate WDC.

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[1]Adapted from *Guide to the World Data Center System. Part 1. The World Data Centers (General Principles, Locations and Services).* International Council of Scientific Unions. Panel on World Data Centers, November 1987, 91pp.

Foreword

This report provides an extensive guide to literature on permafrost and climatic change. The importance of potential changes in ground ice and sediment conditions in high latitudes and many mountain areas under changing climatic conditions is now receiving wide attention through assessments of the Intergovernmental Panel on Climate Change. This annotated bibliography has been prepared by members of the Working Group on Present Global Change and Permafrost of the International Permafrost Association (IPA) and supplemented by other recent references identified by Ann Brennan, WDC-A Glaciology, assisted by Jerry Brown, Fritz Nelson and Alan Heginbottom. It complements the more general bibliographies on permafrost literature for the periods 1978-82, 1983-87 and 1988-92 that have appeared in the *Glaciological Data series, Reports* 14, 21 and 26 and supports the efforts of the IPA Working Group on Permafrost Data and Information to facilitate access to data and information.

We welcome any information on additional publications that have been overlooked, particularly those published in other languages, for inclusion in subsequent bibliographies.

Thanks are due to Lyn Ryder for word processing support and Ann Brennan for her careful editing and especially to the International Permafrost Association for their contribution to the publication cost.

Roger G. Barry
Director, WDC-A for Glaciology
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Contents

Introduction

In the near future a further strong rise in the content of CO_2 and other greenhouse gases in the atmosphere is expected. This will probably lead to significant changes in climate, which will be greatest at high latitudes. As a large part of this area is underlain by permafrost, it is important to study the effects of climatic change on permafrost areas.

At the Fifth International Conference on Permafrost in Trondheim, Norway, in August 1988, the International Permafrost Association established a Working Group on "Present Global Change and Permafrost". This Working Group's mission is to assess the changes in geological, geomorphological, hydrological and ecological processes in permafrost terrain due to climatic change. This annotated bibliography is one of the activities of the Working Group.

The relationship between climate and permafrost is not direct, but is complicated by the "buffer layer" of the earth's surface; this leads to a difference between the air temperature (MAAT) and the temperature of the permafrost (MAGT). The amount of this difference is indicative of the local influence of the "buffer layer". Figure 1 shows the most important interrelationships between climate and permafrost areas. This leads to the variety of topics annotated in the bibliography, including former changes in permafrost (analogue, cryostratigraphic and cryo-geothermal studies), present interrelationships in the permafrost system (monitoring studies), and future changes (impact assessment and simulation studies).

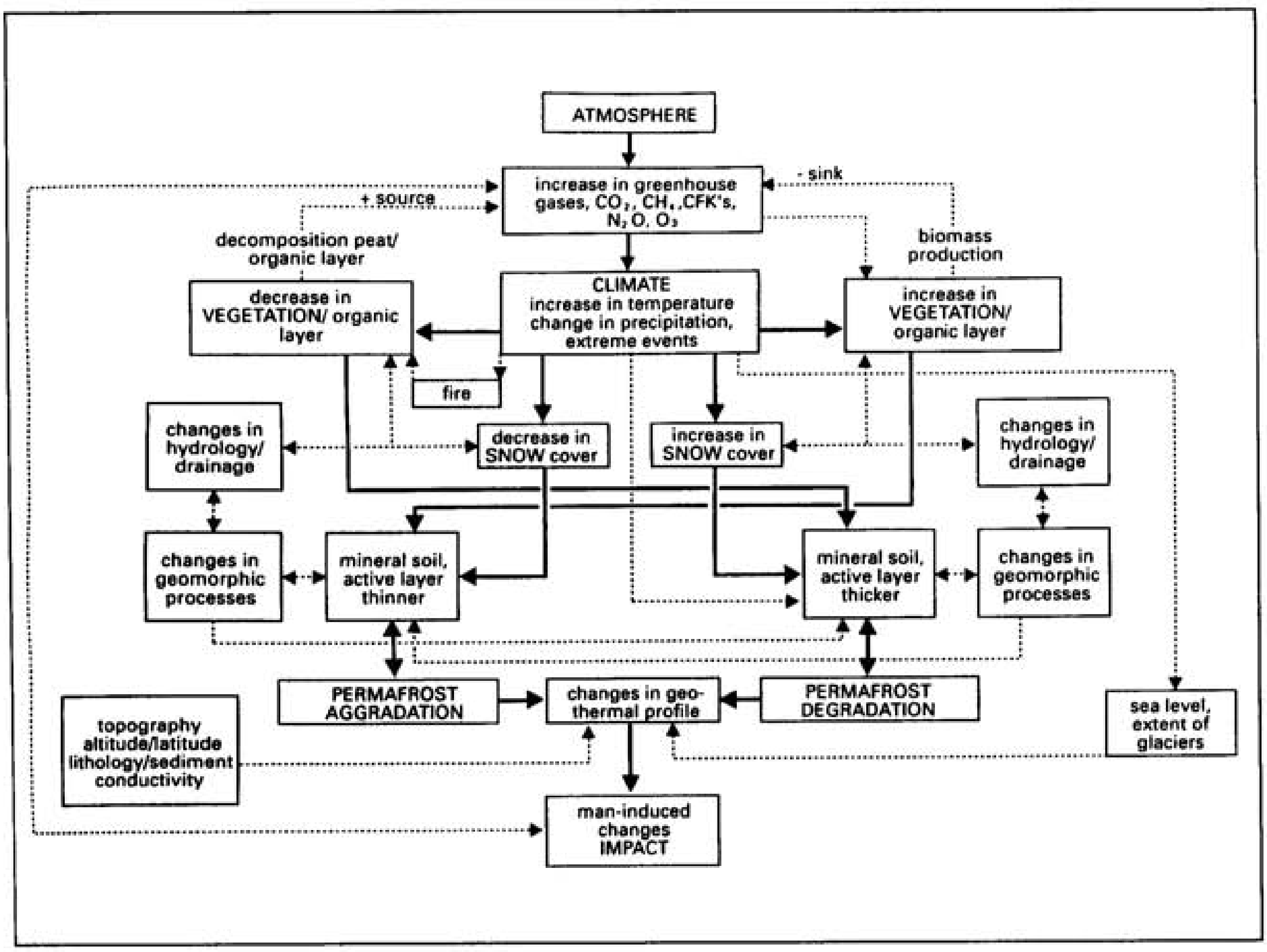

Figure 1. Schematic representation of the interrelationships in the atmosphere - "buffer layer" -permafrost system. (from Koster and Nieuwenhuijzen, 1992)

Former changes in permafrost form possible analogues for the present. They can be studied by cryostratigraphy, and by studying the geothermal gradient and the thickness of the permafrost. This can lead to assumptions of former climates, and associated boundaries of permafrost.

At the moment, Arctic tundras provide a major sink of CO_2. Changes in climate may affect this. If besides getting warmer the climate also gets dryer, peatlands may dry out, and oxidize. They may then become another source for CO_2 and other greenhouse gases. If the climate gets wetter however, an increase in the vegetation and the organic layer may occur, and the tundras may become even more of a sink for greenhouse gases.

An increase in greenhouse gases in the atmosphere will also influence plant growth, causing plant growth to increase if nutrients are not a limiting factor. At the moment nutrients usually are a limiting factor in periglacial regions, but with higher temperatures, decomposition rates of organic matter will increase, which will lead to a higher nutrient availability.

Vegetation mainly has an effect on the surface temperature by shielding it from incoming radiation, thus cooling the ground. Its influence varies with the different types of vegetation.

The organic layer, and to a minor extent the mineral soil, influences the ground temperature by its differential insulating capacities. In summer, conductivity is low, and it is difficult for ground to warm up. In winter, however, as the organic layer freezes, conductivity is greater, which allows the ground to cool. Peat shows this effect to the extreme; in areas with peat, permafrost can occur even if air temperatures are above 0°C.

A snow cover also influences the ground temperature by its insulating properties. Generally a snow cover keeps the ground warmer as the ground heats up in summer, but is hampered in cooling during winter. Important factors are the thickness of the snow cover and its duration and the time of the year.

Vegetation greatly influences the thickness of the snow cover. It diminishes the effect of the wind, so generally more snow can accumulate between vegetation than on bare soils. The type of vegetation is important as well. The importance of snow and vegetation for the occurrence of discontinuous permafrost varies locally. This means that on the one hand a change from forest to tundra may lead to permafrost degradation by less influence from vegetation, but on the other hand the same change may lead to permafrost aggradation by a loss of snow cover.

A warming of the ground temperature, whatever the exact cause, will lead to changes in the ground thermal regime. Firstly, the thickness of the active layer will increase. Secondly, a geothermal gradient exists in the permafrost which will slowly adjust itself to the new surface temperature. The rate at which this happens depends on the thermal conductivity of the permafrost. The variations in temperature profiles of permafrost also constitute a good way of studying the geothermal history of the last decades and centuries, as this is recorded in the upper 100-200 m of the permafrost. Permafrost yields a temporally integrated record of mean annual air temperature changes in the past, but is not influenced by extreme events (with the exception of direct man-made disturbances and fire).

Several preliminary simulation experiments on the response of permafrost to climatic change have already been conducted. They show that widespread thawing of permafrost probably will occur in the discontinuous zone. This will have a major environmental and societal impact.

Description of the Annotated Bibliography

The papers listed in this annotated bibliography were located by manual library techniques. The main criterion for inclusion of a paper in this bibliography is that it concerns one or more of the interrelationships mentioned in Figure 1, as related to permafrost.

A large part of the literature concerned with climatic change and permafrost appeared in conference and symposia proceedings (First International Permafrost Conference, 1963, Lafayette, Indiana, USA; Second International Permafrost Conference, 1973, Yakutsk, USSR; Third International Permafrost Conference, 1978, Edmonton, Alberta, Canada; Fourth International Permafrost Conference, 1984, Fairbanks, Alaska, USA; Fifth International Permafrost Conference, 1988, Trondheim, Norway; Sixth International Conference on Permafrost, 1993, Beijing, China; Fifth Canadian Permafrost Conference, 1990, Québec, Canada, and as theses. (See Selected Sources below.) Papers or books written in a language other than English, French, or German were excluded. General papers or manuals on periglacial environments are also excluded from the annotated bibliography. A weakness common to most summaries of periglacial topics is inadequate coverage of the Russian and Chinese literature. This applies also to this bibliography, although some papers that have been translated into English have been annotated. It is hoped that this bibliography can be substantially upgraded by including these sources of information in the near future.

Annotations are arranged alphabetically by author. When appropriate for the subject, all or part of the author's summary or abstract is used. Where no summary or abstract was available, an annotation was compiled. Abstracts and annotations are followed by a list of key words or descriptors, based on the subjects described in the article. For the sake of brevity, geographic terminology in the titles or the annotations is not repeated in the key words.

A supplement to the annotated bibliography was added in 1993 and covers the period 1988-1993. These additional references give the complete bibliographic citation, but are not annotated and key words have not been added.

The subject index to the annotated bibliography keys the papers to several subject categories based on key words. This is followed by a combined author index for both annotated and supplementary bibliographies. All authors are listed but a differentiation has been made in the index; the first authors are listed at the beginning of the lines, while the other authors are shown as indented.

Selected Sources

French, H.M., ed. 1986 *Climate Change Impacts in the Canadian Arctic. Proceedings of a Canadian Climate Program Workshop (Geneva Park, Ontario, March 3-5, 1986).* Downsview, Ontario, Atmospheric Environment Service, 171 pp.

International Conference on Permafrost, 1st, Lafayette, Indiana, USA, November 11-15, 1963, Proceedings. Washington, D.C., National Academy of Sciences, National Research Council Publication 1287, 563 pp.

International Conference on Permafrost, 2nd, Yakutsk, USSR, July 13-28, 1973. North American Contribution. Proceedings. Washington, D.C., National Academy of Sciences, 783 pp.

International Conference on Permafrost, 3rd, Edmonton, Alberta, Canada, July 10-13, 1978, Proceedings. Ottawa, Canada, National Research Council, 2 vol., 947 pp., 255 pp.

International Conference on Permafrost, 4th, Fairbanks, Alaska, USA, July 17-22, 1983, Proceedings. 1983/1984. Washington, D.C., National Academy Press, 2 vol., 1524 pp., 413 pp.

International Conference on Permafrost, 5th, Trondheim, Norway, August 2-5, 1988, Proceedings (ed. K. Senneset). Trondheim, Norway, Tapir Publishing, 3 vol.

International Conference on Permafrost, 6th, Beijing, China, July 5-9, 1993, Proceedings. South China University of Technology Press, Wushan, China, 2 vol., 1360 pp.

Koster, E.A. (1993) Global warming and periglacial landscapes. In: Roberts, N. (ed.) *The Changing Global Environment.* Blackwell, Cambridge, USA, pp. 127-149.

Koster, E.A. and M.E. Nieuwenhuijzen (1992) Permafrost response to climatic change. In: Boer, M. and E. Koster, eds. *Greenhouse-Impact on Cold-Climate Ecosystems and Landscapes. Catena Supplement,* 22, Catena Verlag, Cremlingen-Destedt, Germany, p. 37-58.

McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications* 83-1, 208 pp.

Nelson, F.E., A.H. Lachenbruch, M.-K. Woo, E.A. Koster, T. E. Osterkamp, M.K. Gavrilova and G.D. Cheng (1993) *Permafrost and changing climate. In: Permafrost, Sixth International Conference Proceedings, Vol. 2, Wushan,. China.* South China University of Technology Press, pp. 987-1005.

Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1990), Collection Nordicana 54, 424 pp.

Street, R.B. and P.I. Mel'nikov (1990) Seasonal snow cover, ice and permafrost. In: Tegart. W.J.M. and G.W. Sheldon, eds. *Climate Change 1992: the Supplementary Report to the IPCC Impacts Assessment,* Canberra, Australian Government Publishing Service, pp. 7.1-7.33.

Working Group on Present Global Change and Permafrost (IPA) (1993) Permafrost and Climate Change. *Permafrost and Periglacial Processes,* 4(2), pp. 95-174.

Annotated Bibliography

ABBEY, F.L., GRAY, D.M., MALE, D.H. AND ERIKSON, D.E.L. (1978) Index models for predicting ground heat flux to permafrost during thawing conditions. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* Ottawa, National Research Council Canada, pp. 3-9.

During the summer of 1973, a comprehensive measurement program was undertaken of the components of the surface energy balance over a tundra polygon near Tuktoyaktuk, N.W.T. It was found that under conditions where the development of an atmospheric boundary layer is incomplete, simple index models may provide reasonable estimates of the ground heat flux. Two index models for predicting the ground heat flux during the thawing period are presented. One model is based on the use of cumulative net radiation; the other on cumulative air temperature measurements. The models are verified by measurements of ground heat flux taken at a depth of about 5 cm. The results suggest that net radiation is the dominant energy source governing the supply of ground heat during the growth of the active layer. (authors, shortened)

Key Words: heat/radiation balance, geothermal gradient/regime, mathematical models/simulation.

ABURAKAWA, H. (1981) Microclimate investigations of the Arctic tundra. In: Kinoshita, S., ed. *Joint Studies on Physical and Biological Environments in the Permafrost, North Canada, July-August 1980 and February-March 1981.* Sapporo, Japan, Hokkaido University, pp. 1-11.

As part of the permafrost expedition in Northern Canada, the microclimate regimes of this region were investigated. The study site, situated on the open tundra area near Tuktoyaktuk, Mackenzie Delta, is characterized by a low-polygonal patterned ground. Micrometeorological observations were carried out at this site. The analyses of the data, part of which were supplied by the meteorological station of Tuktoyaktuk, are summarized. (author)

Key Words: albedo, vegetation, heat/radiation balance.

AFANASENKO, V.E., ZAITSEV, V.N., ROMANOVSKII, V.E. AND ROMANOVSKII, N.N. (1983) On the relationship between the structure and characteristics of bedrock masses and their permafrost history. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1-4.

Comprehensive investigations in the areas of permafrost hydrology and engineering geology within the Stanovoy and Mongol-Okhotsk folded systems revealed the presence of horizons and zones of severe jointing in the bedrock. They occurred both where there was no permafrost and at the top and bottom of the permafrost. The thickness of the zones involved reaches 100 m and more, and the ice content where the rock is frozen reaches 6-10% by volume. The formation of these horizons of severely-jointed rock is related to the dynamics of permafrost development during climatic changes in the late Pleistocene and Holocene, specifically to intense frost shattering caused by repeated freeze-thaw. These horizons and zones of severe jointing exert a major influence on the formation of the existing subsurface drainage and of talik zones which operate both as recharge and discharge zones in terms of ground water and also as lateral transfer zones beneath the permafrost. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, permafrost zonation, hydrology/soil moisture.

ALLARD, M. AND FORTIER, R. (1990) The thermal regime of a permafrost body at Mont du Lac des Cygnes, Québec. *Canadian Journal of Earth Sciences*, 27, pp. 694-697.

A low peat plateau in the alpine forest-tundra at Mont du Lac des Cygnes, 100 km northeast of Québec City, contains a permafrost body 2 m thick. At an elevation of 960 m, this is the southernmost known occurrence of alpine permafrost in eastern Canada. The terrain over the permafrost is windblown and bears a very thin and discontinuous snow cover. One year of continuous temperature records indicates that the mean annual air temperature at the site is about -1.3°C. The permafrost remains at temperatures very near the freezing point for most of the year. (authors)

Key Words: permafrost zonation, mountain permafrost, climate/permafrost monitoring, general surface conditions, snow cover.

ALLEN, D.M., MICHEL, F.A. AND JUDGE, A.S. (1988) The permafrost regime in the Mackenzie Delta, Beaufort Sea Region, N.W.T. and its significance to the reconstruction of the paleoclimatic history. *Journal of Quaternary Science*, 3, pp 3-15.

In the Mackenzie Delta wide variations in the thickness and distribution of permafrost occur. This is due in part to differences in subsurface deltaic lithologies and to the complexity of the past surface temperature history is exhibited, for example, by fluctuations in the mean annual ground temperature. Locally permafrost is thick owing to the high conductivities of ice-rich sandy and gravely sediments. Conversely, where low conductivity shales and mudstones are present, permafrost is thinner. Numerical models of permafrost aggradation suggest paleotemperatures from the Wisconsin. This proposed paleoclimate is sufficient to account for the observed maximum permafrost thickness in the region. (authors, modified)

Key Words: geothermal gradient/regime, subsea/offshore permafrost, mathematical models/simulation, paleotemperatures, ground ice content, soil/sediment conditions.

ANISIMOV, O.A. (1989) Changing climate and permafrost distribution in the Soviet Arctic. *Physical Geography*, 10, pp. 285-293.

Anticipated global warming during the next century will produce many environmental changes, including widespread thawing of permafrost in the northern hemisphere. A nonstationary model of heat and water transport in a stratified medium was used in conjunction with results from a climate-change model to estimate the severity of permafrost degradation. Results suggest that the area of continuous permafrost in the USSR may be reduced by 15 to 20% over a 50-year period. (author)

Key Words: mathematical models/simulation, permafrost aggradation/degradation, climate/permafrost monitoring.

ANISIMOV, O.A. (1989) Estimate of sensitivity of permafrost to change in global thermal regime of the Earth's surface. *Meteorologiya i Gidrologiya*, 1989, No. 1, pp. 79-84. *Soviet Meteorology and Hydrology*, 1989, No. 1, pp. 65-69.

The results of a model investigation of the effect of possible climate changes on the state of permafrost are examined, and numerical experiments on determining the indices of the thermal regime of the soil for many regions of Western Siberia and Yakutia are discussed. The regional properties of the interaction between the climate and permafrost are analyzed. Results are presented from numerical experiments on the combined influence of the variation of air temperature and winter precipitation on the evolution of permafrost. (author)

Key Words: mathematical models/simulation, permafrost sensitivity, geothermal gradient/regime.

ANNERSTEN, L. (1966) Interaction between surface cover and permafrost. *Biuletyn Peryglacjalny*, 15, pp. 27-33.

In the Schefferville Area, Québec, soil temperature measurements were carried out in an attempt to evaluate the influence of certain surface covers and the effect of the exposure upon the thermal regime of the soil in a permafrost area.

Key Words: geothermal gradient/regime, snow cover, vegetation, general surface conditions.

BAKER, G.C. AND OSTERKAMP, T.E. (1988) Implication of salt fingering processes for salt movement in thawed coarse-grained subsea permafrost. *Cold Regions Sciences and Technology*, 15, pp. 45-52.

In laboratory experiments, pore fluid velocities of vertical salt fingers, moving downward with sands and coarse-grained subsea permafrost sediments are on the order of 1 to 3 cm/hr with a maximum velocity of 5.6 cm/hr over distances of 0.1 to 0.4 m. It was demonstrated that fresh meltwater fingers move upward through a saline solution in thawed sand overlying a thawing phase boundary with frozen sand containing freshwater ice. Laboratory measurements of the hydraulic conductivity of thawed coarse-grained subsea permafrost sediments (silty sand) yield values about 103 larger than values obtained in previous field measurements. The results of these laboratory experiments show that gravity driven convection, in the form of salt fingering, can produce rapid salt movements in sands and in thawed subsea permafrost sediments. Field observations of coarse-grained subsea permafrost, including the relatively uniform salinity profiles in the thawed layer, the small change in salinity across the phase boundary, the boundary layer thickness, and the topography of the phase boundary, argue in favor of the larger values for hydraulic conductivity and pore fluid velocities suggested by these experiments. If these laboratory results are indicative of in situ conditions, then new interpretations of field observations and of previous modeling studies of coarse-grained subsea permafrost are required. (authors)

Key Words: hydrology/soil moisture, subsea/offshore permafrost, soil/sediment conditions.

BAKKEHØI, S. AND BANDIS, C. (1988) Meteorological conditions' influence on the permafrost ground in Sveagruva, Spitsbergen. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 39-44.

Recordings of meteorological data and temperatures in the ground at Sveagruva, Spitsbergen, have been taken since 1977. Based on the collected data, this paper gives a presentation of the time dependence of the isotherms in the ground. In addition, measured heat fluxes 5 cm below the surface are compared with other meteorological data, taking into account the composition of the Sveagruva clay and estimations of water content and salinity. The influence of the insulating effect of a snow cover is also described, and the snow cover's change of the albedo and the influence on the radiation conditions are investigated. Finally, thawing depths are compared with the energy exchange in the top of the soil and the snow cover. (authors)

Key Words: snow cover, heat/radiation balance, ground ice content, soil/sediment conditions.

BALOBAEV, V.T. (1980) Reconstruction of paleoclimate from present-day geothermal data. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978).* English translation of 26 of the Soviet papers. Ottawa, Canada, National Research Council, pp. 1-13.

Earth materials are media with a memory. The most informative are freezing and thawing materials which retain information tens of thousands of years old. By calculating and analyzing the temperature field of disequilibrium permafrost thawing from below, an attempt is made to determine the paleotemperatures of earth materials and the paleoclimate during the last cold period (glaciation) in the northern part of the Asiatic continent. Calculations show that 20,000 years ago the climate was colder by 10-13°C, while the thickness of permafrost reached 600-800 m. (author)

Key Words: paleotemperatures, cryostratigraphy, geothermal gradient/regime.

BARNES, P.W. (1990) Effects of rising sea level and elevated temperatures on arctic coasts. *Journal of Cold Regions Engineering,* 4, pp. 21-28.

Coastal processes are presently a balance between the influence of ice and the action of waves and currents. Climatic warming and rising sea levels would decrease the impact of ice processes and expand the role of waves and currents at the coast. Rates of shoreline retreat of the existing low coastal plain would increase, producing a transgressive erosional surface. The beaches and barrier islands presently nourished by ice push processes would decay and disappear. Increased delta sedimentation would probably be masked by concomitant sea level rises. (author, shortened)

Key Words: coastal permafrost, thermokarst/freeze-thaw related geomorphic processes.

BARRY, R.G. (1986) Impacts of CO_2-doubling on snow and ice in the Canadian Arctic. In: French, H.M., ed. *Climate Change Impacts in the Canadian Arctic. Proceedings of a Canadian Climate Program Workshop (Geneva Park, Ontario, March 3-5, 1986).* Downsview, Ontario, Atmospheric Environment Service, pp. 54-66.

The significance and extent of snow and ice cover in the Canadian Arctic is established. Information requirements for the assessment of potential CO_2-induced impacts on snow and ice are highlighted and available sources of data are considered. The anticipated impacts of CO_2-induced climate changes on snow and ice cover in Northern Canada are discussed for each of the main components of the cryosphere beginning with the simply determined effects and proceeding to the more complex.

Key Words: mathematical models/simulation, snow cover, sea ice cover.

BARRY, R.G. (1990) Evidence of recent changes in global snow and ice cover. *GeoJournal,* 20, pp. 121-127.

Data on recent variations in the seasonal extent of snow cover and sea ice, of the terminal position and volume of alpine glaciers, and of ground temperature profiles in permafrost areas are reviewed. The extent of seasonal snow cover and sea ice has fluctuated irregularly over the last 15-20 years. There is no apparent response to global warming trends. In contrast most glaciers retreated and thinned from the late 19th century until the 1960s and Alaskan permafrost temperatures have risen 2°-4°C per century. Recently, some glacier advances have been noted. (author)

Key Words: snow cover, sea ice cover, greenhouse gases.

BAULIN, V.V. AND DANILOVA, N.S. (1984) Dynamics of late Quaternary permafrost in Siberia. In: Velichko, A.A., ed. *Late Quaternary Environments of the Soviet Union* (H.E. Wright, Jr. and C.W. Barnosky, English language editors). Minneapolis, University of Minnesota Press, pp. 69-77.

The history of permafrost formation in Siberia during the late Quaternary is presented. The oldest paleontologically-dated traces of permafrost were discovered in the northeastern USSR and assigned an early Pleistocene age. Depending on climatic fluctuations, the areas occupied by permafrost sometimes increased, covering almost all of the USSR, and at other times greatly decreased. In the Far North and Northeast, the permafrost was preserved during the entire Quaternary. (authors, modified)

Key Words: permafrost zonation, paleotemperatures, permafrost sensitivity.

BAULIN, V.V., BELOPUKHOVA, YE. B. AND DANILOVA, N.S. (1984) Holocene permafrost in the USSR. In: Velichko, A.A., ed. *Late Quaternary Environments of the Soviet Union* (H.E. Wright, Jr. and C.W. Barnosky, English language editors). Minneapolis, University of Minnesota Press, pp. 87-91.

The history of permafrost conditions during the Holocene is presented. The general warming trend in the Holocene caused changes in frost conditions. The southern boundary of permafrost shifted north by 20° of latitude, frost cracking was sharply reduced, average annual temperatures rose by 12 to 13°C, and areas of discontinuity and thermokarst increased. In contrast to present conditions, late Pleistocene relicts were preserved outside the southern boundary of surface frost, and a wide zone was preserved where the permafrost was deeper and appeared to be buried. The overall thickness of the permafrost was also greater. (authors, modified)

Key Words: permafrost zonation, paleotemperatures, permafrost sensitivity.

BENNETT, L.P. AND FRENCH, H.M. (1990) In situ permafrost creep, Melville Island, and implications for global change. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 119-123.

In situ measurements of permafrost creep at a number of sites near Rea Point, eastern Melville Island (latitude 75°22'N; longitude 105°45'W) between 1985 and 1987 indicate rates of deformation between 0.06 to 0.10 cm/yr at a depth of 65 cm. The current mean annual ground temperature (MAGT) is -16.5°C and ground temperatures warmer than -3.0°C occur only in the top 1.0-1.2 m of permafrost and only for 80-100 days per year. If predicted global warming trends were to induce slight thermal changes in the upper 1.0-2.0 m of permafrost at Rea Point, greater creep rates might be expected in addition to increased gelifluction and mass wasting in the active layer. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, permafrost sensitivity, geothermal gradient/regime.

BENNINGHOFF, W.S. (1966) Relationships between vegetation and frost in soils. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings*. National Academy of Sciences, National Research Council Publication 1287, pp. 9-13.

The vegetation-soil thermal regime is redefined, and some approaches are suggested that may assist in understanding the processes that couple these phenomena. The heat balance is discussed for a boundary layer.

Key Words: vegetation, heat/radiation balance.

BIGL, S.R. (1984) Permafrost, seasonally frozen ground, snow cover and vegetation in the USSR. *U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). Special Report 84-36*, 132 pp.

This study compiles information about several Soviet physiographic features: permafrost, seasonally frozen ground, snow cover and vegetation. The primary product of this study is a series of maps depicting the general distribution of each feature throughout the USSR. A short text describes the distribution shown on the maps. A second product is a collection of 57 maps showing the local distribution of ground ice and permafrost in the USSR. (author, shortened)

Key Words: permafrost terminology, snow cover, vegetation, ground ice content.

BILLINGS, W.D. (1987) Carbon balance of Alaskan tundra and taiga ecosystems: past, present and future. *Quaternary Science Review*, 6, pp. 165-177.

During the Holocene, a great amount of carbon has been stored in the peaty soils beneath the wet coastal tundra at Barrow, Alaska, and in the wet peatlands of the bottomland taiga near Fairbanks, Alaska. On the basis of fossil pollen, plant macrofossil spectra, and present vegetation, an attempt is made to estimate rough carbon budgets for the present and during the last 5000 years at these sites. Carbon capture and carbon accumulation rates have varied cyclically in the past at both sites. However, both tundra and taiga have remained sinks for atmospheric CO_2 through this time. In view of the probable warming of these climates due to increasing atmospheric CO_2 concentrations, future fates of this carbon, now stored in permafrost, are in doubt. Future carbon balances may be quite different from those that have prevailed during the Holocene and at present. These ecosystems may well become carbon sources rather than remain carbon sinks. The use of field and phytotron simulation experiments are suggested as well as the use of mathematical models in attempting to predict the future of these carbon-rich ecosystems in the 21st and 22nd centuries. (author)

Key Words: permafrost ecosystems/greenhouse gases.

BILLINGS, W.D., LUKEN, J.O., MORTENSON, D.A. AND PETERSON, K.M. (1982) Arctic tundra: a source or sink for atmospheric carbon dioxide in a changing environment? *Oecologia*, 53, pp. 7-11.

Intact cores from the wet coastal arctic tundra at Barrow, Alaska, were used as microcosms in the measurement of CO_2 fluxes between peat, vegetation and atmosphere under controlled conditions. Net ecosystem CO_2 uptake was almost twice as high at present summer temperatures (4°C) than at 8°C. Lowering the water table from the soil surface to -5 cm also had a pronounced effect in decreasing net ecosystem carbon storage. Warming of the tundra climate could change the ecosystem from a sink for atmospheric CO_2 to a source. (authors)

Key Words: permafrost ecosystems/greenhouse gases, hydrology/soil moisture.

BILLINGS, W.D., LUKEN, J.O., MORTENSON, D.A. AND PETERSON, K.M. (1983) Increasing atmospheric carbon dioxide: possible effects on arctic tundra. *Oecologia*, 58, pp. 286-289.

Cores of wet coastal tundra collected in frozen condition in winter were used as microcosms in a phytotron experiment that assessed the effects of doubling the present atmospheric CO_2 concentration, increasing temperature, and depressed water table on net ecosystem CO_2 exchange. Doubling atmospheric CO_2 had less significance in regard to net carbon capture or loss in this ecosystem as compared to the significant levels of increased temperature and lowered water table. Both of the latter are to be expected as atmospheric CO_2 increases in the arctic. (authors)

Key Words: permafrost ecosystems/greenhouse gases, hydrology/soil moisture.

BLISS, L.C. (1978) Vegetation and revegetation within permafrost terrain. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1*. Ottawa, National Research Council Canada, pp. 30-50.

The data available indicate that northern races of agronomic species are well adapted for use in revegetating northern boreal forest lands. A few of these species and two grasses native to the northern forests and tundra have been used with reasonable success in the Low Arctic. Few studies have been done to date on revegetation in the High Arctic, but the limited results show little promise for reseeding surface disturbed soils. All soils are nutrient deficient and require high applications of nitrogen and phosphorus (100-200 kg/ha) There are examples of successful revegetation in these northern permafrost lands, but those north of 72° hold less promise for soil stabilization through seeding programs. (author)

Key Words: vegetation, permafrost ecosystems/greenhouse gases.

BLISS, L.C. AND WEIN, R.W. (1971) Changes to the active layer caused by surface disturbance. In: *Seminar on the Permafrost Active Layer (Vancouver, British Columbia, Canada, 4-5 May 1971), Proceedings*, pp. 37-48.

As with other world biomes the tundra consists of mosaics of landscapes, soils, climate and vegetation. The data collected for one area may have applicability for others, but problems of extrapolation do exist. The task is to survey enough of the units that some ability is developed to predict levels of potential disturbance and methods for revegetation of vast areas where limits of time, money and manpower prevent detailed studies. After one summer of both intensive and extensive research in the Low and High Arctic, it is evident that many of the problems are different and that the magnitude of problems associated with permafrost and the active layer are both more urgent and intense in the Low Arctic. While much of the surface disturbance is new, areas of older natural and man-induced disturbance occur and clues from these older sites are proving valuable in the decision-making process of determining how to solve the problem of reestablishing and maintaining a plant cover following disturbance. (authors)

Key Words: vegetation, permafrost ecosystems/greenhouse gases, permafrost sensitivity.

BONAN, G.B. (1988) A simulation model of environmental processes and vegetation patterns in boreal forests: test case Fairbanks, Alaska. *Publication No. 76 of the project: Ecologically Sustainable Development of the Biosphere.* Laxenburg, Austria, International Institute for Applied Systems Analysis, 63 pp.

In this study, a simulation model of environmental processes in upland boreal forests was combined with a gap model of species-specific demographic responses to these processes. Required parameters consisted of easily obtainable climatic, soils, and species parameters. The model successfully reproduced seasonal patterns of solar radiation, soil moisture, and depths of freeze and thaw for different topographies at Fairbanks, Alaska. The model also adequately simulated stand structure and vegetation patterns for boreal forests in the uplands of interior Alaska. These analyses suggest that this modeling approach is valid for upland boreal forests in interior Alaska and have identified the critical processes and parameters required to understand the ecology of these forests. If validated in other bioclimatic regions, this model may provide a framework for a circumpolar comparison of boreal forests and a mechanistic context for bioclimatic classifications of boreal forest regions. (author)

Key Words: vegetation, mathematical models/simulation, heat/radiation balance, geothermal gradient/regime.

BREWER, M.C. (1958) Some results of geothermal investigations of permafrost in northern Alaska. *EOS. Tranasctions, American Geophysical Union*, 39, pp. 19-26.

Frequent, regular thermal measurements in northern Alaska over a six-year period have provided information on many of the problems related to the temperature and distribution of permafrost in the Arctic. The maximum depth of permafrost near Barrow is 1330 ft. The minimum permafrost temperature recorded, below the depth of measurable (0.01°C) seasonal fluctuation (70-100 ft.), is -10.6°C. The temperature effect of medium sized heated buildings resting on permafrost is measurable to depths well below 50 ft. It is doubtful that frozen ground at shallow depths extends outward more than a few tens of feet from the shore of the Arctic Ocean although it may be present at depths greater than 100 ft. Lakes deeper than about 7 ft do not freeze to bottom and may have an unfrozen zone approaching several hundred feet in depth beneath them. (author)

Key Words: geothermal gradient/regime, climate/permafrost monitoring, general surface conditions.

BRIAZGIN, N.N. AND KOROTEVICH, E.S. (1975) Arctic and the Antarctic. (Arktika i Antarktida). *Cold Regions Research and Engineering Laboratory Report No. CRREL-TL-474, August 1975*, 69 pp. Originally published in: *Mirovyy Balans i Vodnyy Resursy Zemli USSR* 1974, pp. 422-475.

This excerpt from a book on world water balance describes the Arctic and Antarctic water supply specifically. It describes in great detail the effect of glacier runoff, geographical and topographic characteristics as well as the climatological influence on water balance in these areas. (authors)

Key Words: hydrology/soil moisture.

BRIGHAM, J.K. AND MILLER, G.H. (1984) Paleotemperature estimates of the Alaskan Arctic Coastal Plain during the last 125,000 years. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 80-85.

Amino acid results on mollusks from the last interglacial high sea stand, combined with paleoclimatic proxy data and assumptions concerning permafrost conditions, provide a means of quantifying paleotemperatures in permafrost throughout Wisconsin time and places limits on the possible magnitude of the temperature change throughout this period. Areas such as Ellesmere Island, N.W.T., or the Dry Valleys of Antarctica may serve as partial modern analogues for the glacial climates of the North Slope. (authors, modified)

Key Words: paleotemperatures.

BROWN, J. AND ANDREWS, J.T. (1982) Influence of short-term climate fluctuations on permafrost terrain. In: Carbon Dioxide Effects Research and Assessment Program. Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change, *U.S. Department of Energy Report DOE/EV/10019-02, Vol. 2, Part 3*, 30 pp.

This report discusses how climatic analyses, permafrost temperatures, and geomorphic processes might be used to interpret the influence of a CO_2-induced climate change on northern ecosystems.

Key Words: climate/permafrost monitoring, geothermal gradient/regime.

BROWN, J. AND GRAVE, N.A. (1978) Physical and thermal disturbance protection in permafrost. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 2*. Ottawa, Canada, National Research Council, pp. 51-93.

Disturbance of the terrain, whether by natural or artificial causes, is bound to result in an acceleration of natural processes. This paper reviews the major findings of site and regional investigations dealing with human induced and natural disturbances. The first half of the report deals with literature from North American and other circumpolar regions, excluding the Soviet Union. The second half of the report contains the discussion of the Soviet literature. (authors, modified)

Key Words: thermokarst/freeze-thaw related geomorphic processes, permafrost aggradation/degradation, permafrost engineering/infrastructure, geothermal gradient/regime.

BROWN, J. AND JOHNSON, P.L. (1965) Pedo-ecological Investigations, Barrow, Alaska. *U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, CRREL Report No. TR-159*, 38 pp.

The primary objectives of the study are to quantify the environmental parameters and ecosystem processes which are responsible for generating the complex Arctic landscape and to evaluate the effect of micro-and macrorelief upon soils and vegetation. The experimental design and methodologies employed for acquisition and analysis of data are described. Data are presented from 20 plots which include depth of summer thaw for 1962 and 1963, soil moisture content at 80 sample sites, soil chemical concentrations at the 3/4 meter depth, selected soil temperature for an entire year, and lichen, moss, and vascular plant cover. Microclimatic data at 6 stations along a 2-km transect are presented for summer 1963. The interdisciplinary approach to these investigations has been directed towards an understanding of the edaphic, geomorphic, botanical, and ecological characteristics of the landscape, and to a lesser extent to their interactions with the microenvironment. (authors)

Key Words: permafrost ecosystems/greenhouse gases, vegetation, soil/sediment conditions.

BROWN, J., RICKARD, W. AND VIETOR, D. (1969) The effect of disturbance on permafrost terrain. *U.S. Army Cold Regions Research and Engineering Laboratory, Special Report No. 138*, 13 pp.

In order to evaluate, on a regional basis, how sensitive the permafrost environment really is to both man-oriented disturbances and natural stresses three types of studies were undertaken: 1) A detailed study to evaluate the influence of vegetation and peat thickness on soils underlain by permafrost at shallow depths(<60 cm or so); 2) The influence of fire on permafrost degradation; and 3) The magnitude of permafrost disturbance due to bulldozing and use of winter trails after spring breakup. (authors, modified from introduction)

Key Words: vegetation, general surface conditions, fire.

BROWN, R.J.E. (1965) Some observations on the influence of climatic and terrain features on permafrost at Norman Wells, N.W.T. *Canadian Journal of Earth Sciences*, 2, pp. 15-31.

During the summers of 1959 and 1960, field observations of the influence of some climatic and terrain features on permafrost were carried out at Norman Wells, N.W.T. Five sites, all underlain by perennially frozen ground were selected for investigation. At each site, measurements were taken of evaporation, net radiation at the ground surface, depth of thaw, and ground temperatures in the thawed layer and the permafrost. Although field conditions dictated the use of crude measuring devices, some quantitative information was obtained of the relative importance of these climatic and terrain features in the permafrost environment. The depth of thaw under moss and lichen was less than in areas supporting other types of plant growth. Ground temperatures in the thawed layer and in the permafrost showed the same characteristics, being lower in the moss and lichen areas. (author, shortened)

Key Words: general surface conditions, vegetation, geothermal gradient/regime, heat/radiation balance.

BROWN, R.J.E. (1966) Influence of vegetation on permafrost. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings*. National Academy of Sciences, National Research Council Publication 1287, pp. 20-25.

Vegetation has a direct influence on the permafrost by its thermal properties which determine the quantity of heat that enters and leaves the underlying ground in which the permafrost exists. Components of the energy exchange regime at the ground surface and thermal contribution of each of them to permafrost are modified by surface vegetative cover. Vegetation also exerts an indirect influence on permafrost by affecting climatic and other terrain features, which in turn have a direct influence on the permafrost.

Key Words: vegetation, general surface conditions, heat/radiation balance.

BROWN, R.J.E. (1966) Relation between mean annual air and ground temperatures in the permafrost region of Canada. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings.* National Academy of Sciences, National Research Council Publication 1287, pp. 241-247.

The difference between mean annual air and ground temperature, and variations in this difference from place to place are caused by climatic factors other than air temperature in combination with surface and subsurface terrain factors. The complex energy exchange regime at the ground surface, which is influenced by these factors, is such that the mean annual ground temperature is several degrees warmer than the mean annual air temperature. Factors which seem particularly influential are net radiation, vegetation, snow cover, and ground thermal properties that vary with time; other factors include relief, slope and orientation and surface and subsurface drainage.

Key Words: geothermal gradient/regime, general surface conditions, heat/radiation balance, soil/sediment conditions, ground ice content.

BROWN, R.J.E. (1971) Characteristics of the active layer in the permafrost region of Canada. In: *Seminar on the Permafrost Active Layer, (Vancouver, British Columbia, Canada, 4-5 May 1971), Proceedings*, pp. 1-8.

Nomenclature used in regard to the active layer is presented. Methods of measurement are discussed, and a geographical zonation of Canada is given. The influence of climate and terrain factors on the occurrence of permafrost is described.

Key Words: general surface conditions, geothermal gradient/regime, permafrost terminology, permafrost zonation, soil/sediment conditions.

BROWN, R.J.E. (1973) Ground ice as an initiator of landforms in permafrost regions. In: Fahey, B.D. and R.D. Thompson, eds. *Research in Polar and Alpine Geomorphology.* Proceedings of the Third Guelph Symposium on Geomorphology, Guelph, Ontario, Canada. Norwich, England, Geo Abstracts, Ltd., pp. 25-42.

The role of ground ice as an initiator of landforms in permafrost regions implies also the formation of landforms which result from the melting of ground ice. Many landforms in permafrost regions owe their origin to the build-up of ice in the ground. Several types of prominent features are formed by the aggradation of permafrost and the accompanying formation of large masses of ground ice, many meters in size. Such landforms include pingos, palsas, peat plateaux, ice wedge polygons and rock glaciers. A second group of landforms associated with the degradation of permafrost and melting of ground ice includes thermokarst depressions and hollows, thaw lakes, thaw slumps, cemetery mounds and beaded streams. The Mackay classification of ground ice has systematized to a considerable degree the relationship between these landforms and forms of ground ice in permafrost regions. (author)

Key Words: ground ice content, thermokarst/freeze-thaw related geomorphic processes.

BROWN, R.J.E. (1973) Influence of climatic and terrain factors on ground temperature at three locations in the permafrost region of Canada. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 27-34.

Observations at Thompson, Yellowknife, and Devon Island indicate that mean annual ground temperatures at depths down to 15 m may differ over a 2°C range among various types of terrain at any one location in the permafrost region. These variations are reflected in different depths of active layer that may range from less than 0.5 m to more than 2 m, even in the northern part of the continuous zone. Variations greater than 1°C may occur even between sites only a few tens of meters apart. These local differences can reflect significant differences in the extent and thickness of permafrost and the susceptibility to thawing. Many more observations are required from other parts of the permafrost region to correlate terrain type and ground temperature conditions.

Key Words: general surface conditions, geothermal gradient/regime, permafrost sensitivity.

BROWN, R.J.E. (1978) Influence of climate and terrain on ground temperature in the continuous permafrost zone of northern Manitoba and Keewatin District, Canada. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* Ottawa, National Research Council, Canada, pp. 15-21.

Mineral exploration in northern Manitoba and District of Keewatin and investigation of a proposed natural gas pipeline have produced a need for permafrost information where virtually no data were previously available. Thermocouple and thermistor cables have been installed at various depths down to 15 m in different types of terrain in this region. Ground temperatures recorded during 1974-1976 inclusive and their relation to climatic and terrain factors are presented. Annual variations in ground temperatures and thickness of the active layer in response to annual fluctuations in summer and winter air temperatures indicate the influence of climate on permafrost. Ground temperatures vary in different types of terrain at one location due to variations in vegetation, snow cover, proximity to water bodies, and type of soil or rock. (author)

Key Words: geothermal gradient/regime, general surface conditions, permafrost zonation, permafrost sensitivity, climate/permafrost monitoring.

BROWN, R.J.E. (1983) Effects of fire on the permafrost ground thermal regime. In: Weir, R.W. and D.A. Mackeen, eds. *Conference on the Role of Fire in Northern Circumpolar Ecosystems*. New York, J. Wiley and Sons, pp. 97-110.

Discontinuous permafrost occurs widely in the boreal forest, while throughout the tundra region permafrost is continuous and may be hundreds of meters deep. Until recent years few investigations have been conducted on the effects of fire on the perennially frozen ground in these northern polar ecosystems. Little modification takes place during the actual burning, but the partial or complete destruction of the organic cover produces changes in permafrost lasting many years. There are three major effects of fire on permafrost which are related to the amounts of vegetation and organic soil that are removed: the deepening of the active layer with resultant thermokarst and instability of newly thawed soil or slopes; an increase in soil temperatures; and changes in the ground surface energy exchange regime. These post-fire conditions prevail for many years as natural restoration of burned sites gradually takes place. Long-term observational programs, which are lacking at present, are required to assess more fully the effects of fire on permafrost. (authors)

Key Words: fire, geothermal gradient/regime, permafrost ecosystems/greenhouse gases.

BROWN, R.J.E. AND PÉWÉ, T.L. (1973) Distribution of permafrost in North America and its relationship to the environment: a review 1963-1973. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 71-100.

Relationships between permafrost and environmental factors are discussed. Important factors are climate, relief, vegetation, hydrology, snow cover, fire, soil and rock, and glacier ice. Also ground ice and other periglacial features are discussed. The past distribution of permafrost is summarized.

Key Words: general surface conditions, snow cover, vegetation, fire, hydrology/soil moisture, ground ice content, soil/sediment conditions, permafrost zonation.

BROWN, R.J.E. AND WILLIAMS, W.P. (1972) The freezing of peatland. *National Research Council of Canada, Division of Building Research Technical Paper No. 381*, 40 pp.

The paper is intended to give engineers and other workers a practical appreciation of the rate of freezing and thawing, depth of frost penetration and thaw, and the influence of climate and terrain on these processes. It is based on information available in the literature and on field observations at two sites, one the Mer Bleue Peat Bog near Ottawa in the zone of seasonal freezing, the other at Thompson, Manitoba, in the middle of the discontinuous permafrost zone. (authors)

Key Words: heat/radiation balance, permafrost aggradation/degradation.

BROWN, W.G. AND JOHNSTON, G.H. (1970) Dikes on permafrost: predicting thaw and settlement. *Canadian Geotechnical Journal*, 7, pp. 365-371.

Prediction of permafrost thaw and settlement of dikes constructed on perennially frozen ground is important for maintenance and foundation stability. A method is developed for estimating the rates of thaw and settlement, based on simple heat conduction theory. A comparison of calculated and observed rates of thaw for dikes on ice-rich foundation soils at the Kelsey Generating Station in northern Manitoba shows good agreement and indicates that thaw and settlement rates can be predicted with reasonable accuracy. (authors)

Key Words: heat/radiation balance, soil/sediment conditions, hydrology/soil moisture.

BURGESS, M.M., JUDGE, A.S., TAYLOR, A. AND ALLEN, V. (1982) Ground temperature studies of permafrost growth at a drained lake site, Mackenzie Delta. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference*. Ottawa, National Research Council Canada, pp. 3-11.

Illisarvik Lake on Richards Island, Mackenzie Delta, Canada, was artificially drained in order to investigate the growth of permafrost. Twenty-four boreholes were hydraulically drilled to depths ranging from 15 to 92 m below lake level and were instrumented with temperature cables. Monitoring of ground temperatures beneath the lake and surrounding shoreline prior to drainage delineated a bow-shaped talik extending up to 32 m below lake bottom. The temperature profiles from the central lake holes were used to characterize thermal conditions below the lake bottom prior to drainage. A two-dimensional finite element computer simulation of the formation and growth of Illisarvik suggests a minimum lake age of 900 to 1,000 years. Post-drainage conditions in the first year after drainage were modeled by studying the microclimatic regime together with the ground thermal regime. Although predicted profiles agreed well with measured temperatures, geotechnical and year-round weather gathering programs are necessary before further post-drainage modeling is warranted. (authors, modified)

Key Words: permafrost aggradation/degradation, permafrost zonation, climate/permafrost monitoring, geothermal gradient/regime, mathematical models/ simulation.

BURGESS, M.M. AND RISEBOROUGH, D.W. (1990) Observations on the thermal response of discontinuous permafrost terrain to development and climate change -an 800 km transect along the Norman Wells Pipeline. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 291-297.

Ground temperature instrumentation is installed at 23 study sites along the buried Norman Wells oil pipeline right-of-way as part of the government-industry Permafrost and Terrain Research and Monitoring Program. The pipeline, forming an 869 km transect through the discontinuous permafrost zone of northwestern Canada, was designed to limit energy exchange with the surrounding thaw-sensitive soils. Data collected at the study sites during the first 3.5 years of pipeline operation (April 1985-October 1988) reveal that: 1) mean annual external pipe temperatures are greater than 0°C and show a continuous warming trend (average increase 1.5 K over the observation period); 2) mean annual ground temperatures several meters away from the pipe, on the right-of-way and at the depth of pipe burial, also show a gradual warming trend at most sites (average increase 1.2 K over the observation period); 3) mean annual ground temperatures at a similar depth off the right of way showed no warming trend until 1988 (average increase 0.6 K) Non-permafrost locations show the most rapid changes in mean annual temperatures. The pattern of change off the right-of-way suggests that the ground temperature there is responding to a recent increase in air temperature (about 3 K from 1985 to 1988) at a rate controlled by the initial ground thermal conditions. (authors)

Key Words: geothermal gradient/regime, permafrost sensitivity, permafrost engineering/infrastructure.

BURN, C.R. (1982) *Investigations of thermokarst development and climatic change in central Yukon Territory*. M.A. Thesis, Department of Geography, Carleton University, Ottawa, Ontario, 142 pp.

Investigations of thermokarst development, ground ice conditions and climatic change in the Stewart and Takhini River Valleys, Yukon Territory, are reported. Core drilling to 5 m revealed extensive ground ice in glacio-lacustrine clays in the Stewart Valley. With air photographs, the development of two retrogressive thaw slides is reconstructed, as is pond development. The last is also reconstructed by cross-dating of ring series from submerged trees. A numerical simulation of the effects of climate change and fire on ground thermal regime indicates that fire produces a greater change in surface temperature than a climatic change of 2°C. The features in the Stewart Valley are associated with the post-1850 warming, while the Takhini features have recently enlarged, following a forest fire. (author, modified)

Key Words: geothermal gradient/regime, ground ice content, soil/sediment conditions, fire, thermokarst/ freeze-thaw related geomorphic processes, mathematical models/simulation.

BURN, C.R. (1990) Implications for paleo-environmental reconstruction of recent ice-wedge development at Mayo, Yukon Territory. *Permafrost and Periglacial Processes*, 1, pp. 3-14.

Elevated tritium concentrations in ice veins and wedges recently exposed near, Mayo, Yukon Territory indicate that these features have formed or recracked fro time to time during the past thirty years. The mean annual air temperature at Mayo is -4°C. Therefore, the features are active in an environment that would conventionally be considered as too warm for thermal contraction cracking and ice-wedge development. Periodic cracking is probably related to below normal winter air temperatures, such conditions are not readily apparent in long-term climatic statistics. It follows that many ice-wedges whose casts are preserved in the geologic record may not have formed under conditions a cold as previously suggested. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes.

BURN, C.R. (1992) Recent ground warming inferred from the temperature in permafrost near Mayo, Yukon Territory. In: Dixon, J.C. and A.D. Abrahams, eds. *Periglacial Geomorphology*. Chichester, J. Wiley, pp. 327-350.

Ice-rich glaciolacustrine sediments near Mayo, Yukon Territory, in which permafrost is 34 m thick, show evidence of recent warming. The mean annual ground temperature at the depth of zero annual amplitude (10 m) is -1.3°C. At present, temperatures are slightly warmer, between 0 and 5 m, almost constant between 5 and 15 m, and then increase with depth. Upward projection of the temperature gradient at depth suggests a former mean temperature at the surface of permafrost of at most -2.0°C. Geothermal modeling suggests that if ground temperatures were previously in equilibrium with a near-surface temperature of approximately -3.0°C, then it has taken about 20 years for permafrost to reach present conditions. Observed changes in mean winter temperature and snowfall have probably caused the ground warming. (author, shortened)

Key Words: geothermal gradient/regime, climate/permafrost monitoring, mathematical models/simulation.

BURN, C.R. AND SMITH, M.W. (1990) Development of thermokarst lakes during the Holocene at sites near Mayo, Yukon Territory. *Permafrost and Periglacial Processes*, 1, pp. 161-175.

The origin and growth of numerous lakes near Mayo, Central Yukon, have been examined, using ground surveys, aerial photographs and dendrochronology. Many of the lakes are currently expanding at rates of axial increment up to 1.2 m/yr. Three lakes whose axes are currently expanding at about 1.0 m/yr, were studied in particular detail. Tree-ring analysis indicates that these lakes formed by the middle to the late part of the last century. The talik profile was determined beneath one lake, and is consistent with the Stefan solution for thawing of ice-rich soil with such an initiation date and rate of expansion. Organic-rich horizons containing logs, vegetative detritus and fresh-water ostracods have been exposed in two retrogressive thaw slumps near the lakes. These horizons have been interpreted as the bottoms of former thermokarst lakes. Radiocarbon dates of approximately 8500 BP, 3900 BP and 2300 BP have been obtained indicating several periods of thermokarst activity during the Holocene. The results suggest that thermokarst lake development is not solely associated with changing climatic conditions in this region, since the current lakes and those that formed around 2300 BP do not appear to be directly linked to climatic warming. It is suggested that the most recent initiation of thermokarst activity is related to the effects of forest fires. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, fire, climate/permafrost monitoring.

CARTER, L.D. (1990) Climate change and permafrost: record from surficial deposits. *Journal of Cold Regions Engineering*, **4**, pp. 43-53.

Information that is useful for determining both paleoclimate and past permafrost conditions can be derived from studies of surficial deposits, and thus these deposits provide a record of climatic change and permafrost history. The available record suggests a complex history of permafrost aggradation, degradation, and changes in zonal boundaries in response to climatic changes of varying magnitude and rapidity over at least the last 2.4 million years. We can expect similar changes in permafrost conditions in response to future climatic change.

Key Words: paleotemperatures, cryostratigraphy, permafrost zonation, permafrost aggradation/degradation.

CHAPIN, F.S., III (1984) The impact of increased air temperature on tundra plant communities. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climate Change in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications 83-1*, pp. 143-149.

A major climatic effect of increasing CO_2 levels may be rising temperature, particularly in boreal regions. Physiological studies suggest that tundra plants are so well adapted to low temperature that there would be little immediate effect of rising air temperature on plant production. However, field greenhouse studies, in which air temperature has been raised an average of 10° C, indicate that some arctic plants are quite temperature sensitive, whereas other species are not significantly affected by increased temperatures. An increasing air temperature is most likely to exert through changes in length of growing season rather than through direct temperature effects. The most ecologically significant effects may be changes in reproductive output and seedling establishment, leading in turn to changes in community composition, position of treeline etc. (author)

Key Words: general surface conditions, permafrost ecosystems/greenhouse gases.

CHENG, G.D. (1984) Study of climate change in the permafrost regions of China: a review. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983)*, *Proceedings.* Washington, D.C., National Academy Press, pp. 139-144.

A summary of climate change research in permafrost regions of China is presented. A discussion of periglacial conditions found on the Qinghai-Xizang Plateau and in Northeast China for three separate time periods: 1) Late Pleistocene stage; 2) the last 10,000 years; and 3) the last 1,000 years, is given. Also included is a map showing boundaries of permafrost during the late Quaternary.

Key Words: permafrost zonation, paleotemperatures, climate/permafrost monitoring.

CHENG, G.D. AND DRAMIS, F. (1992) Distribution of mountain permafrost and climate. *Permafrost and Periglacial Processes*, 3, pp. 83-91.

The relationship between mountain permafrost and climate is still relatively unknown. The implications of zonation (latitude, continentality), the various climatic parameters (MAAT; freezing and thawing indices; basal snow temperature, BTS; solar radiation; and surface heat balance) and climate change are outlined for mountain permafrost. Some research priorities are suggested. (author)

Key Words: mountain permafrost, permafrost zonation.

COLLINS, C.M., HAUGEN, R.K. AND KREIG, R.A. (1988) Natural ground temperatures in upland bedrock terrain, Interior Alaska. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings*, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 56-61.

Surface and subsurface ground temperature measurements were made in drill holes representing a variety of permafrost/non-permafrost, slope exposure, elevation, vegetation and soil conditions within the upland taiga of interior Alaska. Algorithms representing equivalent latitude and air temperature/ elevation relationships are developed to more precisely define permafrost/non-permafrost boundaries within this complex terrain. (authors)

Key Words: geothermal gradient/regime, general surface conditions, permafrost zonation, mountain permafrost.

CORAPCIOGLU, M.Y. AND PANDAY, S. (1988) Thawing in permafrost: simulation and verification. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings*, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 61-66.

Governing equations of thawing permafrost are developed for an unsaturated frozen porous medium, to predict the extent and rate of thawing. These are comprised of the conservation of mass equations for unfrozen water, the melting ice, and the deforming porous medium, as well as an energy conservation equation for the entire system. Results are compared with laboratory experiments conducted at CRREL. Excellent match is noticed between observed and simulated temperature and pore pressure profiles, as well as settlement rates. (authors)

Key Words: permafrost engineering/infrastructure, hydrology/soil moisture, mathematical models/ simulation, permafrost aggradation/degradation.

CORBIN, S.W. AND BENSON, C.S. (1982) Thermal regime of a small Alaskan stream in permafrost terrain. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 186-191.

Goldstream Creek near Fairbanks, Alaska, is about 8 m wide, 0.25 m deep, and flows 0.3 to 1.3 $m^3 s^{-1}$. From 1963 to 1973, hydrological and temperature observations were made to determine thermal effects of the stream on relict permafrost that underlies much of the valley. Soil freezing beginning in October causes build-up of ground-water pressure, and the stream overflows repeatedly until about January, forming aufeis deposits 1 to 2 m thick, depending on depth of soil freezing, which is primarily controlled by snow cover. The data permitted calculations of the thermal diffusivity of unfrozen soil. Using Fourier series, numerical step models and differential analyses, average values ranged from about $4 \times 10^{-7} m^2 s^{-1}$ in areas away from the stream to over 15×10^{-7} beneath the stream. Overflows facilitate heat loss from the ice by removing the insulating snow layer. The mechanism of adding heat is more effective than conduction which is the only mechanism for transporting heat to the upper surface. Although the surface temperature in summer is lower in the stream than in the surrounding ground (11°C compared with > 22°C) the summer heat pulse penetrates deeper under the stream; this is partly due to the topography of the stream channel. The net effect on the permafrost is to lower the relict permafrost table, from about 4 m away from the stream, to nearly 6 m beneath the stream. (authors)

Key Words: hydrology/soil moisture, snow cover, geothermal gradient/regime, mathematical models/ simulation.

COURTIN, G.M. AND LABINE, C.L. (1975) Microenvironmental studies of a high arctic coastal lowland, Devon Island, N.W.T. In: *Circumpolar Conference on Northern Ecology (Ottawa, September 15-18, 1975), Proceedings.* Ottawa, National Research Council Canada, pp. IV/1-IV/17.

Measurements of total incoming radiation, net radiation, albedo, temperature, atmospheric humidity, wind and precipitation were made. Some parameters were measured at as many as 12 stations to give some idea of spatial distribution. Net radiation values are largely a function of albedo and are very low until snow melt when they are usually about 50% of incoming radiation. The yearly net radiation balance is very much higher than values calculated for that latitude. This is attributed to the physiography of the lowland and the proximity of the Devon Island ice cap with an elevation of 2000 m that gives rise to dry-adiabatically warmed winds that reduce the incidence of cloud. Precipitation is typical of the polar desert being very variable and not exceeding 70 m in summer. (authors, shortened)

Key Words: heat/radiation balance, snow cover, albedo.

COWELL, D.W., JEGLUM, J.K. AND MERRIMAN, J.C. (1978) Preservation of seasonal frost in peatlands, Kinoje Lakes, Southern Hudson Bay Lowlands. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* Ottawa, National Research Council Canada, pp. 453-459.

In early August 1976, 55 sites were studied near the Kinoje Lakes in the Hudson Bay Lowlands, 85 km NW of Moosonee, at the southern margin of discontinuous permafrost. Wetland types and percentages of samples with frozen peats were: treed bog, 100%; open bog, 40%; treed fen plus swamp, 36%; and open fen, 14%. This paper reports on: the depth to frozen peat; thickness of frozen layer; location of frozen peat in relation to peat depth, groundwater level, and surface irregularities; and insulating material (dominant species, peat type) Black spruce islands, occurring in fens and bogs, always had frozen peats. (authors, shortened)

Key Words: general surface conditions, vegetation, hydrology/soil moisture, soil/sediment conditions.

CRAMPTON, C.B. (1973) The distribution and possible genesis of some organic terrain patterns in the southern Mackenzie River valley. *Canadian Journal of Earth Sciences*, 10, pp. 432-438.

Terrain types in the southern Mackenzie River Valley can be arranged into morphological series which are, in part, continuous and, in part, discontinuous, so as to allow speculation on the probable evolution of organic terrain in the area from frozen to unfrozen landscapes, accompanying the long-term amelioration of the climate during postglacial times. Stipploid terrain on gentle slopes retained its lineated character during progressive thawing. Similarly, polygoid terrain on frozen flats retained its reticulate character, though progressive thawing locally was probably associated with increasingly diffuse pattern boundaries, ultimately yielding marbloid organic terrain. Some frozen terrazoid terrain of raised peat probably evolved into unfrozen polygoid peatland by a progressive enlargement of water-filled depressions. (author)

Key Words: vegetation, general surface conditions, permafrost aggradation/degradation.

CRAMPTON, C.B. (1973) A landscape zonation for the southern and central Mackenzie River valley based on terrain permafrost characteristics. *Canadian Journal of Earth Sciences*, 10, pp. 1843-1854.

A landscape zonation is presented for the southern and central Mackenzie River Valley, based on observed changes in permafrost characteristics of selected terrain types, with changing climate implications. The relative abundance of lichen on specified terrain types suggests the thickness of the active layer within the discontinuous permafrost zone, and is a useful guide in air photograph interpretation for extensive mapping of landscape-permafrost relationships between localities of ground inspection. Widespread, fossil, cryoturbated terrain supports the contention that today's climate in the study area is less severe than that in the past. (author)

Key Words: general surface conditions, vegetation, soil/sediment conditions, permafrost zonation.

CRAMPTON, C.B. (1981) Analysis of synergistic systems for evaluating terrain sensitivity to disturbance of icy permafrost in the Mackenzie River Valley, Canada. *Biuletyn Peryglacjalny*, 28, pp. 15-31.

An extensive land classification for the Mackenzie River Valley has been combined with an analysis of synergistic systems, to quantify field units for a more comprehensive terrain evaluation than could have been produced by either field or analytical work alone. The empirical prediction of ice content and its distribution within different environments has been used with field data to develop a classification for sensitivity of the landscape to damage from disturbance. The zone of most rapidly changing sensitivity, which occurs around Fort Norman and Norman Wells as the discontinuous merges into the continuous permafrost zone, has been quantified. (author)

Key Words: permafrost sensitivity, thermokarst/freeze-thaw related geomorphic processes, ground ice content, mathematical models/simulation.

CRAMPTON, C.B. AND RUTTER, N.W. (1973) A geoecological terrain analysis of discontinuously frozen ground in the upper Mackenzie River Valley, Canada. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 101-105.

The primary aim of this study has been the rapid identification, using aerial photographs of terrain types in terms of surficial geology, microrelief and vegetation, which is significant regarding permafrost conditions. Six examples are cited, which are a few of the terrain-permafrost relationships that can be identified from aerial photographs in the Upper Mackenzie River Valley.

Key Words: general surface conditions, permafrost zonation.

CZUDEK, T. AND DEMEK, J. (1970) Thermokarst in Siberia and its influence on the development of lowland relief. *Quaternary Research*, 1, pp. 103-120.

Thermokarst as a process is the melting of ground ice and the consequent formation of depressions. Thermokarst landforms depend on the tectonic regime of a region, the ground ice content, and the degree to which the permafrost equilibrium is disturbed. Thermokarst forms are especially prominent in the lowlands of the subnival regions with permafrost. The authors distinguish two modes of thermokarst development, permafrost back-wearing and down-wearing. The first mode is characteristic of a more dissected relief, with the process characterized by the development of gullies, thermocirques, and parallel retreat of steep walls with ice veins, resulting in a lower lowland level. Down-wearing is due to permafrost melting from above and is typical of a flat undissected relief, mainly that of watershed regions. Characteristic forms are depressions with steep slopes and flat floors (alases) Thermokarst valleys develop through coalescence of alases. (authors, modified)

Key Words: thermokarst/frost-thaw related geomorphic features, ground ice content, general surface conditions.

DESROCHERS, D.T. AND GRANBERG, H.B. (1988) Schefferville snow-ground interface temperatures. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 67-73.

Snow-ground temperatures have been intensively monitored at an upland tundra site and an open woodland site near Schefferville, Northern Québec. The upland site is underlain by permafrost while the wooded site is affected only by seasonal frost. The aim of the study is to develop a better understanding of the differences in thermal regime between the two sites in particular, and of regional variations in the thermal regime of the Schefferville area in general. The present paper represents a preliminary analysis of the data sets. Interface temperatures beneath and between trees in the woodland area are compared to similar measurements in the alpine tundra. The results indicate the great complexity of the role of the snow cover in the ground temperature regime near Schefferville. (authors)

Key Words: geothermal gradient/regime, snow cover, vegetation.

DICKINSON, R.E. (1989) Use of numerical models to project greenhouse gas-induced warming in polar regions (the conceptual basis developed over the last twenty years) In: *Ozone Depletion Greenhouse Gases, and Climate Change*. Washington, D.C., National Academy Press, pp. 98-102.

The concepts discussed involve predicting, with the aid of numerical general circulation models, the climatic changes caused by greenhouse gases and the results of those efforts as they apply to the polar regions. The major points discussed in terms of modeling results are: 1) expected tropospheric temperature increases on a different time scale with the expected stratospheric temperature decreases; 2) classical (postulated before 1974) mechanisms of high latitude amplification by means of positive feedback processes involving the temperature lapse rate and albedo; 3) the projected magnitude of high latitude warming is strongly dependent upon the seasonal cycle; 4) horizontal transport of heat by both the atmosphere and oceans; 5) vertical energy transfer, as modeled by convective parameters; 6) high latitude cloud cover has a key role through its effect in planetary albedo; 7) sea ice distribution has a critical feedback role and needs to be modeled correctly; and 8) permafrost and seasonal land ice have significant roles and should be included in a comprehensive model.

Key Words: mathematical models/simulation, greenhouse gases, heat/radiation balance.

DOOLITTLE, J.A., HARDISKY, M.A. AND GROSS, M.F. (1990) A ground-penetrating radar study of active layer thicknesses in areas of moist sedge and wet sedge tundra near

Bethel, Alaska, USA. *Arctic and Alpine Research*, 22, pp. 175-182.

Ground-penetrating radar (GPR) techniques were used near Bethel, Alaska, to compare the thicknesses of the active layer between areas of moist sedge and wet sedge tundra. Once set up in the field, the GPR provided a rapid, accurate and effective means for determining the depth to frozen soil and the thickness of the active layer. In areas of silty soil, the average thickness of the active layer under wet sedge tundra (64 cm) was considerably deeper than under moist sedge tundra (38 cm) In areas of moist sedge tundra underlain by silty soils, depths to frozen layers were relatively shallow with active layer thicknesses ranging from 17 to 63 cm. (authors)

Key Words: vegetation, soil/sediment conditions, permafrost zonation.

DREDGE, L.A. (1981) The leaching of carbonates in discontinuous permafrost, boreal Manitoba. *Geological Survey of Canada, Paper No. 81-1C*, pp. 23-25.

In boreal areas, peaty vegetation promotes the dissolution of calcareous parent materials. In non-permafrost terrain carbonate removal has progressed to a depth of 2.5 to 3 m; half of the original carbonates have been leached from the upper 0.5 m of the soil column, where dissolution is most intense. In permafrost terrain, leaching is less intense and is restricted to the upper 0.8 m of the mineral soil. Mudboils have relatively high carbonate contents because of upwelling of unleached material from the subsoil. Soils in permafrost may have low buffering capacities despite their high carbonate contents because meteoric water does not circulate below the active layer. Because of present and past leaching, carbonate contents may not be good indicators of till provenance. (author)

Key Words: soil/sediment conditions, vegetation.

DYKE, L.D. (1988) Permafrost aggradation along an emergent coast, Churchill, Manitoba. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 138-142.

Permafrost along isostatically emerging coasts must be aggrading into land as it becomes exposed in the tidal zone. The initiation of permafrost has been shown, by borehole temperature measurements, to occur in the upper half of the tidal zone at Churchill, Manitoba. A theoretical model, based on the extrapolation of a single surface temperature history, provides a prediction of permafrost extent that may be accurate enough to be of use in reconnaissance site investigations. (author)

Key Words: permafrost aggradation/degradation, coastal permafrost, climate/permafrost monitoring, geothermal gradient/regime.

EBERSOLE, J.J. AND WEBBER, P.J. (1984) Biological decomposition and plant succession following disturbance on the Arctic Coastal Plain, Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 266-272.

Thirty years after abandonment of Oumalik Test Well vigorous stands of grasses and erect willows dominate the mesic disturbed areas. Greater decomposition rates occur than in undisturbed sites. Most important in explaining the variation in decomposition rates are soil temperature and soil moisture. The greater rates of decomposition presumably indicate increased nutrient availability, which is known to favor species with high rates of turnover such as the grasses and willows. As long as the abiotic conditions favoring high decomposition persist, nutrient availability will remain high. We expect that the present communities will not be replaced with communities similar to those of the surrounding undisturbed tundra for several hundred years. (authors, modified)

Key Words: permafrost ecosystems/greenhouse gases, general surface conditions.

EDLUND, S.A. (1982) Plant communities on the surficial materials of North-Central district of Keewatin, North West Territories. *Geological Survey of Canada, Paper No. 80-33*, 20 pp.

A reconnaissance study of the vegetation of north-central District of Keewatin was undertaken in order to gain a better understanding of the relationship between the nature and distribution of plant communities and the surficial materials on which they grow. The four types of surficial materials studied, bedrock, glacial deposits, marine deposits and actively aggrading and eroding deposits each support a suite of plant communities that naturally segregate on the basis of moisture regime. Differences in species occurrence, abundance, and diversity, related to altitudinal and to some extent latitudinal changes, allow a bioclimatic subdivision of the Low Arctic ecosystem in the map area. The removal or disruption of plant communities due to man's activities can lead to destruction of unique or botanically significant communities or species, alteration of drainage, accelerated geomorphic processes, and erosion. Such activities can also lead to the destruction of important feeding and breeding habitats for dependent fauna. Communities on imperfectly and poorly drained materials are the most vulnerable to disruption. (author, shortened)

Key Words: vegetation, general surface conditions, human disturbances.

EDLUND, S.A. (1986) Modern Arctic vegetation distribution and its congruence with summer climate patterns. In: French, H.M., ed. *Climate Change Impacts in the Canadian Arctic. Proceedings of a Canadian Climate Program Workshop (Geneva Park, Ontario, March 3-5, 1986).* Downsview, Ontario, Atmospheric Environment Service, pp. 84-99.

This paper explores some of the relationships between climate and vegetation in the boreal forest, and illustrates how trends in the boreal forest become even more accentuated in the Arctic. The distribution of several arctic vascular plant species illustrates regional vegetation patterns that show congruence with regional climatic patterns. These regional vegetation patterns can be compared to patterns known to exist during the Holocene climatic optimum. A contradictory model predicting vegetation response to climatic warming is also examined. Possibilities for future studies in predicting the impact of climate change on natural ecosystems are suggested. (author, modified)

Key Words: vegetation, paleotemperatures.

EDLUND, S.A. (1989) Vegetation indicates potentially unstable Arctic terrain. *Geos*, 18(3), pp. 9-13.

According to recent climatic models, warming of the atmosphere due to increased "greenhouse gases" would probably affect the North most severely. Predicting likely environmental changes in the Arctic is difficult, however, because we lack detailed knowledge of how plant distributions, the climate and substrates interrelate in the Arctic. Ground ice plays a major role in the hydrology of the study region, often allowing active layer detachment slides, retrogressive thaw slumps and water ejection from sediments to develop. Vegetation patterns may yield clues as to the distribution and susceptibility of the terrain to such disturbances.

Key Words: climate/permafrost monitoring, vegetation, hydrology/soil moisture, ground ice content, thermokarst/freeze-thaw related geomorphic processes.

EGGINTON, P.A. AND DYKE, L.D. (1990) Apparent hydraulic conductivities associated with thawing, frost-susceptible soils. *Permafrost and Periglacial Processes*, 1, pp. 69-77.

Horizontal permeameter tests indicate that the apparent hydraulic conductivity of a frost-susceptible soil increases by one or more orders of magnitude as ice-rich layers are encountered by an advancing thawing front. When thaw progresses into ice-poor layers and the former ice-rich layers consolidate, permeability decreases. On the arctic slopes it is postulated that if the water enters a given slope segment under excess hydraulic head, then consolidation of the thawing soil in that segment may be retarded for some period of time; as a result, macropores formed by thawing ice lenses may be maintained and horizontal permeabilities may be elevated relative to those that may be encountered once the soil has consolidated. (authors)

Key Words: hydrology/soil moisture, ground ice content, thermokarst/frost-thaw related geomorphic features.

ESCH, D.C. (1982) Thawing of permafrost by passive solar means. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference*. Ottawa, National Research Council Canada, pp. 560-569.

By pre-thawing and consolidating the upper layers of permafrost, a thinner stable roadway embankment may be constructed, providing the thickness of the embankment plus that of the pre-thawed layers are adequate to contain the full seasonal thaw zone. Six test plots were established near Fairbanks, Alaska, in April 1980, to determine how surface modifications may be used to accelerate thawing of permafrost by increasing the solar heat gain. The various modifications examined included clearing and stripping the surface, construction of a thin gravel pad, darkening of the gravel pad with asphalt, and the use of clear polythene film to create a "greenhouse effect" on both gravel and stripped sections. Instrumentation was used to monitor performance including heat flow meters, wind speed and radiation sensors, and thermocouples for subsurface temperature observations. Differences between thaw depths achieved with different treatments have been as much as 40 per cent. Results of this study are used in analyses of probable benefits of roadways and airfields constructed after pre-thawing for one season. (author, shortened)

Key Words: heat/radiation balance, general surface conditions, climate/permafrost monitoring, permafrost engineering/infrastructure.

ESCH, D.C. (1984) Surface modifications for thawing of permafrost. In: *Third International Specialty Conference on Cold Regions Engineering (Edmonton, Alberta, 4-6 April 1984), Proceedings.* pp. 711-725.

In preparation for various types of construction, mining, or farming activities in permafrost terrain, some initial thawing and consolidation of near-surface permafrost soils may be beneficial. Current scientific data indicate that a major climatic warming trend is now commencing as a result of man-induced increases in atmospheric carbon dioxide. Engineers should be aware that the future presence and thermal stability of permafrost cannot be assured, and thawing in advance of construction may be the best long-range alternative. Various components of the surface energy balance are analyzed to determine how to increase the solar heat gain of a soil surface during thawing periods. Six field test plots were constructed in 1980 with different combinations of vegetation stripping, gravel pad placement, surface darkening with asphalt, and clear polyethylene film coverings, to intensify the thawing of permafrost silt soils. Results of four years of observations on these plots are presented and discussed. By stripping the vegetation, an increase of 2.0 m in thaw depth was reached after four years. The addition of an asphalt coated gravel pad covered by a clear polyethylene film to create a greenhouse effect, resulted in an increase to 3.0 m in the four year thaw depth. The benefits, and drawbacks are discussed for each surface modification, and possible improvements are suggested. (author)

Key Words: permafrost engineering/infrastructure, vegetation, general surface conditions, geothermal gradient/regime, heat/radiation balance.

ESCH, D.C. AND OSTERKAMP, T.E. (1990) Cold regions engineering: climatic warming concerns for Alaska. *Journal of Cold Regions Engineering*, 4, pp. 6-14.

Most of the engineering concerns related to a climatic warming can be classified into those related to an increase in permafrost temperatures, those related to increases in the active layer thickness (annual thaw depth), and those related to the degradation of the permafrost. Possible climatic changes and effects on permafrost are discussed.

Key Words: geothermal gradient/regime, thermokarst/ freeze-thaw related geomorphic processes, permafrost engineering/infrastructure.

ETKIN, D.A., HEADLY, A. AND STOKER, K.J.L. (1988) A long-term permafrost and climate monitoring program in Northern Canada. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 73-78.

Four locations in northern Canada were instrumented to monitor ground temperature and meteorological parameters on an hourly to daily frequency. The intent is to develop a research dataset extending over a period of about ten years for use in the analysis of climate-permafrost relationships and trend analysis. Parameters measured include soil temperatures, precipitation, air temperature, relative humidity, wind speed and direction, soil moisture and snow depth. Despite problems such as vandalism, equipment failure and equipment noise, the data collection has been generally successful, confirming that current technology allows generation of high quality data through the use of remote systems. A preliminary analysis of data obtained from these stations is presented. (authors, shortened)

Key Words: climate/permafrost monitoring, vegetation, hydrology/soil moisture, snow cover, geothermal gradient/regime.

EVERETT, K.R., MURRAY, B.M., MURRAY, D.F., JOHNSON, A.W., LINKINS, A.E. AND WEBBER, P.J. (1985) Reconnaissance observations of long-term natural vegetation recovery in the Cape Thompson Region, Alaska, and additions to the checklist of flora. *U. S. Army Cold Region Research and Engineering Laboratory, Hanover, NH, CRREL Report No. 85-11*, 77 pp.

The diversity of disturbance types, landforms, vegetation, and soils together with the large, well documented flora, makes Cape Thompson an ideal site to study long-term (20-year) environmental adjustments after impact. Man-caused disturbances there between 1958 and 1962 fall into three categories: runways, excavations and off-road vehicle trails. In addition, natural disturbance by frost action creates scars. Reestablished vegetation after 20 years consisted of species found in adjacent undisturbed landscapes. (authors, shortened)

Key Words: vegetation, human disturbances, soil/ sediment conditions.

FRENCH, H.M. (1974) Active thermokarst processes, eastern Banks Island, western Canadian Arctic. *Canadian Journal of Earth Sciences*, 11, pp. 785-794.

Active thermokarst processes occur on the hummocky and rolling terrain of eastern Banks Island in the western Canadian Arctic. The underlying sediments are ice-rich glacial silts, sands, and gravels. Ground ice slumps, triggered by a variety of local conditions, are particularly numerous in the area to the west of Johnson Point. Maximum rates of headwall retreat of between 6.0-8.0 m/yr appear typical but many slumps are short-lived and become stabilized within 30-50 summers of their initiation. Rapid thermal erosion along ice wedges gives rise to badland topography in certain areas where ice-rich silts enclose large wedges. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes, ground ice content, permafrost aggradation/ degradation.

FRENCH, H.M. (1975) Man-induced thermokarst, Sachs Harbour airstrip, Banks Island, Northwest Territories. *Canadian Journal of Earth Sciences*, 12, pp. 132-144.

The disturbed terrain adjacent to the airstrip at Sachs Harbour is an example of man-induced thermokarst processes operating within the High Arctic environment. An irregular topography of mounds and linear depressions has appeared and evidence indicates preferential subsidence along ice wedges. The underlying sands and gravels are ice-rich with approximately 20-35% excess ice and natural water (ice) contents of between 50 and 150%. Detailed leveling in 1972 and 1973 suggests that subsidence and permafrost degradation is still active, over 10 years later. Gullying of the airstrip is a problem partly associated with the thermokarst activity. A comparison is made with man-induced thermokarst terrain in Siberia. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes, ground ice content.

FRENCH, H.M. AND HARRY, D.G. (1989) Observations on buried glacier ice and massive segregated ice, western Arctic Coast, Canada. *Permafrost and Periglacial Processes*, 1, pp. 31-43.

The two main theories for the origin of the thick bodies of massive ground ice known to exist in the Western Canadian Arctic are: 1) segregation-injection and 2) buried glacier ice. Because buried glacier ice may contain significant quantities of stratified debris and may have experienced thawing and refreezing (regelation) on several occasions, it may be very difficult to distinguish between massive segregated ice and buried basal glacier ice. By use of cryostratigraphic and cryotextural (petrofabric) observations, massive ground ice bodies observed in the Sandhills Moraine, southern Banks Island, and the southern Eskimo Lakes region, Pleistocene Mackenzie Delta, are both interpreted as basal glacier ice Other massive ground ice bodies which have been examined in the Western Canadian Arctic are best explained in terms of segregation-injection. (authors)

Key Words: ground ice content, cryostratigraphy.

FRIEDMAN, J.D. (1971) Observations on Icelandic polygon surfaces and palsa areas: Photo interpretation and field studies. *Geografiska Annaler, ser. A, Physical Geography*, 53, pp. 115-145.

In terms of frozen ground phenomena and their dependence on climatic parameters, Iceland occupies an interesting position between the Eurasian and North American permafrost regions. In this paper, two characteristic forms of frozen ground have been treated: large scale polygonal ground, and frost mounds of the palsa type. The investigation involves: 1) interpretation of existing aerial photographs; 2) experiments in recording polygonal patterns by airborne IR line-scanning and special photographic techniques; and 3) field examination of selected localities. In Iceland, polygon formation of the frost-crack polygon type has occurred and is presently occurring without the presence of permafrost. The frost-crack process has increased during the last decade. The deposition of tephra and other eolian sediments and their sequence of layering offer excellent possibilities for analyzing cryogenic disturbances of older soil surfaces and layers by studying vertical sections of Icelandic soils. Historical volcanic activity provides the special conditions necessary to date morphologic processes by tephrochronologic techniques; tephrochronology indicates that a period of polygon formation, more intense than the present, occurred in the 1600s and 1700s. In central Iceland, the present climate is adequate for the development of palsas. During the last 10 years, the development of palsas has increased after a period of decreasing palsa formation between 1930 and 1950. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes, geothermal gradient/regime, soil/sediment conditions.

FU, L., DING, D. AND GUO, D. (1984) A study of the evolutionary history of permafrost in Northeast China by a numerical method. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 307-310.

The authors quantitatively reconstruct the evolutionary history of permafrost in China. The data obtained from these analyses of the paleoclimate and paleoglacial relics are identical to the data obtained from current field explorations. This method may also be used for other types of permafrost and regions. As long as the change of air temperature is given precisely, the development of permafrost can be accurately predicted. (authors, modified)

Key Words: cryostratigraphy, paleotemperatures, permafrost zonation, mathematical models/simulation.

GAVRILOVA, M.K. (1978) Classification of the relation between climate and permafrost and the permafrost-climatic regions. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* English Translations of 26 of the Soviet papers, Part 1, Ottawa, Canada, National Research Council, pp. 13-29.

The role of climate in the perennial freezing of earth material is examined, and a historical outline of the development of ideas on the relation between climate and permafrost is given. It is pointed out that a particular geocryological phenomenon may be related to entirely different aspects of the climate. An attempt is made to classify the relation between climate and permafrost on the basis of six genetic types of climate: cosmic, planetary, macro-, meso-, and microclimate, and soil climate. The geocryological problems related to each type of climate are examined. (author, shortened)

Key Words: permafrost zonation, cryostratigraphy, general surface conditions.

GAVRILOVA, M.K. (1984) Presumed climate variations and possible dynamics of permafrost. *Soviet Meteorology and Hydrology*, 7, pp. 101-103.

Discussed are the effects of possible anthropogenic changes in the climate on the regimes of freezing and thawing of soils and the phenomena of permafrost. Investigated are regional/local planned and inadvertent micro-and nanoclimatic influences on the climate and also the macroclimate character connected with the presumed warming in the next century. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes, permafrost sensitivity, meteorology.

GAVRILOVA, M.K. (1988) Permafrost-climatic characteristics of different classes. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 78-84.

For each class of the climate-permafrost relationship, we give generalized quantitative examples of permafrost-climatic characteristics according to the freezing and thawing seasons as well as the year. These data include the duration of each season, the sums of radiative and thermal balance components, air, ground surface and soil temperatures, the depth of seasonal freezing and thawing, the thickness of permafrost etc. This study has used data of stationary-based climatic, thermal-balance and geocryological observations obtained in different physio-geographic regions and situations of Eurasia and North America. (author)

Key Words: permafrost zonation, general surface conditions, heat/radiation balance.

GERASIMOV, I.P. (1981) Protection of environment in Northern Siberia. *Polar Geography*, 5, pp. 191-202. (Originally published in: *Izv. AN SSSR, Ser. Geogr.*, 1979, No.1, pp. 42-52.)

The author presents a regionalization of Yakutia on the basis of the sensitivity of the permafrost environment to disturbance. This is related to parallel mapping of the distribution of segregation ice in permafrost throughout the USSR. Not unexpectedly, the coastal and riverine lowlands of northern Siberia emerge as areas of both maximum ground ice concentrations and maximum sensitivity to disturbance. Other topics discussed include the dangers of groundwater pollution in permafrost areas and of industrial air pollution under the special meteorological conditions of northern Siberia. (author, shortened)

Key Words: permafrost sensitivity, general surface conditions, socio-economic impact.

GERWICK, B.C. (1990) The effect of global warming on arctic coastal and offshore engineering. *Journal of Cold Regions Engineering*, 4, pp. 1-5.

It appears that the effects of global warming on Arctic coastal and offshore engineering are both positive, in increasing opportunities, and negative, in presenting problems and needs. The overall effects seem to be more those of economics than engineering, and, even then, they are paradoxical. The author suggests the comparable situation in 100-1400 A.D. when Arctic warming initiated and supported the great years of Viking expansion. This was the most recent period in which the Arctic was a region of sustained growth and development.

Key Words: coastal permafrost, subsea/offshore permafrost, permafrost engineering/infrastructure, socio-economic impact.

GILL, D. (1973) A spatial correlation between plant distribution and unfrozen ground within a region of discontinuous permafrost. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 105-113.

Certain terrestrial locations in the Mackenzie Delta are underlain by taliks. There is a close areal relationship between the distribution of these taliks and one discrete plant association (*Salix-equisetum*) They are however linked by an intermediary: both occur only in combination with youthful slipoff slopes created by channel shifting.

Key Words: general surface conditions, vegetation, soil/sediment conditions.

GOLD, L.W. (1967) Influence of surface conditions on ground temperature. *Canadian Journal of Earth Sciences*, 4, pp. 199-208.

Ground temperatures were measured under two parking lots, one of which was cleared of snow in the winter, and monthly and annual average surface temperatures were estimated by extrapolation. The surface temperatures were compared with monthly and annual surface and air temperatures measured by a nearby grassed site. A dependence of the difference between the monthly average surface and air temperatures on snow cover and convective loss was observed. A correlation was found to exist between the monthly average of the daily global solar radiation and the difference between monthly average air temperature and monthly average parking lot surface temperature. It was demonstrated that, because of a change in surface conditions, there was a change in annual average ground temperature beneath a parking lot. The observations are discussed with reference to the formation of sporadic permafrost. (author)

Key Words: geothermal gradient/regime, snow cover, heat/radiation balance.

GOLD, L.W., JOHNSTON, G.H., SLUSARCHUK, W.A. AND GOODRICH, L.E. (1972) Thermal effects in permafrost. In: *Canadian Northern Pipeline Research Conference (Ottawa, 2-4 February 1972), Proceedings*. Ottawa, National Research Council Canada, pp. 25-45.

The role of climate, and in particular, air temperature in determining the geographical distribution of permafrost is discussed briefly for Canadian conditions. The thermal properties of permafrost materials and the climatic factors that make up the surface heat balance are discussed in general terms. The importance of surface materials in determining the ground thermal regime is illustrated by a number of theoretical calculations based on a one dimensional finite-difference model. Using a two-dimensional finite-difference model, theoretical calculations of thawing around a hot oil and freezing around a cold gas pipeline are presented and the settlement and stability problems that would result are discussed qualitatively. The importance of drainage and the effect of water bodies is commented on. Finally, a brief review is given of current design and construction practice to minimize thermal disturbance when placing fills and foundations in permafrost regions. (authors)

Key Words: heat/radiation balance, general surface conditions, geothermal gradient/regime.

GOLD, L.W. AND LACHENBRUCH, A.H. (1973) Thermal conditions in permafrost -a review of North American literature. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 3-23.

Thermal conditions in permafrost are discussed in two sections: the surface boundary condition (heat balance, surface conditions), and subsurface thermal conditions (geothermal regime, variations in surface temperature) The use of computerized numerical methods is reviewed in an appendix.

Key Words: heat/radiation balance, geothermal gradient/regime, soil/sediment conditions, ground ice content, general surface conditions, mathematical models/simulation, paleotemperatures.

GOODRICH, L.E. (1978) Some results of a numerical study of ground thermal regimes. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1*. Ottawa, National Research Council Canada, pp. 29-34.

The importance to the snow-ground thermal interaction of non-linear effects associated with temperature dependent soil thermal conductivity and with soil latent heat is discussed. Numerical model calculations are presented which indicate that the modification of mean annual ground temperature associated with these effects can be of the same magnitude as the warming due directly to the seasonal snow cover. (author)

Key Words: snow cover, geothermal gradient/regime, mathematical models/simulation.

GOODRICH, L.E. (1982) The influence of snow cover on the ground thermal regime. *Canadian Geotechnical Journal*, 19, pp. 421-432.

This paper presents the results of a numerical study of the effects of snow cover on long-term, periodic, steady-state equilibrium ground temperatures. It is shown that mean annual ground temperatures decrease with depth when the soil thermal conductivity is greater in the frozen than in the unfrozen phase. For permafrost conditions, the increase in mean annual ground temperatures due to seasonal snow cover is augmented significantly when soil latent heat is present. In seasonal frost cases, the calculated depth of frost penetration is extremely sensitive to details of the snow-cover buildup. In permafrost cases, calculated mean annual temperatures are extremely sensitive to the assumptions made in treating the snow-cover. In either case, because it is difficult to model snow cover accurately, the reliability of ground thermal regime computations is adversely affected. (author)

Key Words: geothermal gradient/regime, snow cover, ground ice content, soil/sediment conditions, mathematical models/simulation.

GOODWIN, C.W., BROWN, J. AND OUTCALT, S.I. (1984) Potential responses of permafrost to climatic warming. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications 83-1*, pp. 92-106.

In order to estimate the influence of CO_2-induced climatic change, a one-dimensional heat-transfer model was employed to estimate the changes in the active layer and permafrost temperatures of tundra near Barrow, Alaska, and of open terrain near Fairbanks. The model was sensitivity tested, and the results are discussed. Generally it can be concluded that if a climatic warming occurs, this will result in an areal reduction in permafrost. In the colder areas, continuous-zone permafrost temperatures will rise and summer active layer depths will increase, but the spatial extent of permafrost will be only marginally affected. Where there is ground ice, thermal erosion and thaw consolidation will produce thermokarst terrain. (authors, modified)

Key Words: geothermal gradient/regime, general surface conditions, mathematical models/simulation, permafrost aggradation/degradation, thermokarst/freeze-thaw related geomorphic processes, permafrost zonation.

GOODWIN, C.W. AND OUTCALT, S.I. (1975) The development of a computer model of the annual snow-soil thermal regime in arctic terrain. In: Weller, G., and S.A. Bowling, eds. *Climate of the Arctic, Proceedings of the 24th Alaska Science Conference (Fairbanks, 15-17 August, 1973)*. Fairbanks, University of Alaska, Geophysical Institute, pp. 227-229.

A digital computer model has been developed which simulates the annual evolution of the thermal regime in snow cover and the near surface layers of Arctic soils. The model is a coupled equilibrium-temperature energy budget simulator forced by daily meteorological data. The surface energy budget and the thermal regime of the snow and soil are output. The simulator will eventually be used to approximate the effects of human surface modification and long-term weather trends on hydrologic and thermal-geomorphic evolutionary histories. (authors)

Key Words: mathematical models/simulation, snow cover, geothermal gradient/regime, heat/radiation balance.

GOSINK, J.P. AND OSTERKAMP, T.E. (1990) Models for permafrost thickness variation in response to changes in paleoclimate. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 191-198.

Three models were developed to determine the permafrost thickness response to changes in paleoclimate. Two models represent approximate numerical and analytical techniques to solve the heat balance equation at the permafrost base. The third model (finite element) numerically integrates the thermal energy equation from the surface, through the phase boundary, to the underlying thawed material. The finite element model predicted a value for permafrost thickness variation which was reduced by as much as 30% from the approximate solutions in which the geothermal heat flux was assumed constant (from 78 to 51 m) The lag between surface temperature and permafrost thickness response increases with frequency, soil porosity, and surface temperature variation, and decreases with increasing geothermal heat flux. In response to sinusoidal surface temperature, the phase boundary is displaced asymmetrically with faster thawing than freezing. This also produces asymmetry in the maximum and minimum permafrost thicknesses. (authors, modified)

Key Words: mathematical models/simulation, geothermal gradient/regime, paleotemperatures.

GRANBERG, H.B. (1973) Indirect mapping of the snowcover for permafrost prediction at Schefferville, Québec. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 113-120.

The distribution of discontinuous permafrost near Schefferville is closely related to the patterns of accumulation of the seasonal snow cover. There is a strong relationship between terrain roughness and snow accumulation in this area due to the strong winds associated with snowfall and the generally low temperatures during storms. A statistical model for indirect mapping of the snow depth by using the terrain roughness is given, and its applications in permafrost prediction is discussed.

Key Words: snow cover, permafrost zonation, mathematical models/simulation.

GRANBERG, H.B. (1988) On the spatial dynamics of snowcover-permafrost relationships at Schefferville. In: *Fifth International Conference on Permafrost (Trondheim, Norway,* *2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 159-165.

This paper examines the roles of the seasonal snow cover as a controller of the ground temperature field at Schefferville (54° 48'N, 66° 9'W) The snow cover accumulation sequence in woodland and alpine tundra is described and heat transfers through the snow cover are discussed using simple spatial models. (author)

Key Words: snow cover, vegetation, heat/radiation balance, mathematical models/simulation.

GRAVE, N.A. (1984) Cryogenic processes associated with developments in the permafrost zone. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Final Proceedings.* Washington, D.C., National Academy Press, pp. 188-193.

The article first reviews the type of cryogenic processes (thermokarst, thermal erosion, thermal abrasion, frost heave frost cracking and solifluction) likely to be induced by disturbance of the surface in permafrost areas, focusing on the probable variations in intensity under different conditions of climate, vegetation and ice content. The impact of the abandoned Salekhard-Igarka Railway on the environment, and the degree of recovery achieved after 22 years are presented in a case study from near the southern limit of continuous permafrost, and are compared with the results of a study of the Fish Creek drilling sites (Alaska), 28 years after abandonment. Finally the author presents maps of surface sensitivity to disruption by human activities (with four classes of sensitivity) for both the USSR and North America. Using these he compares the areas with varying sensitivities in the two cases, and concludes that while some 7% of the total permafrost area in the USSR is extremely sensitive to disruption, the equivalent percentage in North America is less than 2%. (author)

Key Words: permafrost sensitivity, thermokarst/freeze-thaw related geomorphic processes, vegetation, ground ice content.

GRAY, J.T. (1984) Reconstructions and future predictions of the effects of climate change. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Final Proceedings.* Washington, D.C., National Academy Press, pp. 156-159.

Main purposes for studying the relationships between climate change and the geothermal regime in cold environments are to reconstruct the past and to predict the effect of future changes. Therefore different types of climatic data are available: meteorological records, temperature logs and proxy climate data (e.g., pollen analysis) The merits of the use of each type of data are discussed.

Key Words: permafrost zonation, climate/permafrost monitoring.

GRAY, J.T. AND BROWN, R.J.E. (1982) The influence of terrain factors on the distribution of permafrost bodies in the Chic-Choc Mountains, Gaspesie, Québec. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference.* Ottawa, National Research Council Canada, pp. 23-35.

Ground temperature studies revealed the presence of several contemporary bodies of discontinuous permafrost on the windswept treeless summits of the Chic-Choc Mountains in Gaspesie. One such permafrost body on Mount Jacques-Cartier is 45 to 60 m thick and related to a mean annual ground surface temperature of -1° to -1.5°C. Snow cover is the principal terrain factor governing the presence or absence of permafrost. The rapid increase in snow depth as one crosses from the tundra into the krummholz zone enabled a close correlation to be made between the permafrost boundary and the treeline and this facilitated regional mapping of permafrost bodies throughout the Chic-Choc Mountains. This correlation is not perfect due to: 1) local treelines occurring at some sites below the critical altitude; 2) topographic hollows allowing deep winter snow pack to inhibit permafrost development; and 3) lenses of permafrost occurring in rock glaciers at the base of steep slopes below the regional treeline. (authors, modified)

Key Words: permafrost zonation, mountain permafrost, general surface conditions, snow cover, vegetation.

GREENE, D.F. (1983) Permafrost, fire and the regeneration of white spruce at tree-line near Inuvik, Northwest Territories, Canada. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 374-379.

Adjacent burned and unburned upland stands were studied at the southwest corner of the 1968 Inuvik burn. Shallow active-layers are poorer habitat than deep active layer sites for white spruce because of a slower rate of thaw (effective growing season length), lower seed dispersal capacity, lower cone production, and poor seedbed creation (because of the depth of the O_f) by fire. Fire delimits the range of white spruce by restricting it to areas where the probability of surviving fire is high, e.g., the steeper valley sides and the most deeply incised or sinuous perennial creeks. Areas where survival through fire is likely also tend to possess deep active layers.

Although such sites are not uncommon, many remain uncolonized because of the poor seed dispersal capacity of these white spruce stems.

Key Words: fire, vegetation, general surface conditions, permafrost ecosystems/greenhouse gases.

HAEBERLI, W. (1984) Permafrost-glacier relationships in the Swiss Alps: today and in the past. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 415-419.

A conceptual model is proposed to explain the geographical distribution of permafrost and glacier phenomena in high altitude/low latitude mountains. The concept developed shows the vertical distance between the lower boundary of permafrost distribution and the equilibrium line on glaciers can be related to the mean annual air temperature at the equilibrium line. This temperature term strongly depends on the continentality of the climate and can be empirically linked to thermal conditions in ice and permafrost, and also to glacier activity. (author, shortened)

Key Words: permafrost zonation, paleotemperatures, mountain permafrost.

HAEBERLI, W. (1989) Glacier and permafrost signals of the 20th-century warming. In: *Proceedings of the Symposium on Ice and Climate (Seattle, Washington, 21-25 August 1989). Annals of Glaciology.* Vol. 14. pp. 99-101.

Currently available evidence of 20th century warming from glaciers and permafrost is briefly reviewed. The signals are clear and strong: warming of polar firn and permafrost, and mass losses of glaciers at lower latitudes, were most striking towards the middle of the century. The easily observable length-reduction of mountain glaciers confirms the global character of the evolution. A probably intermittent reversal of the trend was observed in places after about 1950. (author)

Key Words: heat/radiation balance, climate/permafrost monitoring.

HAEBERLI, W. (1992) Possible effects of climatic change on the evolution of alpine permafrost. In: Boer, M. and E. Koster, eds. *Greenhouse-Impact on Cold-Climate Ecosystems and Landscapes. Catena Supplement,* 22, Catena Verlag, Cremlingen-Destedt, Germany, pp. 25-35.

Climatic changes, especially temperature and snow cover variations, influence the thermal regime and the geometry of mountain permafrost. Localities near the lower boundary of discontinuous permafrost are most sensitive to degradation processes. Twentieth-century warming has probably induced melting and corresponding destabilization of formerly frozen material in such places. If warming were to continue it could lead to local geotechnical problems related to high-altitude installations built for avalanche protection and in connection with tourism. In addition, an increased frequency of far-reaching debris flows could also affect settlements existing in the valleys. Long term monitoring programs are presently being started. They include geothermal analyses of temperature profiles in boreholes as well as photogrammetrical determinations of changes in the flow and geometry of active rock glaciers. (author)

Key Words: mountain permafrost, geothermal gradient/regime

HARPER, J.R., OWENS, E.H. AND WISEMAN, W.J., JR. (1978) Arctic beach processes and the thaw of ice-bonded sediments in the littoral zone. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* Ottawa, National Research Council Canada, pp. 194-199.

Rates of thaw and depth of thaw on arctic beaches differ from those measured on tundra surfaces owing to the influence of seawater. Depth of thaw in the littoral zone limits the redistribution of sediments by wave or ice action. Normal rates of thaw in a beach can be increased rapidly during storms and can permit inlet development in barrier systems that contain deep permafrost. An increase in thaw rates at the unbonded-bonded interface results primarily from temperature and salinity changes caused by groundwater migration within the unbonded sediments. (authors)

Key Words: coastal permafrost, subsea/offshore permafrost, soil/sediment conditions, geothermal gradient/regime.

HARRIS, S.A. (1981) Climatic relationships of permafrost zones in areas of low winter snow-cover. *Arctic*, 34, pp. 64-70.

In areas with under 50 cm snow cover in winter, the permafrost zones show diagnostic long term freezing indices and thawing indices. The warmer boundary of the zone of continuous permafrost traverses the mean annual air temperature (MAAT) The boundary between discontinuous and sporadic permafrost lies just on the cold side of 0°C MAAT. The sporadic permafrost zone includes the zone of ice caves and the regions with patches of ice beneath ponds and peatbogs, extending to

5°C MAAT at a thawing index of 4000 degree days per year. The relationship is applicable to Norway, Iceland, Spitzbergen, Canada and the Peoples Republic of Mongolia. There are some marked variations in lapse rates from one environment to another, the most marked of which occurs above tree line where the lapse rate increases markedly in winter, though not in summer. The changes also occur at some points in non-permafrost areas and it appears likely that they are due to spatial and seasonal changes in albedo. The variations in lapse rate indicate that calculations of past world climatic change based on data from one area may be misleading.

Key Words: climate/permafrost monitoring, snow cover, general surface conditions, mathematical models/ simulation.

HARRIS, S.A. (1983) Comparison of the climatic and geomorphic methods of predicting permafrost distribution in western Yukon Territory. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 450-455.

Drilling and ground temperature measurements along the Dempster Highway demonstrate that continuous permafrost is at least twice as extensive in Western Yukon Territory as previously shown on maps. Between zones of continuous permafrost are areas of discontinuous permafrost in lowland areas, with 30-80% of the landscape underlain by permafrost. The climatic predictive method is reasonably successful at predicting the permafrost distribution on small scale maps but tends to slightly underpredict the distribution in montane valleys. Cold air drainage is widespread and very marked in these areas, and may cause the anomalies. Groundwater movement is undoubtedly also important locally. The geomorphic method based on the distribution of zonal permafrost landforms is of little use in mapping the permafrost boundaries. It was the evidence used to augment the sparse ground-temperature data available to previous workers. (author, shortened)

Key Words: permafrost zonation, climate/permafrost monitoring, geothermal gradient/regime, mathematical models/simulation.

HARRIS, S.A. (1986) Permafrost distribution, zonation and stability along the eastern ranges of the Cordillera of North America. *Arctic*, 39, pp. 29-38.

Considerable quantities of new data have become available recently regarding the nature and distribution of permafrost along the eastern ranges of the Cordillera. These are used to produce an elevation view of permafrost in the ranges north of the 35°N parallel. The mapped apparent permafrost boundaries differ from those of earlier works which were based on considerably less data. It is clear that the terrain factors of mean winter snow depth, local moisture and groundwater conditions, the distribution of different air masses and cold air drainage have considerable effects locally, causing undulations and abrupt changes in the lower limit of the permafrost boundaries to about 56°N. Farther north, climatic factors become more dominant. (author, modified)

Key Words: permafrost zonation, mountain permafrost, permafrost sensitivity, general surface conditions.

HARRIS, S.A. (1986) *The Permafrost Environment.* London, Croom Helm, 276 pp.

This textbook contains an interesting review concerning aspects of permafrost and climatic change in the Chapter 3 (Distribution and stability of permafrost).

Key Words: permafrost zonation, general surface conditions, permafrost aggradation/degradation.

HARRIS, S.A. (1987) Effects of climatic change on northern permafrost. *Northern Perspectives*, 15(5), (Canadian Arctic Resources Committee Newsletter, Ottawa), pp. 7-9.

Permafrost distribution directly reflects climate, and the response of ground temperature to any climatic change will affect the physical environment and the works of man very quickly. This paper focuses on the socio-economic and engineering impacts of climatic change, with examples of foundations, winter roads, use of the sea, mining, water supply, and waste disposal. Trying to design northern facilities to protect against a large (4°C) climatic warming is not feasible due to the high costs involved.

Key Words: permafrost sensitivity, permafrost engineering/infrastructure, socio-economic impact.

HARRIS, S.A. (1990) Long-term air and ground temperature records from the Canadian Cordillera and the probable effects of moisture changes. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 151-157.

Long-term (up to 14 year) measurements of air and ground temperature records from three stations in permafrost in the Canadian Cordillera show that variations in apparent trends of ground temperature at different depths in the ground are relatively common and are often unrelated to variations in air temperature. They are not confined to the upper part of the permafrost zone as suggested previously in the literature and appear to be due to changes in the moisture content with time. They imply: (1) that studying climatic change by monitoring ground temperatures will normally be unsuccessful unless an arid region is chosen; (2) that basing engineering designs on measurements of ground temperatures alone will be hazardous; and (3) that the ground-temperature profile with depth is an unreliable indicator of past climatic changes. (author)

Key Words: geothermal gradient/regime, paleo-temperatures, climate/permafrost monitoring.

HARRISS, R.C. (1989) Historical trends in atmospheric methane concentration and the temperature sensitivity of methane outgassing from boreal and polar regions. In: National Research Council. Board on Atmospheric Sciences and Climate. *Ozone Depletion, Greenhouse Gases, and Climatic Change.* Washington, D.C., National Academy Press, pp. 79-84.

Recent studies have documented two trends in atmospheric methane (CH_4) concentrations. First, a modern trend of increasing global atmospheric CH_4 has been documented in the trapped gas of polar ice cores and with regular monitoring of ambient CH_4 at remote locations around the world. A second trend from low concentrations of CH_4 at times of glacial maximum (approx. 20,000 years B.P.), increasing to 650 ppbv during interglacial times has been observed in ice core samples from Antarctica and Greenland. This variability in prehistoric CH_4 is hypothesized to be due to the expansion of arctic and boreal peatlands following glacial retreat. Methane is also present in large quantities as "frozen" CH_4 clathrates in subsurface sediments of the polar regions, and as trapped gas in permafrost. If substantial warming of polar oceans and landscape were to occur, these "frozen" sources of CH_4 would be released to migrate through soil and overlying sediments into the atmosphere.

Key Words: permafrost ecosystems/greenhouse gases, gas hydrates, permafrost sensitivity.

HARRY, D.G. AND DALLIMORE, S.R. (1989) Permafrost, ground ice and global change in the Beaufort Sea Coastlands. *Geos* (Ottawa), 18(3), pp. 48-53.

Global environmental change may well have a greater effect on the coastal lowlands of northern Canada than on any other area of North America. These lowlands, likely to experience the greatest warming according to current global circulation models, are extensively underlain by temperature-sensitive permafrost or perennially frozen ground. The area is also underlain by thick sequences of unconsolidated and frequently ice-rich Quaternary sediments subject to thermokarst processes of erosion and subsidence during climatic warming. The area is also vulnerable to changes in sea level and coastal erosion. Although the area is not densely populated, it contains oil and gas resources which are crucial to Canada's economic future.

Key Words: coastal permafrost, ground ice content, thermokarst/freeze-thaw related geomorphic processes.

HARRY, D.G. AND FRENCH, H.M. (1984) Cryostratigraphic studies of permafrost, Northwestern Canada. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 784-790.

The cryostratigraphic approach to permafrost geology emphasizes ground ice, and the dynamics of its aggradation and degradation, as an integral component of the geological record. In particular, stratigraphic evidence of paleothermal and paleohydrological conditions may be used to infer both local and regional permafrost history. Cycles of environmental change may be marked by the presence of thaw unconformities. Studies undertaken at four sites in northwestern Canada illustrate the principles of cryostratigraphy in relation to specific problems in permafrost geology. (authors, shortened)

Key Words: cryostratigraphy, paleotemperatures, ground ice content.

HAUGEN, R.K., OUTCALT, S.I. AND HARLE, J.C. (1984) Relationships between mean annual air and permafrost temperatures in North-Central Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 462-468.

Mean annual air temperatures (MAAT) are estimated for a transect from central to northern Alaska. The estimated MAAT are compared to mean annual ground temperatures (MAGT) representative of upper permafrost temperatures. A simple regression relationship showed MAGT to average 3.6°C higher than MAAT. This study suggests that, based on estimated MAAT and MAGT values, the boundary between the zones of continuous and discontinuous permafrost is located at or slightly north of the continental divide at Atigun Pass. (authors, shortened)

Key Words: climate/permafrost monitoring, permafrost zonation, mathematical models/simulation, permafrost terminology.

HEGINBOTTOM, J.A. (1971) Some effects of a forest fire on the permafrost active layer at

Inuvik, N.W.T. In: *Seminar on the Permafrost Active Layer (Vancouver, British Columbia, Canada, 4-5 May 1971), Proceedings*, pp. 31-37.

Two aspects of the effect of fire on the active layer are discussed. The first is a description of the ground surface and measurements of the active layer thickness in a burned area, and the survey and analysis procedures. The second is a brief description of some earth flows in the valley of Boot Creek.

Key Words: fire, thermokarst/freeze-thaw related geomorphic processes.

HILBERT, D.W., PRUDHOMME, T.I. AND OECHEL, W.C. (1987) Response of tussock tundra to elevated carbon dioxide regimes: analysis of ecosystem CO_2 flux through non-linear modeling. *Oecologia*, 72, pp. 466-472.

The response of tussock tundra to elevated atmospheric concentrations of CO_2 was measured at Toolik Lake, Alaska, in the summer of 1983. Computer-controlled greenhouses were used to determine diurnal ecosystem flux of CO_2 under four different treatments. A nonlinear model was used to analyze the data set and to determine some of the reasons for different net CO_2 flux. This model allowed an estimation of light utilization efficiency, total conductance of CO_2, and a comparable measure of total respiration. (authors, shortened)

Key Words: permafrost ecosystems/greenhouse gases.

HINZMAN, L.D. AND KANE, D.L. (1992) Potential response of an arctic watershed during a period of global warming. *Journal of Geophysical Research*, 97(D3), pp. 2811-2820.

To analyze the thermal impact of climatic warming on a permafrost environment, TDHC, a heat conduction model which incorporates phase change, was used. Then the response of the active layer to climatic warming was incorporated into HBV, a hydrologic model, to elucidate the effects on the hydrologic regime. Several scenarios of climatic warming have been examined to determine the impact on the active layer depth, but only results of 4°C warming at a typical arctic site will be presented here. In the case of 4°C warming, three scenarios of precipitation were studied: no change, +15%, and -15%. The most obvious and perhaps significant response to climatic warming was an increase in active layer depth. Other changes worth noting were warming of the entire soil profile, increased soil moisture storage, increased evaporation, and variable response in runoff, depending upon the scenario. Evaporation now vies with runoff as the primary loss of moisture from the watershed. If evaporation increases due to a warmer climate, the entire character of arctic hydrology could change, depending on changes in precipitation. (authors, shortened)

Key Words: hydrology/soil moisture, mathematical models/simulation.

IVES, J.D. (1973) Permafrost and its relationship to other environmental parameters in a midlatitude, high-altitude setting, Front Range, Colorado Rocky Mountains. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 121-125.

The ground temperature data presented here, together with the large number of field observations of frozen ground in late summer and autumn, indicate that permafrost occurs extensively throughout the Colorado Rocky Mountains. One of the most important environmental parameters concerning permafrost in this high-altitude and relatively low-latitude region is incoming shortwave radiation and hence slope angle and aspect; another is the interrelationship of wind, snow distribution and topography. The relationships with permafrost are discussed.

Key Words: general surface conditions, snow cover, heat/radiation balance, mountain permafrost.

JOHNSON, A.W. (1966) Plant ecology in permafrost areas. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings.* National Academy of Sciences, National Research Council Publication 1287, pp. 25-30.

Several interrelationships between permafrost and vegetation are suggested. For example, permafrost impedes drainage; maintains low temperatures in the root zone during the growing season; thawing of permafrost leads to thermokarst; permafrost provides an impervious substrate; plant roots are restricted to the active layer; vegetation helps maintain high permafrost levels by its insulating capacities; and vegetation retards frost action. These interrelationships are further demonstrated in a case study at the Ogotoruk Creek Valley in Alaska.

Key Words: permafrost ecosystems/greenhouse gases, vegetation, general surface conditions, thermokarst/freeze-thaw related geomorphic processes.

JOHNSON, L. AND VIERECK, L. (1983) Recovery and active layer changes following a tundra fire in northwestern Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983),* *Proceedings.* Washington, D.C., National Academy Press, pp. 543-547.

An upland tundra fire, started by lightning, burned 48 km^2 near the Kokolik River (69° 30'N, 151° 59'W) in northwestern Alaska during late July and early August 1977. Permanent plots were established to monitor recovery of severely, moderately, and lightly burned areas as well as unburned tundra. During the following 5 years the original permanent plots and other portions of the burn were observed annually. Vegetative recovery was most rapid and active layer effects were least on the moist sudge-shrub tundra. Accelerated hydraulic and thermal erosion had occurred on some slopes, resulting in exposures of massive bodies of ground ice. Active layer thicknesses averaged 27 cm in the unburned areas and 35 cm within severely burned areas in August 1977 and reached a maximum at all but one site in August 1979. Depth of thaw decreased between 1979 and 1982 in the sedge-shrub tundra and in the lightly burned shrub tundra and remained at the same increased level through 1982 at all other sites. (authors, shortened)

Key Words: fire, vegetation, general surface conditions, ground ice content.

JORGENSON, M.T. AND KREIG, R.A. (1988) A model for mapping permafrost distribution based on landscape component maps and climatic variables. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 176-182.

A computer model for mapping permafrost distribution was developed that uses vegetation, terrain unit and equivalent latitude maps and regional air temperature data as the geographic data base for calculating the heat balance of the ground surface. The ratio of the amount of heat entering the soil in the summer, when the ground was seasonally thawed, and lost during the winter, when the ground was seasonally frozen, was calculated from the degree-day sums at the surface and soil thermal conductivities. The simulated permafrost distribution within the Spinach Creek Watershed near Fairbanks, Alaska, agreed closely with the distribution mapped by photo interpretation. The effects of climatic warming on permafrost distribution were also assessed. (authors, shortened)

Key Words: permafrost zonation, geothermal gradient/regime, vegetation, mathematical models/simulation, permafrost sensitivity.

JUDGE, A.S. (1973) Deep temperature observations in the Canadian North. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 35-40.

Boreholes of depths of 300 m or more have been preserved for temperature observations in the Canadian North. Here the return of borehole temperatures to equilibrium has been measured, and the geothermal gradient has been constructed. The geothermal gradient depends mainly on three things: the surface temperature, the thermal conductivity of the subsurface rocks, and the heat flow from greater depths in the earth. The effects of climatic changes are briefly discussed. Also, permafrost occurrence and thickness are reviewed.

Key Words: geothermal gradient/regime, paleotemperatures, permafrost zonation, soil/sediment conditions, ground ice content.

JUDGE, A.S. (1986) Permafrost distribution and the Quaternary history of the Mackenzie-Beaufort region: a geothermal perspective. In: *Proceedings of the Workshops on Subsea Permafrost, November 18, 1985, and Pipelines in Permafrost, November 19, 1985. National Research Council, Canada. Technical Memorandum* No. 139, pp. 3-10.

Mean surface temperatures, temperature gradients within and below the permafrost and other characteristics of the temperature curves have been used to determine the nature and extent of the permafrost distribution. Permafrost thickness and its relation to Quaternary history are considered. (author)

Key Words: subsea/offshore permafrost, permafrost zonation, permafrost aggradation/degradation.

JUDGE, A.S. AND MAJOROWICZ, J.A. (1992) Geothermal conditions for gas hydrate stability in the Beaufort-Mackenzie area: the global change aspect. *Global and Planetary Change*, 98, pp. 251-263.

Gases locked in hydrates or trapped beneath a gas hydrate cap within the earth are potential contributors to the greenhouse effect, and therefore both thermal conditions of and occurrences of the methane hydrates should be considered in the study of past climate change and of future global warming. The decomposition of methane hydrates triggered by an increase in near surface temperatures and the subsequent upward migration of released gases is occurring at present in the Beaufort-Mackenzie area of northern Canada. In addition to surface warming, the warming effect of the upward flow of the deep fluids, recharged in high elevation areas bordering the Alaska and Yukon coastal plain, may also be a factor in the release of methane directly from deeper buried hydrates in the fluid discharge zones. In this study the zones of methane hydrate stability are predicted by a thermal method and compared with the distribution of hydrates detected on well logs. An extensive hydrate prone layer extending to as deep as 1400 ñ 200 m over an area of 50,000 km^2 is predicted by the thermal data and hydrate stability field. Current estimates suggest that between 10^{11} and 10^{21} tonnes of methane may be presently locked in gas hydrate deposits. (authors, shortened)

Key Words: gas hydrates.

JUDGE, A.S. AND PILON, J. (1984) Climate change and geothermal regime. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Final Proceedings.* Washington, D.C., National Academy Press, pp. 137-138.

The changes in permafrost due to climatic changes are discussed. Past climatic trends, mostly based on proxy data, are summarized, and the possibilities of geothermal analysis of more recent climatic events are discussed in an introductory fashion.

Key Words: geothermal gradient/regime, paleotemperatures, permafrost zonation.

KANE, D.L., HINZMAN, L.D. AND ZARLING, J.P. (1991) Thermal response of the active layer to climatic warming in a permafrost environment. *Cold Regions Science and Technology*, 19, pp. 111-122.

Global warming is occurring, the only question is what will be the magnitude of the temperature change and the temporal and spatial distribution? Existing models predict that the greatest change from present climatic conditions will happen in the polar regions. In the Arctic, continuous permafrost exists and climatic warming could have severe consequences. In this paper the consequences of global warming on the active layer are examined. Soil temperature data were collected over a four-year period at a field site near Toolik Lake, Alaska. A finite-element, two-dimensional, heat conduction model with phase change was used to predict soil temperatures at the site. After verification that the model could be used with confidence to predict the soil thermal regime, various climatic warming scenarios were used as inputs to estimate the thermal response for the next fifty years. The impact of climatic warming on the thickness of the active layer is reported. (authors).

Key Words: geothermal gradient/regime, mathematical models/simulation.

KELLY, R.J., MORLAND, L.W. AND BOULTON, G.S. (1990) Deep penetration of permafrost through saturated ground. *Cold Regions Science and Technology*, 18, pp. 9-27.

The expansion of a permafrost region into an aquifer due to surface cooling is investigated for purely vertical motion. Both permafrost and aquifer are treated as binary mixtures, separated by a moving interface. Simplifying approximations leads to reduced parabolic equations for the temperature fields in the permafrost and aquifer, coupled by jump conditions at their distinct interface. A transformation is introduced which changes the unknown expanding permafrost region into a fixed domain for numerical purposes. Illustrations are presented for linear and exponential surface cooling. (authors)

Key Words: mathematical models/simulation, permafrost aggradation/degradation, hydrology/soil moisture.

KERFOOT, D.E. (1973) Thermokarst features produced by man-made disturbances to the tundra terrain. In: Fahey, B.D. and R.D. Thompson, eds. *Research in Polar and Alpine Geomorphology.* Proceedings of the Third Guelph Symposium on Geomorphology, Guelph, Ontario, Canada. Norwich, England, Geo Abstracts, Ltd., pp. 60-72.

A summary of thermokarst features attributed to man's activities is presented. Thermokarst induced through seismic exploration and winter roads is highlighted with examples coming mainly from the Mackenzie Delta, N.W.T.

Key Words: thermokarst/freeze-thaw related geomorphic processes, human disturbances.

KING, L. (1990) Soil and rock temperatures in discontinuous permafrost: Gornergrat and Unterrothorn, Wallis, Swiss Alps. *Permafrost and Periglacial Processes*, 1, pp. 177-188.

The areas studied display a rich periglacial geomorphology. The effects of seasonal and perennial ground frost are visible in the form of widespread solifluction phenomena, patterned ground and numerous rock glaciers. Soil and rock temperatures have been recorded, and permafrost distribution has been partly checked in selected areas with measurements of the basal snow temperature, and using geoelectrical and hammer seismic soundings. Permafrost is widespread on northerly exposed slopes, with a thickness of several decameters at 3100 m a.s.l. Below 2800 m a.s.l. patchy permafrost occurs. A model for vertical permafrost is presented and an altitude of 3500 m a.s.l. is suggested for the lower limit of continuous permafrost. As a result of aspect, soil and rock temperature fluctuations are different on northern and southern slopes. This induces differences in vegetation cover, debris production and geomorphical processes. (author)

Key Words: permafrost zonation, mountain permafrost, thermokarst/freeze-thaw related geomorphic processes.

KLIEWER, R.M. (1973) A general solution for the two dimensional, transient heat conduction problem in permafrost, using implicit, finite difference methods. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 41-51.

A computer programming technique has been presented for mathematically modeling a large class of problems involving the thermal response of a permafrost medium. Allowance was made for seasonal temperature variation at the surface and also for the addition of extraneous thermal disturbances. This permits prediction of the effect of thermal disturbances on the natural variation of temperature in the permafrost. There is a provision for handling a stratified permafrost medium having layers possessing different thermal properties. Consideration also was given to changes of soil thermal properties with freezing and thawing and the latent heat of fusion was taken into account. (author)

Key Words: geothermal gradient/regime, mathematical models/simulation, soil/sediment conditions.

KLYUKIN, N.K. (1964) Questions related to the ameliorating the climate by influencing the snow cover. *Problems of the North (Problemy Severa)*, 7, pp. 67-90.

The snow cover over a large part of the Soviet Union is one of the most characteristic forms of surface during a considerable part of the year. The properties of snow cover are such that it becomes relatively easy to modify it. This opens up the possibility of controlling one of the principal climate-forming factors, the underlying surface, and thus bringing about a predictable change in the climate, especially the climate of the layer of air closest to the ground and the climate of the soil. The study of snow amelioration is extremely important for the transformation of nature and climate, especially with a view to increased agricultural production, the opening up of new territories, the pushing back of the northern boundaries of warmth-loving crops, and the acceleration of the thawing of soils in the construction of earthworks. In the present paper we will consider a few questions related to increasing the heat supply to the ground by accelerating the removal of the snow cover. Consideration is given to the possibility of changing the soil moisture balance in regions of excessive moisture. (author, modified)

Key Words: snow cover, socio-economic impact, hydrology/soil moisture, general surface conditions.

KOMARKOVA, V. (1973) Recovery of plant communities and summer thaw at the 1949 Fish Creek Test Well 1, Arctic Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 645-651.

The Fish Creek Test Well 1 site on the Arctic Coastal Plain has been abandoned since its construction in 1949. The plant communities which developed on the disturbed site are all successional. The degree of community recovery has differed with the habitat-vegetation type and corresponded to the degree of recovery of the habitat. The average depth of thaw was greater in recovering than in undisturbed habitats, especially in mesic uplands. The time of recovery of mesic upland ecosystems at the Fish Creek site is estimated to be 600-800 years and that of marshes to be 100-200 years. In more general features resulting communities will probably resemble the surrounding undisturbed complex communities. (author, shortened)

Key Words: vegetation, permafrost ecosystems/greenhouse gases, general surface conditions.

KOSTER, E.A. (1991) Assessment of climate change impact in high-latitudinal regions. *Terra*, 103, pp. 3-13.

Regional climate scenarios, e.g., for the Fennoscandian region, simulate mean winter temperature increases of even 5-6°C; however, estimates of regional changes, particularly those for precipitation and evaporation are still very unreliable. The potential consequences of greenhouse-induced climate changes on the environment have been tentatively identified. The attention is focused on specific climate-sensitive processes and phenomena, like cryospheric processes (glaciers, snow cover, permafrost degradation), slope stability, changes in northern peatlands, potential shifts in vegetation zones and other ecosystem responses. (author, shortened)

Key Words: general surface conditions.

KOSTER, E.A. AND NIEUWENHUIJZEN, M.E. (1992) Permafrost response to climatic change. In: Boer, M. and E. Koster, eds. *Greenhouse-Impact on Cold-Climate Ecosystems and Landscapes. Catena Supplement*, 22, Catena Verlag, Cremlingen-Destedt, Germany, pp. 37-58.

The assessment of the effects of climatic change on permafrost is very complicated, as ground temperatures are influenced by local factors, which are interrelated with climate. Most important of these local factors are the snow cover and its duration, the vegetation, and the organic layer and soil properties. Variations in these variables may either enhance or counteract each other, which makes it difficult to predict the accumulated effects of all changes. The analysis of permafrost temperature as a function of depth appears to yield a temporally integrated record of air temperature changes in the past. (authors)

Key Words: geothermal gradient/regime, general surface conditions, permafrost sensitivity.

KOUTANIEMI, L. (1985) The Central Yakutian Lowlands; land of climatic extremes, permafrost and alas depressions. *Soviet Geography*, 26, pp. 421-435.

The extreme nature of the climate in central Yakutia is revealed above all by the low winter temperatures accompanied by highly arid conditions, both of these circumstances being due to the Siberian high pressure system, the shelter afforded by the mountains and the great distances from any sources of air humidity. The failure of the Pleistocene glaciations to reach these lowlands, due to the aridity of the climate together with the still more severe temperature conditions than at present, initiated the formation of permafrost, which is now deeper here and of greater extent than anywhere else in the world. Localized thawing of the permafrost gives rise to a characteristic alas relief. The unique nature of this process, which accounts for almost half of the total relief in places, originates mainly from the geological history of the area and the severity of the climate, both of which have promoted exceptionally intensive growth of ice wedges. The most active period of alas formation would appear to have been the Atlantic climatic optimum, while nowadays such landforms are becoming increasingly a mark of imbalances in nature brought about by human activity. (author)

Key Words: human disturbances, thermokarst/freeze-thaw related geomorphic processes, general surface conditions.

KULLMAN, L. (1989) Geoecological aspects of episodic permafrost expansion in North Sweden. *Geografiska Annaler. Series A, Physical Geography*, 71A(3-4), pp. 255-262.

Exceptionally late thawing and new permafrost were recorded in 1987 for some sites beyond and within the previously known range limit of discontinuous permafrost in Northern Sweden. In 1987, the mean annual ground temperature in this region was 1-1.5°C below the mean for the period 1931-60. Also 1988 was colder or close to normal in the north which explains the survival at some sites of the new permafrost. A particularly notable aspect is the formation of permafrost in spruce forest, a new phenomenon of Fennoscandia. Permafrost expansion conforms to a general trend of increasing ground frost activity and severity, documented by various authors for arctic, subarctic, and north-boreal Europe and adjacent regions. Although possibly transient, the new and wider distribution of permafrost and very late seasonal thawing encroached the permafrost limit of the Little Ice Age. This recent event stresses the climatic sensitivity of permafrost distribution and indicates that large areas of northern Sweden may be affected by discontinuous permafrost in response to minor thermal decline. It is hypothesized that the regional range limit of spruce (*Picea abies*) in this part of Fennoscandia relates to ground frost conditions. (author)

Key Words: vegetation, permafrost aggradation/degradation, permafrost sensitivity.

KVENVOLDEN, K.A. (1988) Methane hydrate-a major reservoir of carbon in the shallow geosphere? *Chemical Geology*, 71, pp. 41-51.

Methane hydrates are solids composed of rigid cage of water molecules that enclose methane. Sediment containing methane hydrates is found within specific pressure-temperature conditions that occur in regions of permafrost and beneath the sea in outer continental margins. Because methane hydrates are globally widespread and concentrate methane within the gas-hydrate structure, the potential amount of methane present in the shallow geosphere at subsurface depths of < 2000 m is very large. Methane hydrates contain so much methane and occur in the shallow geosphere, and are of interest as potential resources of natural gas and a possible source of atmospheric methane released by global warming. As a contributor to a changing global climate, destabilized methane hydrates, particularly those in shallow regions of the Arctic Ocean, may have some effect, but it will probably be minimal, at least during the next 100 years. (author, modified)

Key Words: subsea/offshore permafrost, gas hydrates, permafrost engineering/infrastructure.

LACHENBRUCH, A.H. (1988) Warming of permafrost in the Alaskan Arctic. Preparing for climate change. In: *First North American Conference on Preparing for Climate Change: A Cooperative Approach (Washington, D.C., October 27-29, 1987), Proceedings*. Rockville, MD, Government Institutes, Inc., pp. 102-107.

The use of temperature measurements in deep wells to detect and monitor recent changes in climate are discussed. Measurements show that the surface of permafrost has been warming rapidly throughout much of the Alaskan Arctic during the last century. (author, modified)

Key Words: heat/radiation balance

LACHENBRUCH, A.H., BREWER, M.C., GREENE, G.W. AND MARSHALL, B.V. (1962) Temperatures in permafrost. In: *Temperature: Its Measurement and Control in Science and Industry*, Vol. 3-1. New York, Reinhold, pp. 791-803.

Emphasis in this paper is on temperature and its measurement. Except for the discussion of instrumentation, the material is presented in the form of examples of measurements taken in the vicinity of Barrow, Alaska. The discussion is directed toward demonstrating the consistency of these measurements when viewed within the framework of simple heat conduction models. The examples presented outline the gross features of the temperature field in permafrost at high latitudes. Many thermal problems of engineering and geology are associated with discontinuous permafrost at lower latitudes, but as the relationships are more difficult here they are not discussed.

Key Words: geothermal gradient/regime, mathematical models/simulation, permafrost engineering/infrastructure, general surface conditions, climate/permafrost monitoring.

LACHENBRUCH, A.H., CLADOUHOS, T.T. AND SALTUS, R.W. (1988) Permafrost temperature and the changing climate. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 3. Trondheim, Norway, Tapir Publishing, pp. 9-18.

Temperature profiles in continuous permafrost to depths of a few hundred meters contain a faithful record of change in surface temperature during the past few centuries. When interpreted with heat-conduction theory, this little known source can provide important information of patterns of contemporary climate change. Precision measurements in oil wells in the Alaskan Arctic indicate a variable but widespread warming (typical 2-4°C) at the permafrost surface during the 20th century. Recent statistical studies of 100 years of weather records from the North American Arctic suggest similar large changes have occurred in the air temperature although they might have started somewhat earlier. The permafrost warming is conspicuous and easily measured, and it is occurring at high latitude where anthropogenic climate change is expected to be greatest and first observable. (authors, shortened)

Key Words: geothermal gradient/regime, mathematical models/simulation, soil/sediment conditions, paleo-temperatures, permafrost terminology.

LACHENBRUCH, A.H., GALANIS, S.P., JR. AND MOSES, T.H., JR. (1987) A thermal cross section for the permafrost and hydrate stability zones in the Kaparuk and Prudhoe Bay oil fields. In: Galloway, J.P. and T.D. Hamilton eds. *Geologic Studies in Alaska by the U.S. Geological Survey During 1987, Northern Alaska. U.S. Geological Survey Circular* 1016, pp. 48-51.

Preliminary results of temperature measurements in bore holes at the Kaparuk, Milne Point, and Prudhoe Bay are presented. Systematic changes occur in the geothermal gradients and freezing-point depressions. These can result from corresponding variations in thermal conductivity of the formations or from variation in the rate of heat flow from the earth. The variations in heat flow can, in turn, result from regional changes in deep crustal heat flux or from patterns of fluid circulation in the sedimentary basin.

Key Words: geothermal gradient/regime, soil/sediment conditions.

LACHENBRUCH, A.H., GREENE, G.W. AND MARSHALL, B.V. (1966) Permafrost and the geothermal regimes. In: Wilimovsky, N.J., ed. *Environment of the Cape Thompson Region, Alaska.* Oak Ridge, Tennessee, U.S. Atomic Energy Commission, pp. 149-163.

Analysis of temperatures to a depth of 1200 ft. beneath Ogotoruk Valley reveals that present earth temperatures at depth are strongly influenced by an extinct climate and by an ancient shoreline position. An active climatic change that has been in progress throughout the past century has increased the mean annual ground-surface temperature on the order of 2°C. If the present climate persists, the inland permafrost thickness will eventually be reduced from about 1170 to about 850 feet. Earth-temperature anomalies near the shoreline indicate a rapid encroachment of the Chukchi Sea several thousand years ago, and imply that permafrost extends under the margins of the sea to a maximum distance of about 100 yards at a depth of 200 or 300 feet. Preliminary results indicate that local heat flow from the interior of the earth is close to the world-wide average. (authors)

Key Words: geothermal gradient/regime, coastal permafrost, subsea/offshore permafrost, paleo-temperatures, general surface conditions.

LACHENBRUCH, A.H. AND MARSHALL, B.V. (1986) Changing climate: geothermal evidence from permafrost in the Alaskan Arctic. *Science*, 234, pp. 689-696.

Temperature profiles measured in permafrost in northernmost Alaska usually have anomalous curvature in the upper 100 meters or so. When analyzed by heat conduction theory, the profiles indicate a variable but widespread secular warming of the permafrost surface, generally in the range of 2-4°C during the last few decades to a century. Although details of the climatic change cannot be resolved with existing data, there is little doubt of its general magnitude and timing; alternative explanations are limited by the fact that heat transfer in cold permafrost is exclusively by conduction. Since models of greenhouse warming predict climate change will be greatest in the Arctic and might already be in progress, it is prudent to attempt to understand the rapidly changing thermal regime in this region. (authors)

Key Words: geothermal gradient/regime, paleo-temperatures, mathematical models/simulation.

LACHENBRUCH, A.H., SASS, J.H., LAWVER, L.A., BREWER, M.C., MARSHALL, B.V., MUNROE, R.J., KENELLY, J.P., JR., GALANIS, S.P., JR. AND MOSES, T.H., JR. (1982) Temperature and depth of permafrost on the arctic slope of Alaska. *U.S. Geological Survey. Professional Paper* 1399, pp. 645-656.

The temperature and depth of permafrost in Arctic sedimentary basins are of considerable importance in connection with petroleum exploration and production. Some information can be detected from non-thermal logs, but mostly a knowledge of undisturbed temperature is necessary. Temperature measurements were done in boreholes in the Alaskan North Slope, and at Prudhoe Bay. Of these the basic thermal data are described, the equilibrium temperature profiles are deduced, the permafrost depth is studied, and geothermal profiles are explained.

Key Words: geothermal gradient/regime, soil/sediment conditions, coastal permafrost, mathematical models/simulation, paleotemperatures, subsea/offshore permafrost.

LACHENBRUCH, A.H., SASS, J.H., MARSHALL, B.V. AND MOSES, T.H., JR. (1982) Permafrost, heat flow, and the geothermal regime at Prudhoe Bay, Alaska. *Journal of Geophysical Research*, 87(B11), pp. 9301-9316.

Temperature measurements through permafrost in the oil field at Prudhoe Bay, Alaska, combined with laboratory measurements of the thermal conductivity of drill cuttings permit an evaluation of in situ thermal properties and an understanding of the general factors that control the geothermal regime. A sharp contrast in temperature gradient at ± 600 meters represents a contrast in thermal conductivity caused by the downward change from interstitial ice to interstitial water at the base of the permafrost under near steady state conditions. The anomalously deep permafrost is a result of the anomalously high conductivity of the siliceous ice-rich sediments. Curvature in the upper 160 m of the temperature profiles represents a warming of ± 1.8°C of mean surface temperature during the last 100 years or so. Rising sea-level and thawing of ice-rich sea cliffs probably caused the shoreline to retreat tens of kilometers in the last 20,000 years, inundating a portion of the continental shelf that is presently the target of extensive oil exploration. A simple conduction model suggests that this recently inundated region is underlain by near-melting ice-rich permafrost to depths of 300-500 m; its presence is important to seismic interpretations in oil exploration and to engineering considerations in oil production. With confirmation of the permafrost configuration by offshore drilling, heat conduction models can yield reliable new information on the chronology of arctic shorelines. (authors, shortened)

Key Words: geothermal gradient/regime, ground ice content, soil/sediment conditions, subsea/offshore permafrost, paleotemperatures, mathematical models/simulation.

LAGAREC, D. AND DEWEZ, V. (1990) Dynamique du pergélisol discontinu et changements globaux dans le nord du Québec. [Dynamics of discontinuous permafrost and climate changes in northern Québec.] In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 215-222. [in French].

In northern Québec, the spatial distribution of permafrost related landforms (mineral and peat palsas), those related to its degradation and those associated within its sporadic occurrence is almost entirely explained (80.2%) by combinations of climatic variables. The PEGASE program, based on the concept of entropy, has selected the climatic characteristics giving the best spatial division of permafrost occurrence. The study area is divided into five climatic groups. Those where permafrost degradation is negligible or slight are characterized by the dominance of thermal variables over hydrological ones. The extension of group I (quasi-continuous permafrost) corresponds to very dry and cold conditions all year long. Group II (widespread permafrost) has a very low minimum annual growing temperature and a short growing season. By comparison, group III (permafrost within peat bogs) has milder temperatures with longer cool summers. The degradation of permafrost in palsa pools (group IV) is characterized by the importance of hydrological variables, with abundant precipitation. Finally, group V, where the extension of permafrost is negligible, experiences continental conditions with long warm summers and abundant precipitation all year long. This permafrost zonation in northern Québec presents a NE-SW orientation. This pattern, highlighted by the analysis, is the result of a warming which occurred in the 1940s and was caused by a westerly shift of an upper air trough, allowing for an increased influence of tropical air masses. In the study area, a doubling of CO_2 level should result in an increase of 3 to 5°C in summer temperatures as well as in a significant increase in precipitation. The application of two climatic models to the permafrost gradient highlighted by the PEGASE procedure suggests its disappearance, except in the most exposed locations. The new climatic conditions would lead to the expansion of peat-bogs in the north of the Ungava peninsula. (authors)

Key Words: mathematical models/simulation, permafrost zonation, permafrost aggradation/degradation, greenhouse gases.

LAWSON, D.E. (1983) Erosion of perennially frozen stream banks. *U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, CRREL Report 83-29, 29* pp.

A literature review indicated that the effects or permafrost on streambank erodibility and stability are not yet understood because systematic and quantitative measurements are seriously lacking. Consequently, general controversy exists as to whether perennially frozen ground inhibits lateral erosion and bankline recession, or whether it increases bank recession rates. Perennially frozen streambanks erode because of modification of the bank's thermal regime by exposure to air and water, and because of various erosional processes. Factors that determine rates and locations of erosion include physical, thermal and structural properties of bank sediments, stream hydraulics and climate. Thermal and physical modification of streambanks may also induce accelerated erosion within permafrost terrain removed from the immediate river environment. Bankline or bluffline recession rates are highly variable, ranging from less than 1 m/year to over 30 m/year and, exceptionally, to over 60 m/year. Long-term observations of the physical and thermal erosion processes and systematic ground surveys and measurements of bankline-bluffline recession rates are needed. (author)

Key Words: permafrost ecosystems/greenhouse gases, geothermal gradient/regime.

LAWSON, D.E. (1986) Response of permafrost terrain to disturbance: a synthesis of observations from northern Alaska, USA *Arctic and Alpine Research*, 18, pp. 1-17.

Former exploratory drilling sites in the Natural Petroleum Reserve-Alaska, are examples of the long-term physical modifications resulting from disturbance of perennially frozen terrain. Removal of the vegetation led to the most extensive modifications at all sites, but the subsequent response to disturbance between sites varied with primarily four factors: 1. ground ice volume; 2. distribution and size of massive ground ice; 3. material properties during thaw; and 4. relief, including progressive changes during thaw subsidence. Variations in response time resulted from the influence of these factors on the type and activity of the degradational processes that ensued. Drainage promoted meltwater erosion, whereas undrained areas were modified significantly less and attained stability more rapidly. (author, shortened)

Key Words: geothermal gradient/regime, ground ice content, soil/sediment conditions, general surface conditions, vegetation, thermokarst/freeze-thaw related geomorphic processes.

LEROUEIL, S., DIONNE, J.-C. AND ALLARD, M. (1990) Tassement et consolidation au dégel d'un silt argileux a Kangiqsualujjuaq. [Settling and thawing of a thawing clay silt at Kangiqsualujjuaq.] In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 309-316. [in French].

The physical, compressibility and consolidation characteristics of a clayey silt permafrost from Kangiqsualujjuaq, Québec, have been studied both in the laboratory and in situ, by thawing of permafrost in an excavation It comes out that the thaw settlement parameter (A_o) presents values which are similar in laboratory and in situ, and which correspond to values reported in the literature for the same type of soil. It has also been observed that the thawing of this ice-rich permafrost does not generate excess pore pressures. (authors)

Key Words: permafrost aggradation/degradation, soil/sediment conditions.

LEWKOWICZ, A.G. (1988) Ablation of massive ground ice, Mackenzie Delta. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 605-610.

Short-term rates of ablation and components of the energy fluxes causing melt are described for massive ground ice exposed Tuktoyaktuk, Northwest Territories, Canada. Ice face orientation affects both the timing and total amount of ablation recorded under clear skies. Little variation is present when the incoming short-wave radiation is mainly diffuse. A trend in ablation rates downslope is not evident, indicating that the ice face undergoes essentially parallel retreat. A regression equation using net radiation and a turbulent energy term as independent variables successfully explains 73% of the variation in the ablation flux. Net radiation provides approximately half of the energy used for ablation, and is less important here than at sites on southern Banks Island.

Key Words: heat/radiation balance, ground ice content, thermokarst/freeze-thaw related geomorphic processes.

LEWKOWICZ, A.G. (1990) Morphology, frequency and magnitude of active-layer detachment slides, Fosheim Peninsula, Ellesmere Island, N.W.T. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 118.

Hundreds of active-layer detachment slides are present on the Fosheim Peninsula both above and below the marine limit within a 50 km radius of Eureka. These landslides occur in silty or sandy materials on slopes from 2->40° and range up to 700 m in length and 150 m in width. Length distributions are positively skewed and modal values are 20-40 m. Typical scar depths are 0.3 to 0.5 m and since these represent the position of the thaw front in mid-to late summer, slope failure occurs at this time. Minimum estimates of downslope movement of soil materials by active-layer detachment sliding in three locations range from 6 to 60 mm/yr for the upper 0.5 m of the active layer. These rates correspond to volumetric transport of 30-300 $cm^3/cm/yr$ and indicate that this geomorphic process is at least as important as solifluction. Unequal responses at three sites to a particularly warm period in the summer of 1988 suggest that where active-layer detachment slides are already common, climatic warming might initially induce additional failures. More frequent external triggers will not affect long-term activity rates, however, unless internal slope processes such as weathering and moisture migration are also influenced by climatic change. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes.

LINDH, L., NYBERG, R. AND RAPP, A. (1988) Geomorphological effects and recent climatic response of snowpatches and glaciers in the western Abisko Mountains, Sweden. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 89-94.

A number of snow patches and very small glaciers are studied in the Laktatjakka area west of Abisko (800-1500m a.s.l., mean annual temperature ranging from -4 to -7°C) Permafrost is present in localized frost mounds and to greater depth in the bedrock at high latitudes. Nivation processes are studied at an instrumented snowpatch site at 1200m altitude. The measurements include air and ground temperature, precipitation, snow depth, run off, sediment yield and solifluction. An increased geomorphological activity at snowpatch sites is implied by the studies, especially regarding slope wash and mass movements. Repeated aerial and field photography, snow surveys and old air photos are used to assess the present status and recent climatic response of small glaciers in the area. During the last 45 years, most of them have receded and several are probably stagnated. Variable exposure to snowdrifting seems important to explain different climatic responses. (authors)

Key Words: snow cover, soil/sediment conditions, geothermal gradient/regime.

LINELL, K.A. (1973) Long-term effect of vegetative cover on permafrost stability in an area of discontinuous permafrost. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 688-693.

A comparison of three test sections near Fairbanks, Alaska, one kept in its natural tree covered condition, a second cleared of trees but not stripped, and a third stripped of all vegetative cover to a depth of about 0.4 m has shown that only the original densely tree-covered section has remained free from permafrost degradation over an observation period of 26 years. It is concluded that in an environment like that at Fairbanks, the maintenance or re-establishment of a random mixed-type low vegetative cover cannot be counted on to stop or prevent permafrost degradation an area subject to surface disturbance.

Key Words: vegetation, geothermal gradient/regime, permafrost ecosystems/greenhouse gases, thermokarst/ freeze-thaw related geomorphic processes.

LUTHIN, J.N. AND GUYMON, G.L. (1974) Soil moisture-vegetation-temperature relationships in central Alaska. *Journal of Hydrology,* 23, pp. 233-246.

Measurements of soil moisture and soil temperature were made during the summer of 1972 at four locations in the Goldstream Valley near Fairbanks, Alaska. Two sites were under aspen-birch forest, one in stunted black spruce forest and one in cleared grassland. These field results and observations of conditions in central Alaska led to the development of a model showing the interrelationship among drainage, vegetative cover, and the thermal regime of the mineral soil. In addition the subsystems comprising the thermal regime system have been identified. (authors)

Key Words: general surface conditions, vegetation, geothermal gradient/regime.

MACKAY, J.R. (1970) Disturbances to the tundra and forest tundra environment of the western Arctic. *Canadian Geotechnical Journal*, 7, pp. 420-432.

The more important physical disturbances to the tundra environment are discussed with examples. Thermokarst subsidence, not thermal erosion, is shown to be the dominant result of man-induced disturbances. The typical surface disturbance to the tundra results in a deepening of the active layer. Therefore, foreknowledge of the effect of a disturbance on deepening the active layer, together with information on the ice-content of the permafrost affected, makes it possible to predict the amount of thermokarst subsidence likely to take place. (author, shortened)

Key Words: geothermal gradient/regime, general surface conditions, ground ice content, thermokarst/freeze-thaw related geomorphic processes, fire, vegetation.

MACKAY, J.R. (1970) The origin of massive icy beds in permafrost, Western Arctic coast, Canada. *Canadian Journal of Earth Sciences*, 8, pp. 397-422.

Massive beds of ground ice are shown to exist along the Arctic coastal plain east of the Alaskan-Yukon boundary for a distance of at least 500 km. The massive ground ice can be seen in both undisturbed and glacially disturbed Pleistocene sediments. An examination of several thousand seismic shot hole logs, from drillholes of 15 to 35 m in depth, also corroborated the widespread occurrence of ground ice. The icy beds typically have an ice content, defined in terms of the weight of ice to dry soil, in excess of 200% for sections as much as 35 m thick. A theory is presented which suggests that: the ice is of segregation origin; the source of excess water is from the expulsion of ground water during the freezing of sands: the high pore water pressures, favorable to ice segregation, developed beneath an aggrading impermeable permafrost cover. Permafrost aggradation may have occurred either on an exposed sea floor during a period of sea level lowering which would have accompanied a glacier advance, or following a warm interval in which there had been a deep thaw. Similarities in the origin of pingo ice and massive ice are discussed. (author)

Key Words: ground ice content, thermokarst/freeze-thaw related geomorphic processes, permafrost aggradation/ degradation, hydrology/soil moisture, soil/sediment conditions.

MACKAY, J.R. (1971) Ground ice in the active layer and the top portion of permafrost. In: *Seminar on the Permafrost Active Layer* (Vancouver, British Columbia, Canada. 4-5 May, 1971), *Proceedings. National Research Council Canada. Associate Committee on Geotechnical Research. Technical* Memorandum, No. 103, pp. 26-30.

An examination of the active layer and the top portion of permafrost through the perspective of geologic time. (author)

Key Words: general surface conditions, ground ice content, permafrost aggradation/degradation.

MACKAY, J.R. (1975) The stability of permafrost and recent climatic change in the Mackenzie Valley, N.W.T. In: *Current Research. Geological Survey of Canada Paper* 75-1B, pp. 173-176.

Suggested permafrost changes in the Mackenzie Valley, N.W.T., due to climatic changes are described. Their influence on thermokarst features, active layer thickness, ice wedges and mass movements are also depicted.

Key Words: permafrost zonation, thermokarst/freeze-thaw related geomorphic processes, paleotemperatures.

MACKAY, J.R. (1976) Ice-wedges as indicators of recent climatic change, Western Arctic Coast. In: *Current Research. Geological Survey of Canada Paper* 76-1A, pp. 233-234.

Ice wedges are extremely abundant in many areas with continuous permafrost and unconsolidated materials. As ice wedges can only be preserved in permafrost, it follows that permafrost degradation will thaw the top of an ice wedge and, conversely, permafrost aggradation will cause a secondary wedge to grow if veins open along the same place. Such permafrost degradation and aggradation, with a thickening and thinning of the active layer, should follow a climatic warming and cooling trend. The evidence from active ice wedges along the western Arctic Coast suggest a thinning of the active layer of about 10% to a maximum of 40% in the recent past. (author, modified)

Key Words: permafrost aggradation/degradation, geothermal gradient/regime.

MACKAY, J.R. (1977) Changes in the active layer from 1968 to 1976 as a result if the Inuvik fire. In: *Current Research. Geological Survey of Canada Paper* 77-I B, pp. 273-275.

The active layer on a burned hillslope at Inuvik continued to thicken, but at a decreasing rate, from 1968-1976. The deepening occurred despite the rapid growth of a waist-high vegetation cover. The 8-year period required to reach a quasi-equilibrium active layer depth has resulted from the high ice content of the top of the permafrost. The burnt hillslope probably has subsided nearly 50 cm. The hillslope thickening of the active layer over an 8-year period emphasizes the inherent danger of drawing conclusions on the effect of a disturbance only a year or so after disturbance. The long-term active layer effect can only be inferred if the ice content of permafrost is known, and the extent of the revegetation is estimated. (author, shortened)

Key Words: fire, vegetation, ground ice content, human disturbances, permafrost aggradation/degradation.

MACKAY, J.R. (1981) Active layer slope movement in a continuous permafrost environment, Garry Island, North West Territories, Canada. *Canadian Journal of Earth Sciences*, 18, pp. 1666-1680.

Field investigation have been carried out at Garry Island N.W.T. for the 1964-1980 period in order to study downslope active layer movement at sites with two-sided (downward and upward) freezing and active ice wedge growth. Movements have been determined with reference to semi-flexible plastic tubes inserted vertically into the ground and by deformation of lines of stakes. The results show that the vertical velocity profile on the hill slopes with clayey hummocks is convex downslope; the movement is plug-like and occurs in late summer; the plug-like movement progressively buries the interhummock peat to form a buried organic layer; and most of the plug-like movement can be attributed to frost creep by thaw of an ice-rich layer at the bottom of the active layer. The ice-rich layer forms by upfreezing in winter and the ice content may be augmented by ice lensing in the summer thaw period. In a sedgy drainage swale, the vertical velocity profile is concave downslope. The active layer of ice-wedge polygons shows a net movement outwards from the centers to the troughs. These studies show that active layer movement at sites with two-sided freezing and active ice-wedge polygons may differ substantially from sites with only one-sided freezing and without active ice-wedge polygons. (author)

Key Words: thermokarst/freeze-thaw related geomorphic processes, soil/sediment conditions, ground ice content.

MACKAY, J.R. (1986) Fifty years (1935 to 1985) of coastal retreat west of Tuktoyaktuk, District of Mackenzie, Canada. *Geological Survey of Canada. Paper* No. 86-1, pp. 727-735.

Coastal recession from 1935 to 1985 has been determined for four sites to the immediate west of Tuktoyaktuk, N.W.T. The 1935 shoreline has been mapped from oblique air photographs and the position of the shoreline from 1950 to 1985 from vertical air photographs and field studies. The mean rates of coastal retreat have been between 1 m/yr and 8 m/yr, depending on the underground. The rate of retreat is primarily a function of the amount of excess ice in the coastal bluffs and the severity of late summer storm surges. Where excess ice extends below sea level, some offshore thermokarst depressions have developed. (author, shortened

Key Words: coastal permafrost, ground ice content, subsea/offshore permafrost, geothermal gradient/regime, thermokarst/freeze-thaw related geomorphic processes.

MACKAY, J.R. (1988) Ice wedge growth in newly aggrading permafrost, Western Arctic Coast, Canada. In: ***Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,*** Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 809-814.

The western Arctic Coast of Canada is an area of continuous permafrost where many lakes drain rapidly by erosion of ice wedges at their outlets. Drainage initiates permafrost aggradation in the first winter on the exposed lake bottoms Frequently, thermal contraction cracks open in the first winter even where frozen ground is only 3 or 4 m thick. The annual growth rate of ice wedges is highly variable, being site specific and time dependent. The ice wedge growth rate for the first few years can range from near zero to at least 2.5 cm/yr. (author, shortened)

Key Words: geothermal gradient/regime, hydrology/soil moisture, permafrost aggradation/degradation.

MACKAY J.R. AND MACKAY, D.K. (1974) Snow cover and ground temperatures, Garry Island, N.W.T. *Arctic*, 27, pp. 287-296.

Field measurements of the influence of snow on ground temperatures, at a depth of 90 cm, were carried out during 1968-1973 at Garry Island, N.W.T. The results show that the ameliorating effect of snow can be expressed by a regression equation. The side slopes tend to have the highest mean annual temperatures; the flats the lowest; and the ridges intermediate. At Garry Island, where permafrost is thick, variations in snow cover are probably not reflected in the position of the bottom of permafrost. By contrast, in the nearby alluvial islands of the Mackenzie Delta, where permafrost is thin, the effects of snow on the position of the lower permafrost surface are probably considerable. (authors)

Key Words: snow cover, mathematical models/ simulation.

MACNAMARA, E.E. (1973) Macro-and microclimates of the Antarctic coastal oasis, Molodezhnaya. *Biuletyn Peryglacjalny*, 23, pp. 201-236.

The macroclimate and microclimates of an East Antarctica coastal ice-free area are described. Maximum, average, and minimum values for macro-and microclimatic parameters of temperature, relative humidity, freeze-thaw cycles, etc. are presented graphically. Data show that summer microclimatic phenomena are better expressed than winter phenomena, correlating well with reduced wind velocity in the summer. The data are compared to other ice-free areas. (author, modified)

Key Words: heat/radiation balance, general surface conditions.

MAKSIMOVA, L.N. AND ROMANOVSKII, V.E. (1988) Hypothesis for the Holocene permafrost evolution. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 102-106.

The dynamics of ground thawing and freezing in the Holocene due to climatic fluctuations are discussed. The variation of summary temperature curves obtained for different regions of the USSR has been studied based on an analysis of harmonics corresponding to the climate fluctuations with periods of 41, 21 and 11 thousand years. The results are used to estimate the beginning of formation of the Holocene perennially frozen grounds (completely frozen after the thermal maximum) The stages of their development are related to climatic fluctuations with the period of about 1.5 thousand years. Thus, the expansion of the permafrost zone and growth of its maximum thickness (down to 150-200 m) from the west to the east in the USSR, apart from the existing regional and zonal factors, can be explained by an increase in the duration of freezing due to an earlier Holocene maximum in the eastern regions of Siberia as compared with the European North and West Siberia. The conclusions confirmed by a series of computer calculations of perennial freezing, are in good agreement with paleogeographical reconstructions of the Late Pleistocene and Holocene. (authors)

Key Words: mathematical models/simulation, paleo-temperatures, permafrost aggradation/degradation.

MAXWELL, B. (1987) Atmospheric and climatic change in the Canadian Arctic: causes, effects, and impacts. *Northern Perspectives,* 15(5) (Canadian Arctic Resources Committee Newsletter), pp. 2-6.

This paper discusses past climate in the Arctic as well as the contemporary influences such the greenhouse effect, aerosol abundances, and variances in solar radiation. The large expanse of the Canadian Arctic makes it unwise to generalize about the area as a whole. At any given time, one region may be experiencing warm conditions while another is relatively cool. A summary of temperature trends for various Arctic regions since 10,000 years BP is presented. Possible impacts upon the physical environment (snow, ice, permafrost, vegetation, and wildlife) and socio-economic impacts are presented.

Key Words: climate/permafrost monitoring, general surface conditions, permafrost ecosystems/greenhouse gases, socio-economic impact.

MCBEATH, J.H., WELLER, G., JUDAY, G.D., OSTERKAMP, T.E. AND NEVÉ, R.A. (1984) The potential effects of carbon dioxide-induced climate change in Alaska: conclusions and recommendations. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications* 83-1, pp. 193-199.

This paper presents a summary of the conference. Discussed are: the climatic scenario for Alaska for a doubling of atmospheric carbon dioxide concentration; which human activities will be affected by a climatic change and how; what information is needed to better answer the first two questions; and finally what are we going to do about the carbon dioxide problem.

Key Words: general surface conditions, permafrost engineering/infrastructure, socio-economic impact.

MCGAW, R.W., OUTCALT. S.I. AND NG, E. (1978) Thermal properties and regime of wet tundra soils at Barrow, Alaska. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1.* Ottawa, National Research Council Canada, pp. 47-53.

Measurements of in-situ thermal conductivity and temperature to a depth of 1 meter at Barrow, Alaska, have been presented in this paper. Using finite difference methods, a computation of apparent thermal diffusivity has been performed. Owing to the precision of temperature and depth measurements (± 0.01°C in temperature, ± 0.01 cm in depth), thermal effects were observed in the field which have not previously been reported. These effects include the influence of phase change of soil moisture on thermal diffusivity, and the presence of thermal events apparently related to heat transfer mechanisms other than conduction. From the data obtained it may be concluded that permafrost within a meter of the surface at Barrow, although apparently passive, is a material having dynamic thermal properties under the influence of varying temperatures; it is likely that other physical properties change with temperature as well. (authors)

Key Words: geothermal gradient/regime, mathematical models/simulation, soil/sediment conditions, ground ice content.

MCKAY, G.A. (1970) Climate: A critical factor in the tundra. *Royal Society Transactions of Canada*, Series IV, Vol. III, pp. 405-412.

The harsh arctic climate and the tundra are intimately and intricately related. The tundra is the product of a natural balance which involves climate, soil, water, land forms, and forms of life. If any one of these factors is altered, a delicate balance can be upset, with possible profound effects. Major climatic changes have occurred in the past and even today climatic interludes act as major ecological controls. Sound use of the arctic by man, therefore, demands a sound knowledge of climate from both economic and ecological viewpoints. (author)

Key Words: general surface conditions, socio-economic impact.

MCKAY, G.A. AND BAKER, W.M. (1986) Socio-economic implications of climatic change in the Canadian Arctic. In: French, H.M., ed. *Climate Change Impacts in the Canadian Arctic. Proceedings of a Canadian Climate Program Workshop (Geneva Park, Ontario, March 3-5, 1986)*, Downsview, Ontario, Atmospheric Environment Service, pp. 116-136.

Potential climatic change is discussed with respect to socio-economic impacts upon life in the North. Aspects of the Arctic economy likely to be drastically influenced, such as transportation, infrastructure, and natural resources are presented. Estimates of the severity of changes on various northern communities are also presented.

Key Words: socio-economic impact.

MCROBERTS, E.C. AND MORGENSTERN, N.R. (1974) The stability of thawing slopes. *Canadian Geotechnical Journal*, 11, pp. 447-469.

As a result of recent field exploration and study in the Mackenzie River Valley between Fort Simpson and Fort Good Hope, N.W.T., coupled with a review of the periglacial literature, it is evident that thaw plays an important role in a wide range of landslide types associated with permafrost. This study seeks first to present a description of the most common types of thaw-dominated landslide forms. Within this descriptive framework two important mass movement models, the thaw-consolidation model and the ablation model are considered. Available case records are reviewed in relation to the landslide types and other failure mechanisms are briefly considered. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, soil/sediment conditions.

MCVEE, C.V. (1973) Permafrost considerations in land use planning management. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 146-151.

Permafrost must be considered at all times when making decisions for management of arctic and subarctic lands if we are to enjoy their continued use. Factors that must be considered in the decision-making process and in the development of operational procedures are permafrost conditions and material sensitive to disturbance, land use influenced by permafrost, and land rehabilitation. Several examples are cited.

Key Words: permafrost engineering/infrastructure, thermokarst/freeze-thaw related geomorphic processes, socio-economic impact.

MEL'NIKOV, P.L. (1978) Protection of the environment in permafrost areas. *Polar Geography*, 2(4), pp. 232-239. (Originally published in: *Letopis' Severa*, Vol. 8, 1977, pp. 106-115.)

The author presents a report on the proceedings of a conference on environmental protection in permafrost areas organized by the Academy of Science, and held in Moscow in October 1975. The conference noted that there had been serious cases of environmental damage resulting from economic development in the North. Attention was focused chiefly on such topics as groundwater pollution, provocation of thermokarst, and revegetation of disrupted landscapes. (author, shortened)

Key Words: permafrost sensitivity, permafrost engineering/infrastructure.

NAKANO, Y. AND BROWN, J. (1972) Mathematical modeling and validation of the thermal regimes in tundra soils, Barrow, Alaska. *Arctic and Alpine Research*, 4, pp. 19-38.

Efforts were made to develop a mathematical model of the thermal regimes in tundra soils. The results of field investigations during the summer and fall of 1970 in the vicinity of Barrow, Alaska, were used for validation of this model. Accuracy in simulating the field observations is found satisfactory. Effects of important factors affecting the thermal regime are also discussed. (authors)

Key Words: mathematical models/simulation, general surface conditions, vegetation.

NEKRASOV, I.A. (1984) Dynamics of the cryolithozone in the Northern Hemisphere during the Pleistocene. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 903-906.

Summarizing the information on traces of the past distribution of permafrost, the author has compiled a map of its maximum distribution. On the basis of the trends derived from this, a prognosis of the evolution of the cryolithozone for the next 100 years has been attempted. However, it is emphasized that man's industrial activities are starting to exert a critical impact on the course of natural processes. (author, shortened)

Key Words: cryostratigraphy, paleotemperatures, permafrost zonation.

NELSON, F.E. (1986) Permafrost distribution in central Canada: applications of a climate-based predictive model. *Association of American Geographers. Annals*, 76, pp. 550-569.

A revised permafrost index, computed from mean monthly air temperatures and snow cover data, produces an unambiguous latitudinal zonation of contemporary permafrost. Isarithmic mapping of this "surface frost number" defines a latitudinal zonation that is in substantial agreement with a previous semi-empirical mapping of permafrost in the lowlands of central Canada. A related index, the "Stefan frost number", employs estimates of soil properties in an approximate engineering solution for the depths of freezing and thawing. Mapping of this index by unclassed chloropleth methods provides an estimate of point-to-point variations in permafrost distribution under the assumptions of homogeneous topography and vegetation. The model successfully predicts the presence of permafrost in peatlands outside the zonal limits defined by climatic criteria alone. The frost number provides an easily computed, physically based method for predicting permafrost that lends itself to a variety of cartographic representations of permafrost distribution. (author)

Key Words: mathematical models/simulation, permafrost zonation, geothermal gradient/regime, general surface conditions, soil/sediment conditions.

NEWBURY, R.W. AND MCCULLOUGH, G.K. (1983) Shoreline erosion and restabilization in a permafrost-affected impoundment. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 918-923.

In 1976, an 850 m^3/s river diversion was constructed through 300 km of permafrost affected landscape in northern Manitoba. The diversion was accomplished by raising Southern Indian Lake mean lake level by 3 m, resulting in over 400 km^2 of surrounding permafrost-affected backshore area being flooded. The mean annual temperature in the Southern Indian Lake region is -5°C. Three repeated phases of shoreline erosion in permafrost materials were observed: melting and undercutting of the backshore zone, massive faulting of the overhanging shoreline, and removal of the melting and slumping material. Erosion retreat rates of up to 12 m/yr were measured. After 5 years of erosion, restabilization of the shoreline has occurred only where bedrock has been encountered on the retreating backshore. The rapidly eroding shorelines have increased the suspended sediment concentration in Southern Indian Lake. (authors, modified)

Key Words: coastal permafrost, soil/sediment conditions, permafrost aggradation/degradation, thermokarst/freeze-thaw related geomorphic processes.

NG, E. AND MILLER, P.C. (1977) Validation of a model of tundra vegetation on soil temperatures. *Arctic and Alpine Research*, 9, pp. 89-104.

A model of physical processes of heat transfer through vegetation canopies and soil was developed for the tundra and tested with data from the wet coastal tundra near Point Barrow, Alaska. Calculated air and soil temperatures were within 1°C of the measured temperatures through the profiles. Calculated and observed depths of thaw were usually within 0.01 m through the season. Deviations were greatest during a period of snow. Sensitivity analyses indicated that the important variables and processes, many difficult to measure, are those relating to evaporation from the wet moss surface under the canopy. (authors, shortened)

Key Words: mathematical models/simulation, general surface conditions, vegetation, soil/sediment conditions, snow cover, hydrology/soil moisture.

NICHOLS, H. (1975) The time perspective in northern ecology: palynology and the history of the Canadian boreal forest. In: *Proceedings of the Circumpolar Conference on Northern Ecology, September 15-18, 1975*, Ottawa, National Research Council Canada, pp. 155-166.

Vegetational histories derived from palynological data are presented from sites spaced along 1400 km of the modern forest-tundra ecotone. During the last 7000 years they recorded latitudinal displacements of the ecotone up to 400 km, when estimated mean summer temperatures were 4°C above modern. The amplitude of ecotonal displacement was greater in central Mackenzie and Keewatin than in the northwest. This paleoclimatic scheme shows that much of the northernmost forest has undergone parallel and synchronous paleo-climatic changes, and that the last 2000-3000 years has seen massive forest retreat southwards after the mid-postglacial maximum of warmth. This establishes the probable timing of spruce clone growth in the modern tundra. Major forest fire episodes resulting from summer expansion of the Arctic Front were broadly synchronous along the entire ecotone. Fire has been a normal frequent component of northern forest history throughout the record, with substantial recoveries taking less than fifty years under favorable climate. It is tentatively suggested that woodlands are not fully in equilibrium with modern climate but owe their survival to historical climatic factors; if burned they might not regenerate. (author)

Key Words: vegetation, paleotemperatures, fire.

NICHOLSON, F.H. (1978) Permafrost distribution and characteristics near Schefferville, Québec: recent studies. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1*. Ottawa, National Research Council Canada, pp. 427-434.

Data from 84 new ground temperature measurement installations are presented. On one site 15 cables reach the permafrost base, which averages 85 meters deep but shows considerably more relief than the ground surface. The active layer usually varies with increasing vegetation from 2 to 3.5 m, and the depth at a single site varies by 25% from year to year. Different patterns of suprapermafrost groundwater movement in the active layer were directly observed. "Wet lines" with characteristic vegetation mark suprapermafrost drainage channels, which have a sharply defined subsurface form and much more unfrozen ground either as a very deep active layer or as a talik. The relationship between snow cover and ground temperatures was further quantified. Permafrost prediction based on multiple linear regression with snow and a groundwater variable would predict the discontinuous permafrost correctly for 90% of the sites available. (author)

Key Words: geothermal gradient/regime, snow cover, vegetation, hydrology/soil moisture, permafrost zonation, mathematical models/simulation.

NICHOLSON, F.H. (1978) Permafrost modification by changing the natural energy budget. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1*. Ottawa, National Research Council Canada, pp. 61-67.

A 7500 m^2 plot was modified by removing the vegetation and erecting snow fences. This produced a major change in the energy budget. In 4 ½ years the ground temperature at 10 m increased by 1.8°C, the active layer deepened from 2.8 to 6.5 m and the moisture content was lowered. The natural heat flux is very variable, largely controlled by snowcover, with an average of 30×10^6 J/m^2 being gained and lost at 5.5 m depth. The modifications completely prevented upward heat loss from the 5.5 m level and below, and there was an average gain of 23×10^6 J/m^2 each year at 5.5 m (2% of net radiation) Small plots were used to test various summer surface treatments. The results are potentially useful to the open pit mining industry. (author)

Key Words: heat/radiation balance, geothermal gradient/regime, snow cover, vegetation.

NICHOLSON, F.H. AND GRANBERG, H.B. (1973) Permafrost and snowcover relationships near Schefferville. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 151-158.

It is found that snow is the most important factor controlling permafrost distribution in the Schefferville area and that there is a linear relationship between ground temperatures and snow depth. Groundwater is an important subsidiary factor, but has not yet been quantified. Regressions were calculated which accurately predict presence or absence of permafrost for 82%, and even 94%, of a sample of 123 points if points known to be affected by groundwater are removed. A tentative general equation is presented. (authors, modified)

Key Words: mathematical models/simulation, snow cover, hydrology/soil moisture, geothermal gradient/regime.

NICHOLSON, F.H. AND THOM, B.G. (1973) Studies at the Timmins 4 experimental site. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 159-166.

There is little doubt that snow is the most important factor controlling the distribution of permafrost in the

Schefferville area. The active layer is normally 3-4 m. Several examples of active layers up to 10 m deep have been studied, and this greater depth of thaw is thought to be due to shallow groundwater movement. The thermal diffusivity of the ground is often very high, as evidenced by the penetration of annual temperature waves as deep as 25-30 m. Moisture contents of the frozen ground range between 3 and 40 percent by volume and are commonly in the order of 15 percent. From zero curtain evidence, it is observed that a sharp change in physical properties of the rocks, due to the change from frozen to unfrozen state, occurs at 0°C. The three-dimensional pattern of mean isotherms and the relationships between snow and ground temperatures demonstrate that lateral heat flow is particularly important. It is postulated that the present permafrost distribution in upland sites like Timmins 4 is in equilibrium with contemporary environmental conditions and that relict permafrost is not extensive. (authors)

Key Words: snow cover, geothermal gradient/regime, soil/sediment conditions, hydrology/soil moisture, ground ice content.

NISBET, E.G. (1989) Some northern sources of atmospheric methane: production, history, and future implications. *Canadian Journal of Earth Sciences*, 26, pp. 1603-1611.

Northern sources, including wetlands and perhaps gas hydrates, contribute significantly to the CH_4 content of the atmosphere. Methane production from northern wetlands, including bogs, swamps, and ponds, is probably very seasonal, being most important in late summer, with significant invasion in autumn as lakes overturn. The strong recovery of beaver populations in Canada may also be important, both in creating new wetlands and in the alteration of them; wetlands that have been altered by beaver activity produce orders of magnitude more methane than beaver-free wetlands. In the Arctic, methane gas hydrates represent a significant source of methane, which may become more important if Arctic warming occurs as part of global climate change. The danger of a thermal runway caused by CH_4 release from permafrost is minor, but real. Other high-latitude sources of CH_4 include Arctic peat bogs and losses from natural gas production, especially in the Soviet Union. (author)

Key Words: greenhouse gases, vegetation, permafrost sensitivity.

NIXON, J.F. (1990) Effect of climatic warming on pile creep in permafrost. *Journal of Cold Regions Engineering*, 4, pp. 67-73.

Climatic warning trends may induce long-term warming trends in permafrost ground temperatures at depth. In warmer discontinuous permafrost, the effects of such warming trends on the integrity of foundations on permafrost may be more pronounced. Structures placed on pile foundations in the Arctic have not addressed the potential effects of climatic warming in the past. This paper carries out some one-dimensional geothermal analyses to determine the effects of climatic warming on the ground temperature profile around a pile foundation, and examines the effects on the long-term creep response of a loaded pile. An existing geothermal simulator was modified to incorporate the creep calculation at each time step, and predictions for the creep settlement of a pile in a set of typical permafrost conditions have been made. The analysis indicates that permafrost at depth along the pile shaft has considerable thermal inertia, and does not warm significantly for the first 10-15 years of the simulation. Pile creep, after this time, is accelerated to some extent, induced by the effects of pile warming, averaged over the full length of pile. (author)

Key Words: geothermal gradient/regime, heat/radiation balance, mathematical models/simulation, permafrost engineering/infrastructure.

NIXON, J.F. (1990) Seasonal and climatic effects on pile creep in permafrost. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 335-340.

A one-dimensional geothermal model for predicting the temperature distribution in the ground has been modified to: (a) simply simulate a climatic warming trend by adding 0.1°C/year to the applied surface temperatures; and (b) to calculate the creep rate of a cylindrical pile embedded in the upper permafrost strata. The analysis shows that permafrost has considerable thermal inertia in the upper 6-9 m, and warming at depth due to climatic warming takes place at a reduced rate when compared with the ground surface. Seasonal pile creep effects are explored, and the increase in pile settlement rate that occurs in late summer is very much more pronounced for saline permafrost sites. Climatic warming effects on pile creep settlement are also predicted to be more pronounced for saline permafrost areas. (author)

Key Words: mathematical models/simulation, heat/radiation balance, geothermal gradient/regime.

OBERBAUER, S.F., SIONIT, N., HASTINGS, S.J. AND OECHEL, W.C. (1986) Effects of CO_2 enrichment and nutrition on growth, photosynthesis, and nutrient concentration of Alaskan tundra plant species. *Canadian Journal of Botany*, 64, pp. 2993-2998.

Three Alaskan tundra species were grown in controlled-environment chambers at two nutrition levels with two concentrations of atmospheric CO_2 to assess the interactive effects of these factors on growth, development of technogenic thermokarst in the north of Western Siberia. *Polar Geography*, 10, pp. 184-193. (Originally published in: *Inzhenernaya Geologiya*, 1985, No. 6, pp. 81-88.)

On the basis of available information on snow depth, atmospheric temperature, vegetation cover, types of sediment and ice content of sediments to a depth of 10 m, the authors have developed maps of northern areas of Western Siberia which illustrate the probability of provocation of technogenic thermokarst as a result of: a) increase in snow depth; and b) removal of the vegetation cover. The maps allow one to estimate the permissible increase in snow depth in the case of removal and preservation of the vegetation cover, the probability of the development of thermokarst with the removal of the vegetation cover, and possible settlement of the ground of the sediments thaw. Four separate zones are delimited in terms of potential for thermokarst development with removal of vegetative cover. (authors, modified)

Key Words: thermokarst/freeze-thaw related geomorphic processes, vegetation, snow cover, ground ice content, soil/sediment conditions.

PARRY, M.L. AND CARTER, T.R., EDS. (1984) *Assessing the Impact of Climatic Change in Cold Regions. Summary Report* SR-84-1. Laxenburg, Austria, International Institute for Applied Systems Analysis, 42 pp.

The probable impact of climate change at high latitudes is described. The research problem of assessing the impact of climatic change in cold regions is formulated, and an appropriate methodology is constructed. Some case studies are recommended.

Key Words: climate/permafrost monitoring, permafrost ecosystems/greenhouse gases, socio-economic impact.

PAVLOV, A.V. (1976) Heat transfer of the soil and atmosphere at northern and temperate latitudes. *U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, CRREL Report No. TL-511*, 297 pp.

Drawing from materials on systematic heat balance investigations carried out by the author over a period of more than 15 years in regions with different climatic and frozen conditions. The complex methods of conducting remote observations of elements of heat transfer between the soil and atmosphere are described. Processes of heat and mass transfer in snow and vegetation covers are considered. The results of many years of investigating the intra-yearly course of the components of the external heat transfer of natural landscapes are analyzed for conditions of Zagorsk, Vorkuta, Yakutsk and Igarka. The relationship between the forest and open area heat transfer components is studied experimentally for the first time for Siberian conditions. A great deal of attention was devoted to study of the thermal conditions of the upper layer of the earth's mantle. A number of new methods of forecasting the elements of soil thermal conditions are worked out experimentally. Technogenic changes of the components of external heat transfer and the thermal conditions of the soil which occur during engineering development of high-latitude areas are analyzed. (author, modified)

Key Words: geothermal gradient/regime, heat/radiation balance, snow cover.

PERFECT, E. AND GROENEVELT, P.H. (1990) A model for the clarification of perennial ground ice by thermally-induced regelation. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp 37-42.

A model is presented for the clarification of perennial ground ice by thermally-induced regelation. This is a phenomenon whereby hygroscopic particles embedded in ice migrate up a temperature gradient. Velocities increase exponentially as the temperature approaches zero. In thermo-active permafrost, warm summer temperatures induce particle movement towards the active layer. In winter, the thermal gradients are reversed and transport occurs in the opposite direction. The average temperature for upward migration is warmer than that for downward migration. Thus, grains should experience a net upward displacement. Equations are formulated for both processes assuming a fixed ice lattice, silt sized grains and depth positive downwards. Over geological time, the model predicts ice-enrichment of the coldest permafrost, which is compatible with the observed vertical distribution of massive ground ice bodies. (authors, shortened)

Key Words: ground ice content, mathematical models/ simulation.

PÉWÉ, T.L. (1948) *Terrain and permafrost of the Galena Air Base, Alaska. U.S. Army Chief of Engineers, U.S. Geological Survey Permafrost Program Progress Report* No. 7., 52 pp.

The floodplain of the Yukon River Valley at Galena is divided in four physiographic phases each having distinct permafrost characteristics. The criteria used to distinguish the phases are: drainage pattern, distribution of vegetation, depth to permafrost, amount of ground ice, occurrence of polygonal ground, shape and position, elevation, lithology of sediment, character of the river bank, and distribution of drift wood. (author, shortened)

Key Words: general surface conditions, hydrology/soil moisture, soil/sediment conditions, permafrost zonation, permafrost engineering/infrastructure.

PISSART, A. (1990) Advances in periglacial geomorphology. *Zeitschrift für Geomorphologie, Supplement-Band*, 79, pp. 119-131.

Climate warming in Arctic regions will cause the formation of numerous thermokarstic features and mass movements on slopes. These phenomena will be particularly important at the beginning of warming because most of the ground ice is situated at the top of the permafrost. As warming will occur principally during winter, it is at the southern limit of permafrost that the first signs of thawing of ground ice will occur. (author, shortened)

Key Words: general surface conditions, ground ice content.

POLLARD, W.H. AND FRENCH, H.M. (1980) A first approximation of the volume of ground ice, Richards Island, Pleistocene Mackenzie Delta, Northwest Territories, Canada. *Canadian Geotechnical Journal*, 17, pp. 509-516.

Using data contained in the *Mackenzie Valley Geotechnical Data Bank* together with data derived from morphometric analyses of topographic maps and air photographs, the volume of ground ice present in the upper 10 m of Richards Island is calculated to be 10.27 km^3. Pore and segregated ice constitute over 80% of the total ice volume. Wedge ice constitutes between 12 and 16% of the total ice volume in the upper 4.5 m, and approximately 36% of all excess ice. In the upper 1-2 m, wedge ice may exceed 50% of earth materials. Pingo ice is insignificant in terms of its contribution to total ice volumes. Excess ice constitutes 14% of the upper 10 m of permafrost; it follows that thawing of this layer of permafrost may lead to an average subsidence of 1.4 m. The results of this study are probably typical of other areas of the Pleistocene Mackenzie Delta. There is also general agreement with data obtained from arctic Alaska. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, ground ice content

PRICE, L.W. (1971) Vegetation, microtopography and depth of active layer on different exposures in subarctic alpine tundra. *Ecology*, 52, pp. 638-647.

Four slopes with different exposures, but with similar gradients, elevations and rock type, were studied in the Ruby Mountains of southwest Yukon Territory, Canada. Vegetation was best developed on the southeast-facing slope, and least on the north-facing slope. Solifluction lobes were present in several degrees, their development following that of vegetation. Plant communities repeated themselves in predictable patterns. Depth of the active layer largely corresponded to the presence of vegetation and microtopography. The active layer was shallowest and most variable on the southeast-facing slope. Plant cover, in general, was more important than exposure in determining the depth of thaw. (author, modified)

Key Words: vegetation, general surface conditions, soil/sediment conditions, geothermal gradient/regime.

PRIESNITZ, K. AND SCHUNKE, E. (1978) An approach to the ecology of permafrost in central Iceland. In: *Third International Conference on Permafrost (Edmonton, Alberta, 10-13 July 1978), Proceedings 1*. Ottawa, National Research Council Canada, pp. 474-479.

Based upon fieldwork between 1970 and 1976, the authors give a survey of the permafrost in central Iceland with special emphasis on the actual aggradation and degradation processes. Sporadic permafrost amounting to about 180 km^2 is limited to wet places with peat and silty to fine-sandy material. There are phenomena of degradation initiated in many cases in the warm period 1920-1950 but continuing until now, and of aggradation increasing rapidly during the last ten years. These phenomena are investigated with respect to the ecological conditions The actual decline of temperature shifts the aggradation-degradation balance towards a preponderance of aggradation. (authors, shortened)

Key Words: general surface conditions, permafrost aggradation/degradation, thermokarst/freeze-thaw related geomorphic processes, permafrost ecosystems/greenhouse gases.

PRUDHOMME, T.I., OECHEL, W.C., HASTINGS, S.J. AND LAWRENCE, W.T. 1984) Net ecosystem gas exchange at ambient and elevated carbon dioxide concentrations in tussock tundra at Toolik Lake, Alaska: an evaluation of methods and initial results. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications* 83-1, pp. 155-163.

A small prototype greenhouse with controlled carbon dioxide concentrations and temperatures was developed and used to measure net carbon dioxide flux in tussock tundra in Alaska. The tussock tundra was found to be a major sink for carbon dioxide under ambient conditions during the measuring period. Mean net daily community carbon dioxide uptake increased by five to six times under elevated carbon dioxide concentrations. These measurements suggest that tussock tundra could become an even larger sink for atmospheric carbon with the predicted increases in carbon dioxide concentration. (authors, shortened)

Key Words: permafrost ecosystems/greenhouse gases.

RACINE, C.H., PATTERSON, W.A., III, AND DENNIS, J.G. (1984) Permafrost thaw associated with tundra fires in Northwest Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1024-1029.

Thaw depths, soil temperatures, and vegetation cover were measured between 1978 and 1982 in tussock tundra on burns representing current, and up to 10 year old fires in either the Seward Peninsula or the Noatak River areas of Alaska. Percentage increase of thaw in tussock tundra on flat terrain was 10-40% during the first 5 years following the fire with a possible peak at 2 years and a return nearly to prefire thaw depths by the tenth year. Thaw depths following fire were significantly deeper in tussock tundra on slopes (> 5%) than on flatter terrain. Other factors, such as seasonal time of burning, thickness of the soil organic horizons and tussock density, vary regionally and may affect postfire thawing. (author, shortened)

Key Words: general surface conditions, vegetation, fire.

RAMPTON, V.N. (1973) The influence of ground ice and thermokarst upon the geomorphology of the Mackenzie-Beaufort region. In: Fahey, B.D. and R.D. Thompson, eds. *Research in Polar and Alpine Geomorphology.* Proceedings of the Third Guelph Symposium on Geomorphology, Guelph, Ontario, Canada. Norwich, England, Geo Abstracts, Ltd., pp. 43-59.

The Mackenzie-Beaufort region encompasses the Yukon coastal plain and adjacent mountain ranges, the Mackenzie Delta, Richards Island, Tuktoyaktuk Peninsula, and areas southeast and east of the Eskimo Lakes and Liverpool Bay. This paper describes the ground ice present in the terrain and sediments, its landform expression, and the effect of its melting upon the geomorphology Aspects of the periglacial geomorphology discussed include ice wedges and tundra polygons, pingos, segregated ice and ice cored topography, involuted hills, thermokarst basins on outwash plains, and thermokarst valleys. A review of the history and development of ground ice and ice-cored topography is also presented.

Key Words: thermokarst/freeze-thaw related geomorphic processes, ground ice content.

RISEBOROUGH, D.W. (1985) Modeling climatic influences on permafrost at a boreal forest site. Unpublished M.A. Thesis. Ottawa, Carleton University, Department of Geography, 172 pp.

The influence of a forest canopy and surface organic layer on the ground thermal regime of a permafrost site is investigated with the use of a computer model, using relationships derived from field data. The influence of the canopy on the interception of precipitation and solar radiation penetration to the forest floor is expressed in terms of canopy closure. Evaporation from the forest floor may be described by the equilibrium model. The surface temperature and thermal properties of the surface organic layer are functionally related to the water balance of the forest floor. Geothermal simulation results using a models which combines these relationships indicate that the thermal properties of the surface organic layer play a much greater role in controlling the ground thermal regime than does canopy. (author)

Key Words: vegetation, hydrology/soil moisture, soil/sediment conditions, geothermal gradient/regime, mathematical models/simulation.

RISEBOROUGH, D.W. (1990) Soil latent heat as a filter of the climate signal in permafrost. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 199-205.

This paper explores the effects of latent heat on the thermal response of the upper 20 meters of the ground to warming at the surface. As a problem in geothermal analysis, the response of permafrost to a change in the surface temperature is a function of both the initial condition (ground temperature profile) and thermal properties. The response to warming of one soil under different surface thermal regimes is examined by numerical simulation in order to indicate the range of thermal responses which can be expected of earth materials due simply to differences in their initial thermal condition. The change at the surface is attenuated most in permafrost near the cold end of the temperature range over which phase change is significant. Surface temperature change also alters the annual range at each depth, as seasonal extremes adjust to the new mean in different ways, depending on whether the surface temperature is shifting toward or away from the range in which latent heat has a significant effect. These results demonstrate that short term, near surface ground temperature trends cannot be an absolute measure of the magnitude and rate of change to the surface thermal regime when significant soil latent heat is present. Those sites most vulnerable to climatic warming (warm, ice-rich permafrost) will provide the weakest ground temperature signal. (author)

Key Words: soil/sediment conditions, geothermal gradient/regime, mathematical models/simulation.

RISEBOROUGH, D.W. AND BURN, C.R. (1988) Influence of an organic mat on the active layer. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 633-639.

Field investigations of the thermal and hydrological regimes of the active layer were carried out in summer at sites in the boreal forest near Mayo, Yukon Territory, Canada. The ground surface at these sites was covered by *Hypnum spp.* mosses. Active layer recharge occurred only when the mosses were saturated. The surficial 5 cm of the moss did not retain water readily, but precipitation from rain showers throughout the summer was stored in the peat below the surface. Little net evaporative transfer occurred between mineral and organic horizons. Instead, the mineral soil in the active layer lost water either by temperature-induced downward migration or evapotranspiration through the root system of vascular plants. The apparent thermal diffusivity of the surficial 5 cm of the organic layer was inversely related to a drying index. Below the surface, the diffusivity of the organic material remained constant. hence the organic horizon buffered the ground thermal regime from the higher surface temperatures commonly associated with dry conditions. (authors)

Key Words: vegetation, hydrology/soil moisture, geothermal gradient/regime.

ROOTS, E.F. (1989) Climate change: high latitude regions. *Climate Change*, 15, pp. 223-253.

The distinctive physical setting of high-latitude regions results not only in enhanced change in mean surface temperature for a given perturbation of planetary heat balance, but an enhanced regional and seasonal environmental response due to non-uniformity in pole-ward heat flux, and to the energy relationship of phase change and albedo change connected with ice and snow cover. The environmental response of the Arctic is characteristically different from that of the Antarctic because of differences in planetary geography and energy circulation. Ecosystems that have adapted to the low natural energy flows of high latitudes are relatively more sensitive to a given change in magnitude and timing of available energy, and to changes in physical and geochemical conditions, than most of those in lower latitudes. These natural sensitivities have a profound influence on human activities in polar areas. Policies to adapt to, or where possible to benefit from, the environmental changes that will be brought about by climate change in high latitudes will have to be adapted to the distinctive environmental responses of polar areas. Careful research to understand the environmental response to climate change is essential as Arctic and Antarctic regions assume a greater importance in world affairs, and as the Arctic regions in particular are the subject of increasing policy attention on strategic, resource development, socioeconomic and environmental protection grounds. (author)

Key Words: general surface conditions, heat/radiation balance, vegetation, snow cover, sea ice cover, human disturbances.

ROOTS, E.F. (1990) Environmental issues related to climate change in northern high latitudes. In: McCullough, J.A.W., ed. *Arctic and Global Change. Proceedings of the Symposium on the Arctic and Global Change (Ottawa, Canada, 25-27 October 1989).* Washington, D.C., Climate Institute, pp. 6-31.

An overall synthesis of Arctic concerns as related to climate change is presented. Factors influencing the characteristics of the arctic environment: 1) surface heat flux; 2) geographical asymmetry planetary geography; and 3) snow and ice, are discussed. Important changes might be expected in the arctic regions in six main areas: 1) regional climate and precipitation; 2) sea level; 3) carbon storage; 4) distribution of toxic substances; 5) biogeographical zones and habitats; 6) frozen ground. Other environmental changes in arctic regions will change the pattern and nature of human resource use in northern areas and possibly the pattern of global transportation. These changes will in turn affect human impacts on the global environment.

Key Words: permafrost ecosystems/greenhouse gases, socio-economic impact, general surface conditions, heat/radiation balance.

ROUSE, W.R. (1975) Energy budgets over high-latitude surfaces. In: *Circumpolar Conference on Northern Ecology (Ottawa, September 15-18, 1975), Proceedings.* Ottawa, National Research Council Canada, pp. IV/39-IV/56.

Six high latitude surfaces comprising a shallow-tundra lake, wet sedge tundra, mature spruce-lichen woodland, upland lichen heath and a 25-year-old burn are examined for the mid-summer period in terms of their radiation balances. A comparison of the radiation and heat balances is made with middle latitude surfaces of rye grass, corn and bare soil. The magnitude of the component fluxes of the radiation balance as proportions of incoming solar radiation at 100% are considered. The implications of the radiation balance behavior are discussed with respect to latitude and longevity of the snow cover. The magnitudes of the component fluxes of the heat balance are shown for the various surfaces and are again compared to the middle latitude surfaces. (author, shortened)

Key Words: vegetation, heat/radiation balance, snow cover, albedo.

ROUSE, W.R. (1982) Microclimate of low Arctic tundra and forest at Churchill, Manitoba. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference*. Ottawa, National Research Council Canada, pp. 68-80.

Detailed energy balance measurements collected in 1978 and 1979 at Churchill, Manitoba, for an open tundra site and a contiguous outlier forest site were examined along with one year's data for a snow-fenced site in the tundra. All sites were located on a raised beach system about 1 km inland from the Hudson Bay coast. Measurements made or derived were net radiation, ground heat storage, snow depths, rainfall, soil moisture, and soil temperature at all sites, and additionally, the latent and sensible heat fluxes at the open tundra site. In the outlier forest site, the forest creates its own ameliorated soil climate, through the agency of wet soils and the prolonged zero curtain effect. The snow-fenced site has a curtailed frost-free period at all depths due to a late-lying snow cover in spring and the early-accumulating snow cover in fall. Energy balance measurements at the open tundra site showed that the ground heat flux during the thaw period for both years comprised 18% of the net radiation. (author, shortened)

Key Words: heat/radiation balance, vegetation, climate/permafrost monitoring, snow cover, soil/sediment conditions.

ROUSE, W.R. (1984) Active layer energy exchange in wet and dry tundra of the Hudson Bay Lowlands. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1089-1094.

Results of weekly calculations of ground heat flux for Churchill, Manitoba, made from September 1981 to December 1982 are presented. Measurement sites included a variety of well-drained upland, semi-upland and wet lowland locations, a forested site, and an ice-cored palsa. Net radiation Q^*, was measured at representative sites in summer and at one site in winter with the latter measurement being applied with corrections to all sites. The ground heat flux, Q^G, was divided into sensible and latent heat components and was determined from soil moisture and temperature measurements. Snow depths were shallow on open tundra sites and deep at the forested and a forest-influenced site. As a result, final snow melt at the latter sites occurred seven weeks later than at the former ones. Q^* was similar for all sites with a maximum variation of 14% from the all-site average. Active layer depths on upland sites were double those on wet lowland. During the thaw season, Q^G, was almost the same for all sites and averaged 12% of Q^*. Q^G during freezeback fully compensated for the net radiational heat loss in winter. The similarity in Q^G for such a heterogeneous group of sites is explained in terms of thermal conductivities and vertical temperature gradients. The results are seen as having some general applicability and show that Q^G is an important component of the surface energy balance. (author)

Key Words: heat/radiation balance, hydrology/soil moisture, vegetation, geothermal gradient/regime

ROUSE, W.R. (1984) Microclimate at arctic treeline. 1. Radiation balance of tundra and forest. *Water Resources Research*, 20, pp. 57-66.

Components of the radiation balance were measured or calculated for upland tundra and adjacent open spruce forest for the period from April to September 1979 at Churchill, Manitoba, Canada, which is positioned near the tree line and which is underlain by continuous permafrost. The tundra radiative surface temperatures are almost always larger than those of the forest, but temperatures decrease systematically as the summer progresses. In late winter on clear days, the forest canopy averages 6.6°C warmer than the surrounding air and 12.6°C warmer than the snow beneath. The forest has a larger net radiation than the tundra at all times, but this is particularly pronounced with the large solar radiation input of late winter before any snowmelt takes place. Destruction of the forest will lead to a greatly modified radiation and surface temperature regime. (author, shortened)

Key Words: heat/radiation balance, vegetation.

ROUSE, W.R. (1984) Microclimate of arctic treeline. 2. Soil microclimate of tundra and forest. *Water Resources Research*, 20, pp. 67-73.

Forest and tundra soils display distinctive microclimates for a climatically normal year at Churchill, Manitoba. Forest soils are distinctively warmer in the active layer than those of the tundra but the tundra active layer is deeper. Forest soils are much wetter than those of the tundra. This results from the deep winter snow pack, which provides abundant meltwater to already thawed soils. The magnitude of soil heat storage is large, both in the tundra and the forest. Much of it is involved in the latent heat exchange accompanying thawing and freezing. Soil heat flux plates strongly underestimate the ground heat exchange and are unreliable in permafrost terrain. (author, modified)

Key Words: geothermal gradient/regime, vegetation, hydrology/soil moisture, snow cover, soil/sediment conditions.

SANGER, F.J. (1966) Degree-days and heat conduction in soils. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings.* National Academy of Sciences, National Research Council Publication 1287, pp. 253-262.

The degree-day concept is used for computing heat conduction in soils to get approximate results for engineering purposes while more precise techniques are being evolved. Simple degree-day techniques permit rapid computations, in the field if necessary.

Key Words: mathematical models/simulation, geothermal gradient/regime.

SCHELL, D.M. AND ZIEMANN, P.J. (1984) Accumulation of peat carbon in the Alaska Arctic Coastal plain and its role in biological productivity. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1105-1110.

Terrestrial peat on the coastal plain of Arctic, Alaska, is estimated to be accumulating at a rate equivalent to about 7-18 g cm^{-2} yr^{-1}, or 10-20% of annual net carbon fixation. The accretion of root matter and surficial vegetation as peat is inversely proportional to microbial activity and grazing pressures by herbivores since the depth of the permafrost horizon responds to the insulative properties of the vegetative mat. Basal peats along the coastline in the vicinity of Prudhoe Bay range from 8,000-12,000 years B.P. and their stable carbon isotope ratios indicate that vascular plants and mosses contribute the bulk of the organic matter. The aquatic habitats of the tundra represent active sites for peat oxidation and conversion to faunal biomass. Inputs of peat occur via streambank erosion, thaw lake expansion and coalescence, and coastline inundation and erosion. Stable carbon isotope ratios and carbon dating of surface lake sediments indicate that peat, rather than algal production or recent terrestrial vegetation, constitutes the bulk of the organic matter.

Key Words: vegetation, coastal permafrost, general surface conditions, permafrost ecosystems/greenhouse gases.

SCOTT, R.F. (1966) Factors affecting freeze or thaw depth in soils. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings.* National Academy of Sciences, National Research Council Publication 1287, pp. 263-267.

A method was developed which attempts to predict freeze or thaw depth in any soil under any conditions as a function of time. The technique can also be used to investigate the effect of different factors on heat flow into the soil and on thaw or freeze depth. Results of a study of various appropriate factors (incoming heat flux, surface albedo, evaporation, surface transfer coefficient, mean annual temperature and soil thermal diffusivity) and their relative effects on the freezing or thawing processes are presented. Also, a brief summary of the calculations is presented.

Key Words: mathematical models/simulation, geothermal gradient/regime, general surface conditions, soil/sediment conditions.

SENYK, J.P. AND OSWALD, E.T. (1984) Ecological relationships within the discontinuous permafrost zone of Southern Yukon Territory. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1121-1127.

Recognizing the immediate need for baseline resource information to cope with present and anticipated exploitation and development, an exploratory level integrated resource survey was undertaken in the Yukon Territory. This survey, which identified 22 broad scale ecosystems (ecoregions), was succeeded by more detailed ecological land classification studies (ecodistrict, ecosection) in a number of locations in the southern part of the Territory. During these surveys a number of ecosystems containing perennially frozen soils and/or that evolved as a result of permafrost degradation were examined and characterized. Several of these are described and relationships between the various ecosystem components discussed. (authors)

Key Words: general surface conditions, permafrost ecosystems/greenhouse gases, permafrost zonation.

SHAMANOVA, I.I. AND PARMUZIN, S.Y. (1988) Some aspects of the impact of climate on the development of thermokarst in the low-temperature cryolithozone of Northern Yakutia. *Polar Geography and Geology*, 11, pp. 306-312. (Originally published in: *Izvestiya AN SSSR, Seriya Geograficheskaya*, No. 2, pp. 84-88.)

The authors argue that the main cause for the initiation of thermokarst is local changes in the conditions of heat exchange between ground and atmosphere, e.g., changes in vegetation cover (natural or man-induced), in snow depth, or in moisture conditions. Climate change is not the immediate initiator of thermokarst but simply provides the background against which these other local changes occur. This thesis is demonstrated with reference to temperature data for Cherskiy in the Kolyma Lowland, taking into consideration increases of varying magnitude in mean annual air temperature, mean summer air temperature, variations in snow depth and varying thermal resistivities of the moss and snow covers. It is further argued that even the Holocene Climatic Optimum could not have induced the development of thermokarst. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, soil/sediment conditions, vegetation, snow cover.

SHATALOVA, T.Y. (1983) An attempt at a study of heat transfer for prognosing changes in geocryological conditions in western Siberia. *Moscow University. Geology Bulletin*, 38 (3), pp. 78-84.

This paper examines the specific features of heat transfer under microclimatic conditions and their effect on the changes in geocryological conditions resulting from the action of the external natural environment. (author)

Key Words: geothermal gradient/regime, heat/radiation balance.

SHAVER, G.R., GARTNER, B.L., CHAPIN, F.S., III AND LINKINS, A.E. (1984) Revegetation of Arctic disturbed sites by native tundra plants. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1133-1139.

The aim of this research was to develop new methods by which the recovery of native vegetation might be promoted on development-related disturbances in northern Alaska. Current methods depend on the introduction of non-native grasses, often with detrimental effects on native plant recovery. The research includes studies of both native plant population dynamics and the regulation of tundra nutrient cycles. Results are discussed. Future management practices should include conservation of soil organic matter as a top priority, with heavy fertilization and seeding only where erosion potential is great or the organic mat is lost. (authors, shortened)

Key Words: permafrost ecosystems/greenhouse gases.

SLUSARCHUK, W.A. AND WATSON, G.H. (1975) Thermal conductivity of some ice rich permafrost soils. *Canadian Geotechnical Journal*, 12, pp. 413-424.

Values are presented for the thermal conductivity of frozen and thawed ice-rich permafrost soils from Inuvik, North West Territories, measured under field and laboratory conditions with a cylindrical heat source. Samples were shipped to Ottawa, Canada, in the frozen condition at temperatures ranging from -5° to -7°C. It was found that temperature of shipping and repositioning of the probe between measurements had no statistically significant effect on results. The dependence of thermal conductivity on bulk unit weight and dry unit weight is given for both frozen and thawed samples. Measured thermal conductivities were found to be in good agreement with other values obtained for similar soils and corresponding unit weight and water content. (authors)

Key Words: geothermal gradient/regime, soil/sediment conditions.

SMITH, M.W. (1973) Factors affecting the distribution of permafrost, Mackenzie Delta, N.W.T. Ph.D. Thesis. University of British Columbia, 186 pp.

Variations in ground temperature regime and permafrost distribution were studied in a small area about 50 km northwest of Inuvik, N.W.T., in the east-central part of the Mackenzie Delta. The ground thermal regime is influenced by surface conditions, the nature of which varies spatially and temporally. The most important are the occurrence of a river and vegetation. Relationships obtained for the present set of environmental conditions are applied to the analysis of permafrost dynamics where surface boundary conditions have changes. (author, shortened)

Key Words: hydrology/soil moisture, geothermal gradient/regime, vegetation, mathematical models/ simulation, general surface conditions.

SMITH, M.W. (1975) Microclimatic influences on ground temperatures and permafrost distribution, Mackenzie Delta, Northwest Territories. *Canadian Journal of Earth Sciences*, 12, pp. 1421-1438.

Variations in ground thermal regime were studied over a small area in the east-central part of the Mackenzie Delta, Northwest Territories, about 50 km northwest of Inuvik. Vegetation shows a successional sequence related to river migration and there is a complex interaction between vegetation, topography and microclimate. Measurements from five sites show that significant differences in thermal regime exist beneath various types of vegetation. There is a general decrease in mean annual ground temperature with increasing vegetation. Snow cover is also a permafrost-controlling factor in this area;

where accumulations are greatest, a talik has formed due the insulating effect of deep snow. (author, shortened)

Key Words: geothermal gradient/regime, vegetation, snow cover.

SMITH, M.W. (1984) Climate change and other effects on permafrost. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1178-1183.

More than just climate conditions prescribe the surface temperature regime under which permafrost may or may not be present; e.g., fire, snow cover, and vegetation are important factors. Possible changes of some of these interrelated factors are described.

Key Words: general surface conditions, vegetation, fire, snow cover.

SMITH, M.W. (1986) The significance of climate change for the permafrost environment. In: French, H.M., ed. *Climate Change Impacts in the Canadian Arctic. Proceedings of a Canadian Climate Program Workshop (Geneva Park, Ontario, March 3-5, 1986).* Downsview, Ontario, Atmospheric Environment Service, pp. 67-84.

Climatic relations of permafrost are discussed. Important is the buffer layer model, in which the surface organic layer, the vegetation, and the snow cover govern. The implications of climatic warming and the time constant of permafrost sediment are reviewed, and processes and features of the permafrost environment are discussed.

Key Words: geothermal gradient/regime, vegetation, snow cover, general surface conditions, soil/sediment conditions, thermokarst/freeze-thaw related geomorphic processes.

SMITH, M.W. (1988) The significance of climatic change for the permafrost environment. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 18-24.

The nature and magnitude of climatic changes that are predicted in association with the greenhouse effect are considered in terms of their implications for the permafrost environment. With a climatic warming it is inevitable that some permafrost would eventually disappear and ultimately there would be a new "permafrost map". This would be a slow process, however, but a more important and immediate question is how quickly degradation effects would be seen, and at what rate they would develop. The relationship between climate (change) and permafrost is not a simple one, and the possible modulations introduced by local (microclimatic) and lithologic conditions are illustrated. Finally, the general implications of climatic change for periglacial processes are also briefly considered. (author)

Key Words: permafrost zonation, general surface conditions, geothermal gradient/regime, thermokarst/freeze-thaw related geomorphic processes, soil/sediment conditions.

SMITH, M.W. (1990) Potential responses of permafrost to climatic change. *Journal of Cold Regions Engineering*, 4, pp. 29-37.

A brief review of climatic warming effects on permafrost is given. Factors affecting permafrost sensitivity to climatic change are surface conditions, lithologic conditions, and the nature of the climatic change. These are discussed. Other effects of climatic change on permafrost environments, such as slope movements, are also briefly discussed. Recommendations for future research are given.

Key Words: general surface conditions, soil/sediment conditions, geothermal gradient/regime, thermokarst/freeze-thaw related geomorphic processes.

SMITH, M.W. AND BURN, C.R. (1986) Instrumentation for long-term monitoring of permafrost temperatures, in relation to climatic change, near Mayo, Yukon. Downsview, Ontario, *Atmospheric Environment Service, Canadian Climate Centre, Contract Report*, 34 pp.

A network of seven sites for monitoring ground temperature near Mayo, Yukon Territory, was installed to observe what changes occur in ground temperature with changing climate. The local characteristics of each site are described. A description is also given how the sites are installed, and how the data should be obtained to get best use of them.

Key Words: heat/radiation balance, climate/permafrost monitoring, general surface conditions.

SMITH, M.W. AND HWANG, C.T. (1973) Thermal disturbance due to channel shifting, Mackenzie Delta, N.W.T., Canada. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 51-60.

The geomorphological pattern of permafrost distribution under a shifting channel is studied, and analyzed quantitatively, in the framework of heat conduction theory. Against these field data, a computer program for predicting the effects of thermal disturbance due to engineering operations in permafrost has been verified. The finite element formulation of the heat conduction equation provides good temperature predictions for such a problem and demonstrates the consistency of the ground temperature field in the framework of heat conduction theory.

Key Words: mathematical models/simulation, geothermal gradient/regime, soil/sediment conditions, permafrost aggradation/degradation, permafrost engineering/infrastructure.

SMITH, M.W. AND RISEBOROUGH, D.W. (1984) Permafrost sensitivity to climate change. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1178-1183.

A numerical microclimatic model based on the surface energy balance, has been used to investigate the range of ground temperature response under a uniform climate, due to variation in site conditions. Site factors included slope, albedo, wetness, roughness, snow cover, and soil thermal properties. Site wetness and snow cover were the most sensitive factors. The potential for permafrost degradation during 25 years of climatic warming was then simulated for various site using climatic data for Whitehorse, Yukon Territory. In one part of the analysis, three different patterns of warming were observed at a single site. The distribution of warming during the year had relatively little effect on the long term permafrost degradation. Much greater differences in degradation resulted from variation in site conditions, for the case of uniform warming. (authors, shortened)

Key Words: general surface conditions, soil/sediment conditions, hydrology/soil moisture, geothermal gradient/regime, mathematical models/simulation.

STASHENKO, A.I. (1986) Changes in geocryological conditions with exploitation of natural forested complexes in the south of Central Yakutia. *Polar Geography and Geology*, 10, pp. 194-199. (Originally published in: *Izvestiya Geograficheskogo Obshchestva*, Vol. 118, No. 2, pp. 150-153.)

The article discusses changes in geocryological conditions resulting from the destruction of various vegetation associations on terraces of the Lena River about the town of Pokrovsk, and from restoration of the vegetation cover. It was found that with removal of a larch forest, the active layer increased by 40-50% and moisture content of the sediments decreased by 25%, whereas with removal of a pine forest the active layer depth increased by only 10% and the moisture content of the sediments effectively remained unchanged. With recolonization by vegetation it was found that the re-establishment of the geocryological conditions and especially the return to the original active layer depth, occurred much more rapidly than re-establishment of the original natural vegetation association. (author)

Key Words: vegetation, hydrology/soil moisture, general surface conditions.

STONER, M.G., UGOLINI, F.C. AND MARRETT, D.J. (1984) Moisture and temperature changes in the active layer of arctic Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1194-1199.

Occasional deep percolation of meteoric water in the foothills of the Brooks Range is critical to the genesis and physical behavior of well-drained spodosols. In situ measurements of soil water tension and temperature were made during three consecutive summers at two sites in northern Alaska: one in the boreal forest and one in the arctic tundra. Soil climate responses to changes in weather conditions are explained with additional data on soil physical properties measured in the laboratory. Important factors controlling depth of wetting front penetration include: precipitation, vegetation cover, soil texture and antecedent soil moisture content. Stable soil temperature profiles develop by July, exhibiting a sharp decrease in temperature with depth. These conditions are abruptly altered by a significant pulse of heat transmitted through the active layer during summer storms. This study shows that deep percolation is an important mechanism of transport for soil water, solutes, and heat at well-drained sites in permafrost affected regions.

Key Words: vegetation, hydrology/soil moisture, general surface conditions, climate/permafrost monitoring, geothermal gradient/regime.

STREET, R.B. AND MEL'NIKOV, P.I. (1990) Seasonal snow cover, ice and permafrost. In: Tegart, W.J.M. and G.W. Sheldon, eds. *Climate Change. IPCC Impacts Assessment Report.* Prepared for IPCC by Working Group II, Chapter 7, Intergovernmental Panel on Climate Change (Commonwealth of Australia), pp. 7.1-7.33.

This report examines the impact of climate change on the terrestrial component of the cryosphere, including seasonal snow cover, mountain glaciers, ice sheets, frozen ground including permafrost and seasonally frozen ground. Potential changes in these elements of the terrestrial cryosphere as a result of the projected changes in climate induced by enhanced atmospheric concentrations of greenhouse gases are discussed. In addition, this report reviews the current understanding of the likely ecological and socioeconomic consequences of these changes. (authors).

Key Words: permafrost zonation, socio-economic impact, permafrost aggradation/degradation.

STUART, R.A. (1991) Climate and climate change in the permafrost regions of western Siberia. *Geological Survey of Canada, Report, Terrain Sciences Division*, 24 pp.

This study presents a basic understanding of climate controls of the western Siberian Plain and the implications for permafrost stability under various scenarios of global warming due to the greenhouse effect. The study area is bounded by longitudes 60°E and 90°E and by latitudes 60°N and 75°N, an area of considerable climatological interest. It includes the western Siberian Plain from the Ural Mountains in the west to the Yenisey River and the central Siberian Uplands to the east. Of particular interest are the Yamal and Gydan Peninsulas which extend into the Arctic Ocean on either side of the mouth of the Ob River. With respect to permafrost stability, the winter season is especially important, and this season is emphasized accordingly. The application of relevant temperature and precipitation statistics in a permafrost index model is also given, along with scenarios of climate change for the area. (author, modified)

Key Words: climate/permafrost monitoring, permafrost sensitivity, mathematical models/simulation.

STUART, R.A., ETKIN, D.A. AND JUDGE, A.S. (1991) Recent observations of air temperature and snow depth in the Mackenzie Valley area and their implications on the stability of permafrost layers. Downsview, Ontario, *Atmospheric Environment Service. Canadian Climate Centre Report* No. 91-2 (unpublished manuscript), 179 pp.

The objective of this study was to review atmospheric climate changes in the Mackenzie Valley which are of relevance to the stability of permafrost layers in that region. Temperature observations have been made at several stations along the Mackenzie River for 50-90 years, while snow depth observations are available for the past 50 years. Since 1970, a warming trend of between 0.4 and 0.5°C per year for January temperatures has been sufficient to completely reverse cooling trends observed in this area in the sixties. For the entire post-1940 period, which includes several warming and cooling intervals, a small but significant warming was observed at many stations. A trend towards decreasing snow depths was observed since 1970 for most stations in the Mackenzie Valley. Frost index values include the effects of warming temperatures and the opposite effects of thinning snow depths on the probable presence of permafrost. For most stations, the effects of warming temperatures were decisive, and the stability of permafrost was estimated to have declined since 1970. (authors, modified)

Key Words: permafrost aggradation/degradation, climate/permafrost monitoring, heat/radiation balance, snow cover.

SVEINBJØRNSSON, B. (1984) Alaskan plants and atmospheric carbon dioxide. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University of Alaska-Fairbanks, Miscellaneous Publications* 83-1, pp. 149-155.

The effects of the different aspects of climatic change must be evaluated together in order to obtain a framework for analysis and research. First the effect of each parameter, e.g., CO_2 concentration, temperature, and water relations, is discussed separately, then an attempt is made to combine the potential effects. The effects of raised CO_2 concentration per se have been studied in relation to plant photosynthesis. Photosynthetic restraints such as limited nutrient supply are expected to be alleviated by the temperature effects on soil decomposition and induced enzyme activity. Expected changes in vegetation patterns and community composition are discussed. (author, modified)

Key Words: general surface conditions, hydrology/soil moisture, permafrost ecosystems/greenhouse gases.

TARNOCAI, C. (1984) Characteristics of soil temperature regimes in the Inuvik area. In: Olson, R., F. Geddes, and R. Hastings, eds. *Northern Ecology and Resource Management. Memorial Essays Honoring Don Gill.* University of Alberta Press, pp. 19-37.

Soil temperature data obtained during 2 ½ years of a 5-year study were evaluated to determine the thermal regime of the active layer and the near-surface permafrost and its relationship to soil properties, patterned ground type, vegetation, and snow cover. These soil temperatures were collected at the 2.5, 5, 10, 20, 50 and 100 cm depths on eight of the most common soil types in the Inuvik area. Soil texture and type of soil material had little effect on the soil temperature, but vegetation cover, thickness of the surface organic layer, moisture content, and topographic location had a much greater effect. Soils on the Mackenzie Delta were generally found to be cooler than soils on the till uplands. (author, shortened)

Key Words: general surface conditions, soil/sediment conditions, vegetation, climate/permafrost monitoring, geothermal gradient/regime.

TAYLOR, A., BROWN, R.J.E., PILON, J. AND JUDGE, A.S. (1982) Permafrost and the shallow thermal regime at Alert, N.W.T. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference*. Ottawa, National Research Council Canada, pp. 12-22.

In 1978, a shallow permafrost and terrain study was started at Canadian Forces station Alert, N.W.T. (82°30'N, 62°26'W) Five holes, drilled to depths down to 60 m, were instrumented with multi-thermistor cables, and temperature measurements have been taken every two or three weeks for the last three years. The drilling sites were chosen to cover various terrain types accessible from the Alert station. Preliminary air-photo analysis indicates that the principal landforms are of glacial and marine origin. A site within 100 m of a shoreline emerging due to glacial unloading yields temperatures 4 to 5 K warmer than two similar inland plateau sites. Temperature cables installed in two 15 m holes on gentle north-and south-facing slopes have shown that aspect has little influence on temperatures at this extreme latitude. (authors, shortened)

Key Words: coastal permafrost, climate/permafrost monitoring, geothermal gradient/regime.

TAYLOR, A., JUDGE, A.S. AND DESROCHERS, D.T. (1984) Shoreline regression: its effect on permafrost and the geothermal regime, Canadian Arctic Archipelago. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1239-1244.

In the Queen Elizabeth Islands in the Canadian Arctic Archipelago, the late Quaternary event with the most profound influence on ground temperatures is shoreline regression accompanying post-glacial isostatic uplift. The coastal margins of many islands have experienced hundreds to several thousand years of submergence since 8,000 years ago. The effect on the geothermal regime is far from subtle because of the large contrasts between arctic air temperatures and sea temperatures. Permafrost thicknesses measured today reflect this surface temperature history. Geothermal analysis explains variations in thickness in terms of a simple sea regression model derived from emergence curves published for the region. (authors, shortened)

Key Words: paleotemperatures, coastal permafrost, subsea/offshore permafrost, geothermal gradient/regime, mathematical models/simulation.

TERASMAE, J. (1976) Geological effects of climatic change in the Canadian Arctic. *Brock University. Department of Geological Sciences Research Report Series* 21, 36 pp. Also In: 25th International Geological Congress, (Sydney, August 16 to 26, 1976), pp. 512-513.

Sea ice, glaciers, ground ice, patterned ground, abundance of icebergs and ice islands, snow cover, fog, white outs, length of shipping season, extreme winter cold, and high velocity winds are all climate-linked phenomena. Melting of permafrost and the resulting thermokarst features is one example. Fine grained surficial deposits with high ice content are especially sensitive in this respect and serious slope instability can result from temperature rise and disturbance of permafrost regime by various technological activities of man. Although precipitation is low in the arctic, compared with southern regions, surface water is commonly abundant in the short summer, because of low evaporation and impervious permafrost, and can cause serious problems in road building and airstrip construction. Climate changes in the arctic have occurred both in a long-term basis and as yearly anomalies of considerable magnitude. Climate controls also the character of vegetation and fauna, changes in plant cover, many landforms, and rates of geomorphological processes. (author, shortened)

Key Words: vegetation, general surface conditions, geothermal gradient/regime, thermokarst/freeze-thaw related geomorphic processes, permafrost engineering/ infrastructure.

THIE, J. (1974) Distribution and thawing of permafrost in the southern part of the discontinuous permafrost zone in Manitoba. *Arctic*, 27, pp. 189-200.

This study was carried out to evaluate the environmental factors which influence the distribution and collapse of perennially frozen peats on the southern part of the discontinuous permafrost zone in Manitoba. The changes in permafrost bodies were measured by means of aerial photography carried out over a period of 20 years. About 25% of the once occurring permafrost is still present. Melting seems to have exceeded aggradation of permafrost since about 150 years B.P. Two types of collapse were noticed: peripheral collapse around very small permafrost bodies and a central collapse for larger bodies. The amount of collapse has varied from 0 to 30 meters horizontally in a 20 year period. (author)

Key Words: vegetation, general surface conditions, permafrost aggradation/degradation, thermokarst/freeze-thaw related geomorphic processes.

THOMPSON, H.A. (1966) Air temperatures in northern Canada with emphasis on freezing and thawing indexes. In: *First International Conference on Permafrost (Lafayette, Indiana, 11-15 November 1963), Proceedings.* National Academy of Sciences, National Research Council Publication 1287, pp. 272-280.

Whether permafrost will form, or if already present will persist, depends not only on frost penetration during the freezing season, as measured by the freezing index, but also on frost retreat during the thawing season, which, in turn, is indicated by the thawing index. Freezing and thawing indices are determined for northern Canada, based on measured air temperatures.

Key Words: mathematical models/simulation.

THOMPSON, R.D. (1977) The influence of climate on glaciers and permafrost. University of Reading, England, Department of Geography *Reading Geographical Papers* No. 57, 44 pp.

This paper examines the critical relationship between climate and the development of glaciers and permafrost. Section 1 refers to glaciers. Section 2 examines the influence of the atmospheric elements on permafrost in Canada. Microclimatological parameters seem to be the major controlling factors in terms of energy balance fluxes and terrain factors, which influence the energy exchange mechanisms. The paper also attempts to relate observed ground heat flux to ground thawing and concludes with an assessment of modifications imposed by terrain factors and human interference. (author, modified)

Key Words: heat/radiation balance, general surface conditions, permafrost zonation.

TISSUE, D.T. AND OECHEL, W.C. (1987) Response of *Eriophorum vaginatum* to elevated CO_2 and temperature in the Alaskan tussock tundra. *Ecology*, 68, pp. 401-410.

Small greenhouses were used in the arctic to study the effects on tussock tundra of several treatments, representing present levels of atmospheric CO_2 and temperature, and those predicted for the next century. The results are discussed. (authors, shortened)

Key Words: permafrost ecosystems/greenhouse gases.

UNTERSTEINER, N. (1984) Cryosphere. In: Houghton, J.T., ed. *Global Climate*. Cambridge University Press, pp. 121-140.

Permafrost is a manifestation of past and present climate, changing significantly on time scales of centuries or longer. It affects surface ecosystems and river discharge into the ocean, especially along the estuaries and vast shelf areas of the Eurasian continent, and influences the convective regime of the ocean. In the northern hemisphere, permafrost underlies regions with considerable populations and natural resources, and poses engineering problems. (author)

Key Words: hydrology/soil moisture, geothermal gradient/regime, permafrost engineering/infrastructure, socio-economic impact.

VALLEJO, L.E. (1980) A new approach to the stability of thawing slopes. *Canadian Geotechnical Journal*, 17, pp. 607-612.

A new approach to the stability analysis of thawing slopes at shallow depths, taking in to consideration their structure (a mixture of hard crumbs of soil and a fluid matrix), is presented. The new approach explains shallow mass movements, such as skin flows and tongues of bimodal flows which usually take place on very low slope inclinations independently of excess pore water pressures or increased water content in the active layer, which are necessary conditions in the methods available to date to explain these movements. (author)

Key Words: permafrost engineering/infrastructure, thermokarst/freeze-thaw related geomorphic processes, mathematical models/simulation, soil/sediment conditions.

VAN CLEVE, K., BARNEY, R. AND SCHLENTNER, R. (1981) Evidence of temperature control of production and nutrient cycling in two interior Alaska black spruce ecosystems. *Canadian Journal of Forest Research*, 11, pp. 258-273.

Selected indices of structure and function were used to evaluate the effect of differing soil thermal regimes on soil-permafrost-dominated (muskeg) and permafrost free (north-slope) black spruce ecosystems in interior Alaska The poorly drained permafrost site displayed cooler soil temperatures and higher soil moisture content than were encountered on the well-drained north slope. Mineral soil nutrient pools generally were largest on the permafrost site. However, low soil temperature acted as a negative feedback control, suppressing soil biological activity, nutrient mineralization, and tree primary production to lower levels on the soil-permafrost-dominated site as compared with the permafrost-free site. Forty percent larger accumulation of tree biomass and 80% greater annual tree productivity occurred on the warmer site. (authors)

Key Words: permafrost ecosystems/greenhouse gases, general surface conditions, geothermal gradient/regime, soil/sediment conditions, hydrology/soil moisture.

VAN CLEVE, K. AND VIERECK, L.A. (1984) A comparison of successional sequences following fire on permafrost-dominated and permafrost-free sites in interior Alaska. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1286-1292.

The structure and function of upland interior Alaskan forest ecosystems has been examined across two secondary successional sequences. One, the most common in interior Alaska, follows fire in black spruce stands on permafrost sites. The other, less common sequence, follows fire on warmer, generally south aspect sites and passes through a shrub and hardwood stage to white spruce. On black spruce sites, the thickness of the forest floor is a key factor responsible for maintaining moist soil, cold soil temperatures and permafrost. The low temperatures result in lowest rates of soil biological activity, nutrient cycling and, in turn, lowest tree productivity. (authors, shortened)

Key Words: permafrost ecosystems/greenhouse gases, general surface conditions, vegetation, geothermal gradient/regime, soil/sediment conditions, hydrology/soil moisture.

VELICHKO, A.A. AND NECHAYEV, V.P. (1984) Late Pleistocene permafrost in European USSR. In: Velichko, A.A., ed. *Late Quaternary Environments of the Soviet Union* (H.E. Wright, Jr. and C.W. Barnosky, English language editors). Minneapolis, University of Minnesota Press, pp. 79-86.

The European part of the Soviet Union has a special place in the history of the development of permafrost. Permafrost in this region now only occurs in a narrow band adjacent to the Arctic coast. Only about 15,000 years ago almost all of eastern Europe was included in the region of permafrost and deep seasonal freezing, as shown by traces in the sediments and landforms. In comparison with regions farther east, the European part of the USSR was characterized by a greater instability of the geothermal regime of the upper part of the lithosphere during the Pleistocene.

Key Words: permafrost zonation, paleotemperatures, permafrost sensitivity.

VIERECK, L.A. (1973) Ecological effects of river flooding and forest fires on permafrost in the taiga of Alaska. In: *North American Contribution. Second International Conference on Permafrost (Yakutsk, USSR, 13-28 July 1973), Proceedings.* Washington, D.C., National Academy of Sciences, pp. 60-67.

In the taiga of Alaska, permafrost and vegetation are closely related. In areas underlain by permafrost, the nature of the vegetation is important in determining the thickness of the active layer. Flooding has been shown to have several effects on the vegetation-permafrost relationship on floodplain forest stands mostly giving rise to a warming of the soil. Fire in forest types underlain by permafrost results in a temporary thickening of the active layer. For the first 15 years after fire, thaw is more than 1 m; return to preburn thaw levels takes about 50 years. (author, modified)

Key Words: vegetation, fire, hydrology/soil moisture.

VIERECK, L.A. (1982) Effects of fire and firelines on active layer thickness and soil temperatures in interior Alaska. In: French, H.M., ed. *Roger J.E. Brown Memorial Volume. Proceedings of the Fourth Canadian Permafrost Conference.* Ottawa, National Research Council Canada, pp. 123-135.

Thaw depths and soil temperatures are compared for three adjacent sites in interior Alaska: unburned stand of black spruce/feathermoss-Cladonia type; adjacent stand, originally of the same type, burned in 1971; and a fireline between the two in which all vegetation and most of the organic layer was removed in 1971. Maximum thawing of the active layer in the unburned stand has ranged from 40 to 50 cm in the ten summers of the study. In the burned stand, the depth of thaw increased each year following the fire and reached a maximum thaw depth of 187 cm in 1980, about four times that of the original thaw depth. Thawing was deepest in the fireline and a maximum of 227 cm was reached in 1979. In 1980, the thaw depth was only 200 cm, most likely resulting from the insulating effect of the re-establishment of vegetation. Yearly average temperatures at 200 cm depth were warmest in the fireline, intermediate in the burned stand, and coldest in the unburned stand. (author, modified)

Key Words: fire, vegetation, general surface conditions, geothermal gradient/regime.

VIERECK, L.A. AND VAN CLEVE, K. (1984) Some aspects of vegetation and temperature relationships in the Alaskan taiga. In: McBeath, J.H., ed. *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. Proceedings of a Conference. University* *of Alaska-Fairbanks, Miscellaneous Publications* 83-1, pp. 129-143.

Vegetation distribution and productivity are strongly influenced by temperature and moisture both on a regional and a local basis. This paper reports on a study of a number of forested stands on an environmental gradient in interior Alaska, on ecosystem parameters closely correlated with the temperature gradient. Also the results of disturbances (e.g., by forest fires) are discussed. In addition, the paper discusses treeline dynamics and their correlation with summer temperature; climatic changes can be expected to manifest themselves first at treeline sites. Prediction of vegetation change resulting from an increase in mean annual temperature must be extremely speculative unless seasonal distribution of temperature as well as changes in precipitation can be determined. Two scenarios of vegetation change resulting from the predicted climatic warming are discussed. (authors, modified)

Key Words: vegetation, hydrology/soil moisture, fire, permafrost ecosystems/greenhouse gases, permafrost zonation.

VOSKRESENSKIY, K.S. AND ZEMCHIKHIN, V.Y. (1986) Thermal erosion in the north of Western Siberia. *Polar Geography*, 10, pp. 130-138. (Originally published in: *Geomorfologiya*, No. 1, pp. 41-46.)

Gully landforms caused by thermal erosion which have been observed in the north of Western Siberia are discussed. A new index is introduced to characterize volumes of material removed by thermal erosion; the area has been subdivided into regions on the basis of the index values. The main factors controlling the nature and distribution of thermal erosion are considered. It is shown that the process is most fully developed in the north within the arctic tundra zone; the size and volume of the gullies are at a maximum in this zone. Values decrease towards the south becoming lowest in the forest tundra and northern taiga. The zonal nature of the thermal erosion is controlled by the climatic parameters of the various zones; the northern regions characterized by a maximum concentration of runoff (due to rapid snowmelt) and by an almost total absence of a developed root system, since most of the vegetation consists of mosses and lichens. (authors)

Key Words: thermokarst/freeze-thaw related geomorphic processes, vegetation.

WALKER, H.J. (1984) Erosion in a permafrost-dominated delta. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1344-1349.

Field trips to the Colville River delta have provided the opportunity to repeatedly examine and monitor the types and rates of erosion occurring at a number of locations. Field measurements have been made in several distinct environmental situations, including high banks composed of Gubik materials, peat banks in locations of lake tappings, a pingo and adjacent lake fill, and the head of a mid-channel bar. In all cases permafrost is involved, and in some, ice wedges are important. Rates of retreat are variable. During the past 30 years a number of banks have been eroding at average rates of between 1 and 3 m/yr; rates that have a high annual variability. At times of block collapse, retreats of up to 12 m may be almost instantaneous. However, in areas of block collapse the average annual rates of erosion are usually similar to those elsewhere because collapsed blocks serve as buffers to further retreat for 1 to 4 years. (author)

Key Words: general surface conditions, thermokarst/freeze-thaw related geomorphic processes.

WALSH, J.E. AND BARRY, R.G. (1990) Cryospheric data for studies of global change. In: *Symposium on Global Change Systems, Special Session on Climate Variation and Hydrology (Anaheim, California, February 5-9, 1990).* Boston, MA, American Meteorological Society, pp. 127-132.

Global circulation models indicate that the climatic effects of increasing greenhouse gas concentrations will be greatest in high latitudes. This paper is a survey of existing cryospheric data in the context of high latitude monitoring and model verification. Datasets are distinguished based on pertinence to four cryospheric variables: 1) sea ice; 2) continental snow cover; 3) glaciers and ice sheets; and 4) permafrost. This survey emphasizes the datasets themselves rather than the climatic roles of the various cryospheric variables.

Key Words: mathematical models/simulation, permafrost sensitivity, snow cover, climate/permafrost monitoring.

WEBBER, P.J. (1984) Terrain sensitivity and recovery in arctic regions. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Final Proceedings.* Washington, D.C., National Academy Press, pp. 135-136.

There is a lack of knowledge of arctic ecosystem dynamics and variability. Also, a semantic confusion inhibits the acquisition of new knowledge. A few examples are given. Better monitoring of the ecosystem is required.

Key Words: permafrost terminology, general surface conditions, permafrost ecosystems/greenhouse gases.

WELLER, G. AND HOLMGREN, B. (1974) The microclimates of the arctic tundra. *Journal of Applied Meteorology*, 13, pp. 854-862.

The microclimates of the arctic tundra at Barrow, Alaska, are described for the near surface terrestrial layers in which most biological activities take place. Temperature profiles are constructed from detailed measurements in the air, vegetation, and soil, from 16 m above to 6 m below the tundra surface. Wind and radiation measurements supplement these data. Considering the tundra as a two-dimensional heat exchange surface, daily components of the heat balance are computed and summarized for a number of periods throughout the year which are characterized by changes in the physical nature of the tundra surface such as appearance and disappearance of snow, meltwater and precipitation, and growth and decay of vegetation. Through changes in surface terrain parameters such as albedo and roughness length, and availability of water for phase changes, the thermal and moisture regimes of the near-surface layer change markedly during these periods as reflected by the heat balance. (authors)

Key Words: geothermal gradient/regime, heat/radiation balance, general surface conditions, soil/sediment conditions, hydrology/soil moisture.

WILLIAMS, G.P. (1971) Surface heat exchange and permafrost. In: *Seminar on the Permafrost Active Layer (Vancouver, British Columbia, Canada, 4-5 May 1971), Proceedings*, National Research Council, Canada, Committee on Geotechnical Research. Technical Memorandum No. 103, pp. 8-13.

The formation and degradation of permafrost depends largely on long-term changes in the amount of heat transferred to the ground surface from the atmosphere. Such changes can result from changes in the surface cover or from climatic changes. Man has little influence on climatic fluctuations, but he can readily change ground surface covers. A qualitative understanding of the exchange of heat and moisture at natural surfaces and how this exchange can influence permafrost are discussed.

Key Words: heat/radiation balance, general surface conditions.

WILLIAMS, P.J. AND SMITH, M.W. (1989) *The Frozen Earth: Fundamentals of Geocryology*. Cambridge, Cambridge University Press, 306 pp.

This textbook contains a very useful review on various aspects of permafrost and climatic change in the Chapters 3 (Climate and frozen ground) and 4 (The ground thermal regime).

Key Words: heat/radiation balance, mathematical models/simulation, geothermal gradient/regime, ground ice content, general surface conditions.

WOO, M.-K. (1990) Consequences of climatic change for hydrology in permafrost zones. *Journal of Cold Regions Engineering*, 4, pp. 15-20.

Various hydrologic consequences of climatic change are conjectured. Changes in the water balance are discussed. Three approaches for future research are recommended.

Key Words: hydrology/soil moisture.

WOO, M.-K. AND YOUNG, K.L. (1990) Thermal and hydrological effects of slope disturbances in a continuous permafrost environment. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp. 175-180.

In a continuous permafrost area near Resolute, N.W.T., a berm, trench and an impermeable subsurface flow barrier were placed across a slope, and compared with two undisturbed segments. These plots enabled the observation of thermal and hydrological effects of these disturbances in a continuous permafrost environment, during the course of an Arctic summer. The disturbed slope plots interrupted the downslope movement of water. Where the snow distribution was affected by the presence of a trench or berm, the pattern of ground thaw was modified also. Additionally, a section of a vehicular track across a wet depression was examined. Compared with the dry road bed, the wet section had a shallower frost table, retained more snow in the ruts and, being fed by the wet depression upslope, maintained a high water table for most of the summer. (authors)

Key Words: hydrology/soil moisture.

ZHANG, J. AND RONG, F. (1983) Preliminary experimental study of water migration at the ice/soil interface. In: *Fourth International Conference on Permafrost (Fairbanks, Alaska, 17-22 July 1983), Proceedings.* Washington, D.C., National Academy Press, pp. 1469-1472.

On the basis of the theory of adsorption and Darcy's Law, and by using the contact method, samples of Qinghai-Xizhang red clay and Lanzhou yellow silt were tested to determine their individual amounts of frozen water and the hydraulic conductivity and diffusivity in unsaturated soil (without ice in soil at negative temperature) The results show the following regularities. The amount of different soils have different adsorption rates and different processing curves. At high temperature, the adsorption rate is high, and the unfrozen water content is also large, while the rate of curvature approaching the final value of unfrozen water is also smaller. During the entire process, diffusivity is not constant, but is a function of water content. The accuracy of the results depends on the interval of measurement used in the experiment. (authors)

Key Words: hydrology/soil moisture, mathematical models/simulation, ground ice content.

ZOMOLOTCHIKOVA, S.A. (1988) Mean annual temperature of grounds in east Siberia. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 237-241, 8 refs.

The paper presents a brief discussion of the mean annual temperature of grounds in East Siberia and quantitative assessment of natural factors affecting it. The reasons for the mean annual temperature inversion of grounds in the eastern USSR are also revealed. Ground temperature inversion is caused by: (1) heat exchange on the soil surface (parameters of the radiation-heat balance and temperature on the soil surface) that depends on natural factors; and (2) a pattern of redistribution of heat generated on the earth surface by the air masses migrating in the vertical and other directions. Examples of inversion variation of ground temperature with altitude are given and the reasons of this phenomenon are discussed. (author)

Key Words: heat/radiation balance, general surface conditions.

Permafrost and Climatic Change: Supplement

This listing offers additional references (1988-1993) to supplement the detailed Annotated Bibliography. Entries are listed by first author and include only a bibliographic citation; neither key words nor annotations have been added. However, all authors are included in the combined Author Index (p. 89).

The references listed were compiled through searches of the major bibliographic data bases available online or on CD-ROM, including:

Arctic and Antarctic Regions CD-ROM
Compendex
Geoarchive
Georef
INSPEC

Because we do not have all of the original material in hand, we cannot be certain of the completeness of each citation. However, every effort has been made to ensure accuracy.

We would appreciate your comments on the bibliography—on references not included, sources not searched or subject areas or geographic regions not adequately covered. Your suggestions are welcome.

Ann M. Brennan
Compiler

Supplemental References
(1989-1993)

ADAMS, P.W. (1992) Ice and snow in the Arctic and global change. In: Woo, M.-K. and D.J. Gregor, eds. *Arctic Environment: Past, Present and Future*. Hamilton, Ontario, McMaster University, Department of Geography, pp. 35-44.

AKERMAN, H.J. (1993). *Nordic Permafrost - A Bibliography*. Lund University, Department of Physical Geography, Rapporter Och Notiser, No. 77, 17 pp.

AKERMAN, J. (1991) Aspects on the significance of climatic changes for the periglacial environment in northern Sweden. *Svensk Geografisk Arsbok*, 67, pp. 176-187.

ALIMCHANDANI, S. (1992) Climate change and arctic hydrology. In: *Alaska Water Issues*. Fairbanks, American Water Resources Association, Alaska Section. University of Alaska, Water Research Center, WRC-114, pp. 101-111.

ALLARD, M., FORTIER, R. AND SÉGUIN, M.K. (1992) Thermal regime of intertidal permafrost, George River estuary, Ungava Bay, Québec. *Canadian Journal of Earth Sciences*, 29(2), pp. 249-259.

ALLARD, M. AND PILON, J.A. (1993) Quaternary geology and geocryology in northern Québec, Canada. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1344.

ALLEN, D., MICHEL, F. AND JUDGE, A.S. (1988) Paleoclimate and permafrost in the Mackenzie Delta. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 33-38.

AN, W., WU, Z., ZHU, Y. AND JUDGE, A.S. (1993) Influence of climate change on highway embankment stability and permafrost in the permafrost region of the Qinghai-Xizang Plateau. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 11-16.

ANISIMOV, O.A. (1990) Estimate of the influence of expected climate changes on the permafrost regime. *Soviet Meteorology and Hydrology*, (3) pp. 32-37.

ANISIMOV, O.A. AND NELSON, F.E. (1990) Application of mathematical models to investigate the interaction between the climate and permafrost. *Soviet Meteorology and Hydrology*, 10, pp. 8-13.

ANISIMOV, O.A. AND SKVORTSOV, M.Y. (1989) Application of mathematical models in investigating the influence of climate change on permafrost. *Soviet Meteorology and Hydrology*, 9, pp. 81-85.

APPENZELLER, T. (1991) Fire and ice under the deep-sea floor: vast undersea deposits of gas hydrates may play a major role in climate change and the future energy economy. *Journal of Inclusion Phenomena and Molecular Recognition in Chemistry*, 11(1), pp. 1790-1796.

AZIZ, A. AND LUNARDINI, V.J. (1992) Assessment of prediction methods for the thickness of the active layer in permafrost regions. In: Ayorinde, O.A., N.K. Sinha, D.S. Sodhi, and W.A. Nixon, eds. *International Conference on Offshore Mechanics and Arctic Engineering, 11th, (Calgary, Alberta, 7-12 June 1992) Proceedings*, Vol. 4. New York, American Society of Mechanical Engineers, pp. 131-138.

AZIZ, A. AND LUNARDINI, V.J. (1993) Temperature variations in the active layer of permafrost. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 17-22.

BARNES, P.W. (1990) Effects of elevated temperatures and rising sea level on Arctic coast. *Journal of Cold Regions Engineering*, 4(1), pp. 21-28.

BARRY, R.G. (1991) Climate-ice interactions. In: Nierenberg, W.A., ed. *Encyclopedia of Earth System Science, Vol. 1.* San Diego, Academic Press, pp. 517-524.

BARRY, R.G. (1991) Observational evidence of changes in global snow and ice cover. In: Schlesinger, M.E., ed. *Greenhouse-Gas-Induced Climatic Change: a Critical Appraisal of Simulations and Observations.* Amsterdam, Elsevier Science Publishers, pp. 329-345.

BARRY, R.G. AND BRENNAN, A.M. (1993) Towards a permafrost information and data system. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 23-26.

BARSCH, D. (1992) Permafrost creep and rock glaciers. *Permafrost and Periglacial Processes*, 3(3), pp. 175-188.

BEGÉT, J. (1990) Middle Wisconsinan climate fluctuations recorded in central Alaskan loess. *Géographie physique et quaternaire*, 44(1), pp. 3-13.

BELANGER, J.R., DALLIMORE, S.R. AND EGGINTON, P.A. (1990) Applications of thematic mapper thermal infrared imagery for permafrost and terrain studies, Richards Island, N.W.T. In: *Permafrost Canada: Proceedings of the Fifth Canadian Permafrost Conference (Québec, Canada, Centre d'études nordiques, l'Université Laval, 1989)*, pp 231-238.

BELLONI, S., PELFINA, M. AND SMIRAGLIA, C. (1988) Morphological features of the active rock glaciers in the Italian Alps and climatic correlations. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings*, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 678-682b.

BELLONI, S., CARTON, A., DRAMIS, F. AND SMIRAGLIA, C. (1993) Distribution of permafrost, glaciers, and rock glaciers in the Italian mountains and correlations with climate: an attempt to synthesize. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 36-41.

BERGGREN, A.-L. (1992) Recent ground freezing in Scandinavia. In: Yu, X. and C. Wang, eds. *Ground Freezing 91. Proceedings of the Sixth International Symposium of Ground Freezing, Vol. 2, (Beijing, China, 10-12 September 1991).* Rotterdam, A.A. Balkema, pp. 517-519.

BJÖRCK, S. (1991) Stratigraphic and paleoclimatic studies of a 5500-year-old moss bank on Elephant Island, Antarctica. *Arctic and Alpine Research*, 23(4), pp. 361-374.

BOCKHEIM, J.G. (1993) Global change and soil formation in the Antarctic region. In: Gilichinskii, D.A., ed. *Joint Russian-American*

Seminar on Cryopedology and Global Change (Pushchino, 15-16 November 1992), Post-Seminar Proceedings. Russian Academy of Sciences, pp. 132-140.

BOCKHEIM, J.G., BÖLTER, M. AND CAMPBELL, I.B. (1993) Design of an experiment to detect the effects of global change on soil development in the southern circumpolar region. In: Gilichinskii, D.A., ed. *Joint Russian-American Seminar on Cryopedology and Global Change (Pushchino, 15-16 November 1992), Post-Seminar Proceedings*. Russian Academy of Sciences, pp. 146-164.

BONAN, G.B. (1989) *Environmental Processes and Vegetation Patterns in Boreal Forests*. Ph.D. Thesis. University of Virginia, 1988, University Microfilms Order No. DA8914631, 297 pp.

BONAN, G.B., SHUGART, H.H. AND URBAN, D.L. (1990) The sensitivity of some high-latitude boreal forests to climatic parameters. *Climatic Change*, 16(1), pp. 9-29.

BONAN, G.B., POLLARD, D. AND THOMPSON, S.L. (1992) Effects of boreal forest vegetation on global climate. *Nature*, 359 (6397), pp. 716-718.

BRENNAN, A.M. (1988) Permafrost Bibliography Update 1983-1987. *Glaciological Data Report GD-21*. Boulder, CO., World Data Center A for Glaciology, 225 pp.

BRENNAN, A.M. (1993) Permafrost Bibliography Update 1988-1992. *Glaciological Data Report GD-26*. Boulder, CO., World Data Center A for Glaciology, 401 pp.

BRENNAN, A.M. AND HANSON, C.S. (1992) Permafrost information and data management activities of the National Snow and Ice Data Center. In: Lay, L.B. and L.T. Everett, eds. *International Sharing of Polar Information Resources. Proceedings of the Polar Libraries Colloquy, 14th, (Columbus, OH, 3-7 May 1992)*. Ohio State University. Byrd Polar Research Center. BPRC Report, 1992, No. 4, pp. 119-124.

BRIGHAM-GRETTE, J. ET AL. (1991) Project CELIA: Climate and environment of the last interglacial (isotope atage 5) in Arctic and subarctic North America. In: *International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol.* 2. Fairbanks, University of Alaska, pp. 644-648.

BROWN, J. (1992) Circumarctic map of permafrost and ground ice conditions. In: Gilichinskii, D.A., ed. *First International Conference on Cryopedology, (Pushchino, 15-16 November 1992), Proceedings*. Vol. 1. Pushchino Research Centre, Russian Academy of Sciences, pp. 15-21.

BROWN, J., FERRIANS, O.J., JR., HEGINBOTTOM, J.A. AND MEL'NIKOV, E.S. (1992) A new circumarctic map of permafrost and ground ice conditions. In: Lay, L.B. and L.T. Everett, eds. *International Sharing of Polar Information Resources. Proceedings of the Polar Libraries Colloquy, 14th, (Columbus, OH, 3-7 May 1992)*. Ohio State University. Byrd Polar Research Center. BPRC Report, 1992, No. 4, pp. 353-360.

BURN, C.R. AND FRIELE, P.A. (1989) Geomorphology, vegetation succession, soil characteristics and permafrost in retrogressive thaw slumps near Mayo, Yukon Territory. *Arctic*, 42(1), pp. 31-40.

BURN, C.R. (1992) Canadian landform examples, 24. Thermokarst lakes. *Canadian Geographer*, 36(1), pp. 81-85.

BURN, C.R., SMITH, M.W. AND SENNESET, K., ED. (1988) Thermokarst lakes at Mayo, Yukon Territory, Canada. In: *Fifth*

International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 700-705.

CARTER, L.D. (1989) Climatic change and permafrost: The record from surficial deposits. In: *Workshop on Climatic Change and Permafrost: Significance to Science and Engineering.* Preprint volume, National Academy of Sciences, Committee on Permafrost, pp. 19-28.

CARTER, L.D. AND HILLHOUSE, J.W. (1992) Age of the late Cenozoic Bigbendian marine transgression of the Alaskan arctic coastal plain: Significance for permafrost history and paleoclimate. In: Bradley, D.C. and A.B. Ford, eds. *Geologic Studies in Alaska by the U.S. Geological Survey, 1990.* U.S. Geological Survey Bulletin, No. 1999, pp. 44-51.

CARTER, L.D. (1993) Late Pleistocene stabilization and reactivation of Eolian sand in northern Alaska: implications for the effects of future climatic warming on an Eolian landscape in continuous permafrost. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 78-83.

CARTON, A., DRAMIS, F. AND SMIRAGLIA, C. (1988) First approach to the systematic study of the rock glaciers in the Italian Alps. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 712-717.

CHACHO, E.F., JR. (1993). Snowmelt runoff and total solids production in a discontinuous permafrost basin. *Nordic Hydrology,* 24(2-3), pp. 65-78.

CHAPIN, F.S., III, JEFFERIES, R.L., REYNOLDS, J.F., SHAVER, G.R., SVOBODA, J. AND CHU, E.W., EDS. (1992) *Arctic Ecosystems in a Changing Climate. An Ecophysiological Perspective.* San Diego, Academic Press.

CHEKHOVSKII, A.L. AND ZENOVA, O.A. (1989) Nomographs of soil annual average temperature. In: Rathmayer, H., ed. *International Symposium on Frost in Geotechnical Engineering (Saariselkä, Finland, Mar. 13-15, 1989). VTT Symposium 94. Proceedings. Vol. 1.,* Espoo, Finland, Valtion teknillinen tutkimuskeskus, pp. 219-231.

CHENG, G., HUANG, X. AND KANG, X. (1993) Recent permafrost degradation along the Qinghai-Tibet Highway. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1010-1013.

CHIMITDORZHIEVA, G.D. (1992) Characteristics of the organic matter of cryogenic soils. *Soviet Soil Science,* 23(10), pp. 68-76.

CHRISTENSEN, T.R. (1993) Methane emission from Arctic tundra. *Biogeochemistry,* 21(2), pp. 117-139.

CHUECA, J. (1992) A statistical analysis of the spatial distributions of rock glaciers, Spanish central Pyrenees. *Permafrost and Periglacial Processes,* 3(3), pp. 261-265.

CICERONE, R.J. AND OREMLAND, R.S. (1988) Biogeochemical aspects of atmospheric methane. *Global Biogeochemical Cycles,* 2(4), pp. 299-327.

CLOW, G.D. (1992) The extent of temporal smearing in surface-temperature histories derived from borehole temperature measurements. *Global and Planetary Change,* 6, pp. 81-86.

CLOW, G.D., LACHENBRUCH, A.H. AND MCKAY, C.P. (1991) Inversion of borehole temperature data for recent climatic changes: examples from the Alaskan Arctic and Antarctica. In: Weller, G., C.L. Wilson and B.A.B. Severin, eds. *International Conference on the Role of the Polar Regions in Global Change, Proceedings, (Fairbanks, Alaska, 11-15 June 1990), Vol. II.* Fairbanks, University of Alaska, Geophysical Institute, pp. 533-536.

COLLINS, C.M., HAUGEN, R.K. AND HORRIGAN, T.O. (1993) Comparison of two ground temperature measurement techniques at an interior Alaskan permafrost site. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1076-1078.

CUI, Z.S.C. (1992) Holocene periglacial processes and environmental changes in Daqingshan mountains, inner Mongolia, China. *Permafrost and Periglacial Processes*, 3(1), pp. 55-62.

DALLIMORE, S.R. AND DAVIS, J.L. (1992) Ground penetrating radar investigations of massive ground ice. *Geological Survey of Canada. Paper*, 90-4, pp. 41-48.

DIONNE, J.-C. AND SÉGUIN, M.K. (1992) Recherches sur le pergélisol dans la région de Blanc-Sablon, Québec. (Research on permafrost in the region of Blanc-Sablon, Québec.) *Geological Survey of Canada. Paper* 92-1D, pp. 59-65.

DRAMIS, F. AND KOTARBA, A. (1992) Southern limit of relict rock glaciers, Central Apennines, Italy. *Permafrost and Periglacial Processes*, 3(2), pp. 257-260.

DREDGE, L.A. (1992) Field guide to the Churchill region, Manitoba. Glaciations, sea level changes, permafrost landforms, and archeology of the Churchill and Gillam areas. *Geological Survey of Canada. Miscellaneous Report*, 53, pp. 1-52.

DUCHKOV, A.D. AND DEVIATKIN, V.N. (1992) Reduced geothermal gradients in the shallow West-Siberian platform. *Global and Planetary Change*, 6(2-4), pp. 245-250.

EDLUND, S.A., WOO, M.-K. AND YOUNG, K. (1990) Climate, hydrology and vegetation patterns, Hot Weather Creek, Ellesmere Island, Arctic Canada. *Nordic Hydrology*, 21(4-5), pp. 273-286

ENGLISH, M.C., SCHIFF, S.L. AND BOIKE, J. (1992) Will surface freshwater chemistry change in the high Arctic as a result of predicted global warming?. *EOS. Transactions, American Geophysical Union*, 73(14), pp. 105.

ERSHOV, E.D. AND IAKUSHEV, V.S. (1992) Experimental research on gas hydrate decomposition in frozen rocks. *Cold Regions Science and Technology*, 20(2), pp. 147-156.

ESCH, D.C. (1988) Is Alaska's permafrost melting? *Alaska Department of Transportation and Public Facilities. Research Notes*, 13(1), 2 pp.

ESCH, D.C. AND OSTERKAMP, T.E. (1989) Arctic and cold regions engineering: climatic warming concerns. In: *Workshop on Climatic Change and Permafrost: Significance to Science and Engineering.* Preprint volume. National Academy of Sciences, Committee on Permafrost, pp. 71-75.

ETKIN, D. (1989) Greenhouse warming: consequences for Arctic climate. In: *Workshop on Climatic Change and Permafrost: Significance to Science and Engineering.* Preprint volume. National Academy of Sciences, Committee on Permafrost, pp. 1-18.

ETKIN, D., HEADLEY, A. AND STOKER, K.J.L. (1988) Permafrost climate activities within the Canadian Climate Centre. *Canada. Atmospheric Environment Service. Canadian Climate Centre. Report* No. 88-7, 89 pp.

EVANS, B.M., WALKER, D.A., BENSON, C.S., NORDSTRAND, C.S. AND PETERSEN, G.W. (1989) Spatial interrelationships between terrain, snow distribution and vegetation patterns at an Arctic foothills site in Alaska. *Holarctic Ecology*, 12(3), pp. 270-278.

EVANS, D.J.A. (1993). High latitude rock glaciers; a case study of forms and processes in the Canadian Arctic. *Permafrost and Periglacial Processes*, 4(1), pp. 17-35.

EVIN, M. (1992) Origine et rythmes de progression des glaciers rocheux alpins et nord-américains. (Origin and rates of progression of Alpine and North American rock glaciers.) *Association de Géographes Français. Bulletin*, 69(3), pp. 271-273.

FERRIANS, O.J., JR. (1988) Pingos in Alaska: a review. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 734-739.

FORBES, B.C. (1993) Aspects of natural recovery of soils, hydrology and vegetation at an abandoned high Arctic settlement, Baffin Island, Canada. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 176-181.

FORTIER, R. (1991) Caracterisation du pergelisol de buttes cryogenes a l'aide de diagraphies electriques au Nunavik, Québec [Characterization using electric logs of the permafrost of cryogenic tussocks in Nunavik in Québec]. *Permafrost and Periglacial Processes*, 2(2), pp. 79-93.

FRANCOU, B. AND REYNAUD, L. (1992) 10 year surficial velocities on a rock glacier (Laurichard, French Alps). *Permafrost and Periglacial Processes*, 3(2), pp. 209-213.

FRENCH, H.M. AND HARRY, D.G. (1992) Pediments and cold-climate conditions, Barn Mountains, unglaciated northern Yukon, Canada. *Geografiska Annaler. Series A*, 74A(2-3), pp. 145-157.

FUKUDA, M. AND ISHIZAKI, T. (1992) General report on heat and mass transfer. In: Yu, X. and C. Wang, eds. *Ground Freezing 91. Proceedings of the Sixth International Symposium of Ground Freezing, Vol. 2, (Beijing, China, 10-12 September 1991).* Rotterdam, A.A. Balkema, pp. 309-415.

FUKUDA, M. AND SONE, T. (1992) Some characteristics of alpine permafrost, Mt. Daisetsu, central Hokkaido, northern Japan. *Geografiska Annaler. Series A*, 74A(2-3), pp. 159-167.

GATES, D.M. (1993) *Climate Change and its Biological Consequences*. Sunderland, MA., Sinauer Associates, 280 pp.

GAVRILOVA, M.K. (1993). Climate and permafrost. *Permafrost and Periglacial Processes*, 4(2),pp. 99-111.

GAVRILOVA, M.K. (1993) Present human induced climatic change and cryoecology. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University (Technology Press, pp. 1006-1009.

GIBSON, J.J., EDWARDS, T.W.D. AND PROWSE, T.D. (1993). Runoff generation in a high boreal wetland in northern Canada. *Nordic Hydrology*, 24(2-3). pp. 213-224.

GILICHINSKII, D.A., ED. (1992) *First International Conference on Cryopedology, (Pushchino, 15-16 November 1992), Proceedings.* Vol. 1. Pushchino Research Centre, Russian Academy of Sciences, 272 pp.

GILICHINSKII, D.A., ED. (1993) *Joint Russian-American Seminar on Cryopedology and Global Change (Pushchino, 15-16 November 1992), Post-Seminar Proceedings.* Russian Academy of Sciences, 362 pp.

GIORGI, F. AND MEARNS, L.O. (1991) Approaches to the simulation of regional climate change: a review. *Reviews of Geophysics*, 29(2), pp. 191-216.

GRAY, J.T., PILON, J. AND POITEVIN, J. (1988) A method to estimate active-layer thickness on the basis of correlations between terrain and climatic parameters as measured in northern Québec. *Canadian Geotechnical Journal*, 25(3), pp. 607-616.

GREBENETS, V.I. AND FEDOSEEV, D.B. (1992) Industrial influence on glacial processes in mountains of circumpolar regions. *Annals of Glaciology*, 16, pp. 212-214.

GREGORI, G.P. AND MARTELLUCCI, S. (1992) Underground record of global climate change. *Italian Research on Antarctic Atmosphere. Conference Proceedings. Vol. 35.* Bologna, Italian Physical Society, pp. 279-293.

GRIGORIEV, M.N., POZDNIAKOV, I.V. AND ROMANOV, V.P. (1990) Cryogenic processes in ice complex ground caused by man-induced disturbance of the surface. In: *Ratsionalnoie prirodopolzovanie v kriolitozone.* Y Yakutsk, IMZ SO AN SSSR.

GROSS, M.F., HARDISKY, M.A., DOOLITTLE, J.A. AND KLEMAS, V. (1990) Relationships among depth to frozen soil, soil wetness, and vegetation type of biomass in tundra near Bethal, Alaska, USA *Arctic and Alpine Research*, 22(3), pp. 275-282.

GROSSO, S.A. AND CORTE, A.E. (1989) Pleistocene ice wedge casts at 34°. Eastern Andes piedmont, southwest of South America. *Geografiska Annaler*, 71A(3-4), pp. 125-136.

GUBIN, S.V. (1992) Recent cryomorphic soils and underlying permafrost. In: Gilichinskii, D.A., ed. *First International Conference on Cryopedology, (Pushchino, 15-16 November 1992), Proceedings.* Vol. 1. Pushchino Research Centre, Russian Academy of Sciences, pp. 56-59.

HAEBERLI, W. (1990) Permafrost. *Zurich. Eidgenössische Technische Hochschule. Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie. Mitteilungen*, No. 108, pp. 71-88.

HAEBERLI, W., ED. (1992) Permafrost and periglacial environments in mountain areas. In: *Permafrost and Periglacial Processes*, 3(2), pp. 175-273.

HAEBERLI, W. (1993) Research on permafrost and periglacial processes in mountain areas: status and perspectives. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1014-1018.

HAEBERLI, W., CHENG, G., GORBUNOV, S.A. AND HARRIS, S.A. (1993). Mountain permafrost and climatic change. *Permafrost and Periglacial Processes*, 4, (2), pp. 165-174.

HAEBERLI, W., HOELZLE, M., KELLER, F., SCHMID, W., VONDER MÜHLL, D.S. AND WAGNER, S. (1993) Monitoring the long-term evolution of mountain permafrost in the Swiss Alps. In: *Sixth International Conference on Permafrost (Beijing, China,* *5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 214-219.

HAGEN, J.O. (1989) Isbreer og permafrost som klimaindikatorer. (Glaciers and permafrost as climate indicators.) *Norsk Polarinstitutt. Rapportserie*, 53, pp. 1-7.

HALL, D.K. (1988) Assessment of polar climate change using satellite technology. *Reviews of Geophysics*, 26(1), pp. 26-39.

HANSON, W. (1992) Three years of natural revegetation on the 1977 Bear Creek burn in interior Alaska. *U. S. Bureau of Land Management. Alaska State Office. BLM-Alaska Open File Report*, No. 28, 43 pp.

HANVEY, P.M. AND MARKER, M.E. (1992) Present-day periglacial microforms in the Lesotho Highlands: implications for present and past climatic conditions. *Permafrost and Periglacial Processes*, 3(4), pp. 353-361.

HAPPOLDT, H. AND SCHROTT, L. (1992) A note on ground thermal regimes and global solar radiation at 4720 m a.s.l, high Andes of Argentina. *Permafrost and Periglacial Processes*, 3(3), pp. 241-245.

HARRIS, S.A. (1988) Alpine periglacial zone. In: Clark, M.J., ed. *Advances in Periglacial Geomorphology*. Chichester, England, John Wiley and Sons, pp. 369-413.

HARRIS, S.A. (1988) Effects of climatic change on northern permafrost. *Northern Perspectives. Canadian Arctic Resources Committee Newsletter*, 15(5), p. 7.

HARRIS, S.A. (1989) Continentality index: its uses and limitations applied to permafrost in the Canadian Cordillera. *Physical Geography*, 10(3), pp. 270-284.

HARRIS, S.A. AND CORTE, A.E. (1992) Interactions and relations between mountain permafrost, glaciers, snow and water. *Permafrost and Periglacial Processes*, 3(2), pp. 103-110.

HARRIS, S.A. AND NYROSE, D. (1992) Palsa formation in floating peat and related vegetation cover as illustrated by a fen bog in the MacMillan Pass, Yukon Territory, Canada. *Geografiska Annaler, Series A, Physical Geography*, 74A(4), pp. 349-362.

HARRIS, S.A., SCHMIDT, I.H. AND KROUSE, H.R. (1992) Hydrogen and oxygen isotopes and the origin of ice in peat plateaus. *Permafrost and Periglacial Processes*, 3(1), pp. 19-27.

HARRISON, W.D. (1991) Permafrost response to surface temperature change and its implications for the 40,000-year surface temperature history at Prudhoe Bay, Alaska. *Journal of Geophysical Research*, 96B(1), pp. 683-695.

HEGINBOTTOM, J.A., BROWN, J., MEL'NIKOV, E.S. AND FERRIANS, O.J., JR. (1993) Circumarctic map of permafrost and ground ice conditions. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1132-1136.

HEGINBOTTOM, J.A. AND DUBREUIL, M.-A. (1993) A new permafrost and ground ice map for the National Atlas of Canada. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 255-260.

HENRICK, M. AND THOMSEN, T. (1993) Permafrost studies in Greenland. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings,* *V. 2.* Wushan, China, South China University of Technology Press, pp. 1137-1143.

HINZMAN, L.D. (1991) *Interdependence of the Thermal and Hydrologic Processes of an Arctic Watershed and Their Response to Climatic Change*. Ph.D. Thesis. University of Alaska, Fairbanks, 425 pp.

HINZMAN, L.D., KANE, D.L., GIECK, R.E. AND EVERETT, K.R. (1991) Hydrologic and thermal properties of the active layer in the Alaskan Arctic. *Cold Regions Science and Technology*, 19(2), pp. 95-110.

HIRAKAWA, K. (1990) Permafrost environment during the last glacial in east and north Hokkaido, northernmost Japan. *Tokyo Metropolitan University, Geographical Reports*, 25, pp. 155-165.

HOELZLE, M. (1992) Permafrost occurrence from BTS measurements and climatic parameters in the eastern Swiss Alps. *Permafrost and Periglacial Processes*, 3(2), pp. 143-147.

HOFMANN, J. (1992) Investigations of present and former periglacial, nival and glacial features in central Helan Shan (Inner Mongolia/Peoples Republic of China). *Zeitschrift für Geomorphologie*, Suppl. 86, pp. 139-154.

HOGENBIRK, J.C. (1991) Fire and drought experiments in northern wetlands: a climate change analogue. *Canadian Journal of Botany*, 69(9), pp. 1991-1997.

HOUGHTON, J.T., JENKINS, G.J. AND EPHRAUMS, J.J. (1990) *Climate Change. The IPCC Scientific Assessment*. Cambridge, Cambridge University Press, 364 pp.

HOUGHTON, J.T., CALLANDER, B.A. AND VARNEY, S.K., EDS. (1992) *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment*. Cambridge, England, University Press, 200 pp.

HRYNYSHYN, J. (1992) Studying the permafrost for signs of change. *The Inuvik Drum*, March 5, 1992, p. 2.

HU, R. AND MA, H. (1993) Snow and permafrost in the Tian Shan Mountains. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1144-1147.

HUNTER, J.A. (1988) Permafrost aggradation and degradation on arctic coasts of North America. *Frost i jord*, No. 27, pp. 27-34.

HYATT, J.A. (1992) Cavity development in ice-rich permafrost, Pangnirtung, Baffin Island, Northwest Territories. *Permafrost and Periglacial Processes*, 3(4), pp. 293-313.

JAKOB, M. (1992) Active rock glaciers and the lower limit of discontinuous alpine permafrost, Khumbu Himalaya, Nepal. *Permafrost and Periglacial Processes*, 3(2), pp. 253-256.

JETCHICK, E. AND ALLARD, M. (1990) Soil wedge polygons in northern Québec: description and paleoclimatic significance. *Boreas*, 19(4), pp. 353-367.

JIN, H., QUI, G., ZHAO, L., WANG, S. AND ZENG, Z. (1993) Thermal regime of alpine permafrost in the upper reach of Urumqi River, Xingiang, China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 307-311.

JUDGE, A.S., TUCKER, C.M., PILON, J.A. AND MOORMAN, B.J. (1991) Remote sensing of permafrost by ground-penetrating radar at two airports in Arctic Canada. *Arctic*, 44(1), pp. 40-48.

KAHL, J.D., CHARLEVOIX, D.J., ZALTSEVA, N.A., SCHNELL, R.C. AND SERREZE, M.C. (1993) Absence of evidence for greenhouse warming over the Arctic Ocean in the past 40 years. *Nature*, 361(6410), pp. 335-337.

KAKUTA, S. (1992) Surface-temperature history during the last 1000 years near Prudhoe Bay, Alaska: Applying control theory to the inversion of borehole temperature profiles. *Global and Planetary Change*, 6(2-4), pp. 225-244.

KANE, D.L., HINZMAN, L.D., WOO, M.-K. AND EVERETT, K.R. (1992) Arctic hydrology and climate change. In: Chapin, F.S., III, R.L. Jefferies, J.F. Reynolds, G.R. Shaver and J. Svoboda, eds. *Arctic Ecosystems in a Changing Climate: an Ecophysiological Perspective*. San Diego, Academic Press, pp. 35-57.

KANE, D.L. (1993) Northern hydrology and water resources in a changing environment. In: Wall, G., ed. *Impacts of Climate Change on Resource Management in the North, A Combined Fourth Canada-United States Symposium and Biennial AES/DIAND Meeting on Northern Climate*. Canadian Climate Centre, Environment Canada, *University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No. 16, pp. 55-68.

KARLSTROM, E.T. (1990) Relict periglacial features east of Waterton-Glacier Parks, Alberta and Montana, and their palaeoclimatic significance. *Permafrost and Periglacial Processes*, 1(3-4), pp. 221-234.

KATASONOV, E.M. (1988) Continuous persistence of the permafrost zone during the Quaternary period. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings*, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 801-804.

KHRUSTALEV, L.N., PUSTOFOIT, G.P. AND EMELYANOVA, L.V. (1993) Reliability and durability of bases of engineering structures in permafrost soils under global climatic heating conditions. *Soil Mechanics and Foundation Engineering*, 30(3), 92 pp.

KOLCHUGINA, T.P. AND VINSON, T.S. (1993). Climate warming and the carbon cycle in the permafrost zone of the former Soviet Union. *Permafrost and Periglacial Processes*, 4(2), pp. 149-163.

KONDRATJEVA, K.A., KHRUTZKY, S.F. AND ROMANOVSKII, N.N. (1993) Changes in the extent of permafrost during the late Quaternary period in the territory of the former Soviet Union. *Permafrost and Periglacial Processes*, 4(2), pp. 113-119.

KOSTER, E.A. (1993). Introduction: present global change and permafrost within the framework of the International Geosphere-Biosphere Programme. *Permafrost and Periglacial Processes*, 4(2), pp 95-98.

KOSTER, E.A. (1993) Global warming and periglacial landscapes. In: Roberts, N., ed. *The Changing Global Environment*, Blackwell, Cambridge, USA, pp. 127-149.

KRISTENSEN, M. (1988) Climatic conditions and permafrost development on the Svalbard Archipelago. *Frost i jord*, No.27, pp. 24-26.

KRUMMENACHER, B. AND BUDMIGER, K. (1992) Monitoring of periglacial phenomena in the Furggentälti Swiss Alps. *Permafrost and Periglacial Processes*, 3(2), pp. 16-20.

KVENVOLDEN, K.A. (1988) Methane hydrates and global climate. *Global Biogeochemical Cycles*, 2(3), pp. 221-229.

KVENVOLDEN, K.A. (1991) Review of arctic gas hydrates as a source of methane in global change. In: Weller, G., C.L. Wilson and B.A.B. Severin, eds. *International Conference on the Role of the Polar Regions in Global Change, Proceeding, Vol. II.* Fairbanks, University of Alaska, Geophysical Institute, pp. 696-701.

KVENVOLDEN, K.A. AND COLLETT, T.S. (1993). Permafrost and gas hydrates as possible sources of atmospheric methane at high latitudes. In: Kelmelis, J.A. and K.M. Snow, eds. *First U.S. Geological Survey Global Change Research Forum (Herndon, Virginia March 18-20, 1991), Proceedings.* U.S. Geological Survey Circular C 1086, pp. 92-93.

KVENVOLDEN, K.A. AND LORENSON, T.D. (1993). Methane in permafrost: preliminary results from coring at Fairbanks, Alaska. *Chemosphere*, 26(1-4), pp. 609-616.

KVERNDAL, A.-I., ELVEBAKK, A. AND JAWOROWSKI, Z. (1990) Virkninger av klimaendringer i polaromradene. Bidrag til den inter-departmentale klimautredningen. (Effects of climatic changes in polar areas.) *Norsk Polarinstitutt. Rapportserie*, 62, pp. 1-118.

LACHENBRUCH, A.H. (1989) Permafrost research and global change. *Glaciological Data Report GD-23.* Boulder, CO., World Data Center A for Glaciology, pp. 111.

LACHENBRUCH, A.H., ET AL. (1989) Temperature and depth of permafrost on the Arctic Slope of Alaska. In: Grye, G., ed., *Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982. U.S. Geological Survey Professional Paper* 1399, pp. 645-656.

LAFLEUR, P.M., ROUSE, W.R. AND CARLSON, D.W. (1992) Energy balance differences and hydrologic impacts across the northern treeline. *International Journal of Climatology*, 12(2), pp. 193-203.

LAVOIE, C. AND PAYETTE, S. (1992) Black Spruce growth forms as a record of a changing winter environment at treeline, Québec, Canada. *Arctic and Alpine Research*, 24(1), pp. 40-49.

LAWFORD, R.G. (1988) Climatic variability and the hydrological cycle in the Canadian North: knowns and unknowns. In: *Third Meeting on Northern Climate (Whitehorse, September 7-8, 1988), Proceedings.* Atmospheric Environment Service. Canadian Climate Program, pp. 143-162.

LAWFORD, R.G. AND COHEN, S.J. (1991) Impacts of climatic variability and change in the Mackenzie Delta. *Environment Canada. National Hydrology Research Institute, Saskatoon, Saskatchewan. NHRI Symposium*, No.4, pp. 155-172.

LEWKOWICZ, A.G. (1992) Climatic change and the permafrost landscape. In: *Arctic Environment: Past, Present and Future.* Hamilton, Ontario, McMaster University, pp. 91-104.

LEWKOWICZ, A.G. (1992) Factors influencing the distribution and initiation of active-layer detachment slides on Ellesmere Island, arctic Canada. In: Dixon, J.C. and A.D. Abrahams, eds. *Periglacial Geomorphology.* Chichester, England, John Wiley and Sons, pp. 223-250.

LEWKOWICZ, A.G. (1993) Ice wedge development slopes, Fosheim Peninsula, Ellesmere Island, Eastern Canadian Arctic. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings,* *V. 2.* Wushan, China, South China University of Technology Press, pp. 1345.

LI, SHUDE AND LI, SHIJIE (1993) Permafrost and periglacial landforms in Kekexili area of Qinghai Province. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1174-1177.

LI, Z., LI, S. AND WANG, Y. (1993) Regional features of permafrost in Mahan Mountains and their relationship to the environment. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1178-1182.

LIANG, F. AND GU, Z. (1993) Application of remote sensing images to the investigations of the changes of permafrost environment in burned forest regions, Da Hingganling, China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 388-392.

LIVINGSTON, G.P. AND MORRISSEY, L.A. (1991) Methane emissions from Alaska arctic tundra in response to climatic change. In: *International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol.* 2. Fairbanks, University of Alaska, pp. 372-377.

LU, G. (1988) *Pinus hingganensis* and permafrost environment in the Mt. Dahinganling, Northeast China. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 205-207.

LU, G., WANG, B. AND GUO, D. (1993) The geographic southern boundary of permafrost in the northeast of China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1186-1189.

LUNARDINAI, V.J. AND BOWEN, S.L., EDS. (1993) *Fourth International Symposium on Thermal Engineering and Science for Cold Regions, Proceedings.* U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, Special Report 93-22, 364 pp.

MACDONALD, G.J. (1990) Role of methane clathrates in past and future climates. *Climatic Change*, 16, pp. 247-291.

MACDONALD, G.M., AND GAJEWSKI, K. (1992) Ecology and palaeocology of the northern treeline. In: *Arctic Environment: Past, Present and Future.* Hamilton, Ontario, McMaster University, pp. 113-120.

MACKAY, J.R. (1988) Pingo collapse and paleoclimatic reconstruction. *Canadian Journal of Earth Sciences*, 25(4), pp. 495-511.

MACKAY, J.R. (1992) Frequency of ice-wedge cracking (1967-1987) at Garry Island, western Arctic coast, Canada. *Canadian Journal of Earth Sciences*, 29(2), pp. 236-248.

MACKAY, J.R. AND DALLIMORE, S.R. (1992) Massive ice of the Tuktoyaktuk area, western Arctic coast, Canada. *Canadian Journal of Earth Sciences*, 29(6), pp. 1235-1249.

MARION, G.M. AND OECHEL, W.C. (1993) Mid- to late-Holocene carbon balance in Arctic Alaska and its implications for future global warming. *The Holocene*, 3, pp. 193-200.

MARTIN, H.E., WHALLEY, W.B. AND CASELDINE, C. (1991) Glacier fluctuations and rock glaciers in Tröllaskagi, Northern Iceland, with special reference to 1946-1986. In:

Maizels, J.K. and C. Caseldine, eds. *Environmental Change in Iceland: Past and Present*. Dordrecht, Netherlands, Kluwer Academic Publishers, pp. 255-265.

MAXWELL, J.B. (1992) Arctic climate: potential for change under global warming. Arctic ecosystems in a changing climate; an ecophysiological perspective. In: Chapin, F.S. III, R.L. Jefferies, J.F. Reynolds, G.R. Shaver and J. Svoboda, eds. *Arctic Ecosystems in a Changing Climate: an Ecophysiological Perspective*. San Diego, Academic Press, pp. 11-34.

MAXWELL, J.B. AND BARRIE, L.A. (1989) Atmospheric and climatic change in the Arctic and Antarctic. *Ambio*, 1, pp. 42-49.

MCCULLOCH, J.A.W., ED. (1990) *Arctic and Global Change: Proceedings of the Symposium*. Washington, D C., Climate Institute, 156 pp.

MEIER, M.F. (1990) Ice and snow and global change. In: *Symposium on Global Change Systems. (Anaheim, CA, February 5-9, 1990)*. Boston, MA, American Meteorological Society, 45 pp.

MEL'NIKOV, P.I. AND STREET, R.B. (1992) Terrestrial component of the cryosphere. In: Tegart, W.J.M. and G.W. Sheldon, eds. *Climate Change 1992: the Supplementary Report to the IPCC Impacts Assessment*. Canberra, Australian Government Publishing Service, pp. 94-102.

MIGALA, K. (1993) Role of climate on active layer variations, Svalbard. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1*. Wushan, China, South China University of Technology Press, pp. 919-922.

MONSERUD, R.A., TCHEBAKOVA, N.M. AND LEEMANS, R. (1993) Global vegetation change predicted by the modified Budyko model. *Climatic Change*, 25(1), pp. 59-83.

MOORE, J.P., ET AL. (1993) *International Correlation Meeting on Permafrost Affected Soils: Guidebook - Alaska Portion, July 1993*. Lincoln, NE, USDA Soil Conservation Service, 152 pp.

MOORE, T.R. (1990) Gas exchanges between peatlands and the atmosphere. *Canadian Geographer*, 34, pp. 86-87.

MOORE, T.R. (1990) Spatial and temporal variations of methane flux from subarctic/northern boreal fens. *Global Biogeochemical Cycles*, 4(1), pp. 20-46.

MOORE, T.R. AND KNOWLES, R. (1990) Methane and carbon dioxide evolution from subarctic fens. *Canadian Journal of Soil Science*, 67, pp. 77-81.

MORAES, F. AND KHALIL, M.A.K. (1993) Permafrost methane content: 2. Modeling theory and results. *Chemosphere*, 26(1-4), pp. 595-608.

MORRISSEY, L.A. (1988) Predicting the occurrence of permafrost in the Alaskan discontinuous zone with satellite data. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings*, Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 213-217.

MORRISSEY, L.A. AND LIVINGSTON, G.P. (1992) Methane emissions from Alaska Arctic tundra: an assessment of local spatial variability. *Journal of Geophysical Research*, 97(D15), pp. 16,661-16,670.

NAKAWO, M. (1990) On the role of cryosphere in the global climate/environment. *Seppyo*, 52(3), pp. 185-194. (In Japanese.)

NAKAYAMA, T., SONE, T. AND FUKUDA, M. (1993) Effects of climatic warming on the active layer. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, Guangzhou, China, South China University of Technology Press, pp. 488-493.

NEKRASOV, I.A. (1991) *Vechnaya li Vechnaya Merzlota?* (Is permafrost permanent?) Moscow Nedra, 128 pp.

NELSON, F.E. (1989) Permafrost in eastern Canada: a review of published maps. *Physical Geography*, 10(3), pp. 233-248.

NELSON, F.E. AND ANISIMOV, O.A. (1993). Permafrost zonation in Russia under anthropogenic climatic change. *Permafrost and Periglacial Processes*, 4(2), pp. 137-148.

NELSON, F.E., HINKEL, K.M. AND OUTCALT, S.I. (1992) Palsa-scale frost mounds. In: Dixon, J.C. and A.D. Abrahams, eds. *Periglacial Geomorphology*. Chichester, J. Wiley, pp. 25-30.

NELSON, F.E., LACHENBRUCH, A.H., WOO, M.-K., KOSTER, E.A., OSTERKAMP, T.E. AND GAVRILOVA, M.K. (1993) Permafrost and changing climate. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 987-1005.

NYBERG, R. (1993). Freeze-thaw activity and some of its geomorphic implications in the Abisko Mountains, Swedish Lappland. *Permafrost and Periglacial Processes*, 4(1), pp. 37-47.

NYBERG, R. AND LINDH, L. (1990) Geomorphic features as indicators of climatic fluctuations in a periglacial environment, northern Sweden. *Geografiska Annaler*, 72A(2), pp. 203-210.

OECHEL, W.C. AND BILLINGS, W.D. (1992) Effects of global change on the carbon balance of Arctic plants and ecosystems. In: Chapin, F.S., III, R.L. Jefferies, J.F. Reynolds, G.R. Shaver and J. Svoboda, eds. *Arctic Ecosystems in a Changing Climate: an Ecophysiological Perspective*. San Diego, Academic Press, pp. 139-168.

OECHEL, W.C., HASTINGS, S.J., VOURLITIS, G., JENKINS, M., RIECHERS, G. AND GRULKE, N. (1993) Recent change of Arctic tundra ecosystems from a net carbon sink to a source. *Nature*, 361, pp. 520-523.

OECHEL, W.C. AND HOLTEN, J.I. (1993) *Global Change and Arctic Terrestrial Ecosystems: an International Conference* (Oppdal, Norway, 21-26 August 1993), *Recommendations*. Trondheim, Norway, Norwegian Institute for Nature Research, 53 pp.

OMMANNEY, C.S.L. (1992) Canadian frozen ground and ice properties references (1991-1992) and recent work. *National Hydrology Research Institute, NHRI Contribution* 92036, 47 pp.

OSTERKAMP, T.E. (1989) Occurrence and potential importance of saline permafrost in Alaska. In: *Proceedings of the Workshop on Saline Permafrost*, Winnipeg, Manitoba.

OSTERKAMP, T.E. (1993) Field investigation of water and salt movement in permafrost and the active layer. Final report. Fairbanks, University of Alaska, Geophysical Institute.

OSTERKAMP, T.E. AND FEI, T. (1993) Potential occurrence of permafrost and gas hydrates in the continental shelf near Lonely, Alaska. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 500-505.

OSTERKAMP, T.E. AND GOSINK, J.P. (1991) Variations in permafrost thickness in response to changes in paleoclimate. *Journal of Geophysical Research*, 96(B3), pp. 4423-4434.

OSTERKAMP, T.E., GOSINK, J.P., FEI, T., AND ZHANG, T. (1991) Response of permafrost to changes in paleoclimate. In: *International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol.* 2. Fairbanks, University of Alaska, pp. 505-507.

PAIN, S. (1988) No escape from the global greenhouse. *New Scientist*, 120(1638), pp. 38-43.

PAN, A. (1993) The paleoclimate characteristics in Xinjiang since the late Pleistocene. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V.* 2. Wushan, China, South China University of Technology Press, pp. 1202-1207.

PAVLOV, A.V. (1993) Evolution of soil and ground thermal state in permafrost in connection with contemporary global changes of climate. In: Gilichinskii, D.A., ed. *Joint Russian-American Seminar on Cryopedology and Global Change (Pushchino, 15-16 November 1992), Post-Seminar Proceedings*. Russian Academy of Sciences, pp. 170-178.

PEARCE, F. (1989) Methane: the hidden greenhouse gas. *New Scientist*, 1663, pp. 37-41.

PEDDLE, D.R. (1990) Remote Sensing of Arctic Permafrost. Calgary, Alberta, M.A. Thesis, University of Calgary.

RAMOS, M. (1993) Preliminary data for permafrost thermal regime and its correlation: meteorological parameters near the Spanish Antarctic Station. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V.* 2. Wushan, China, South China University of Technology Press, pp. 1211-1214.

RAPP, A. AND NYBERG, R. (1988) Mass movements, nivation processes and climatic fluctuations in northern Scandinavian mountains. *Norsk geografisk tidsskrift*, 42(4), pp. 245-253.

RASMUSSEN, R.A., KHALIL, M.A. AND MORAES, F. (1993). Permafrost methane content: 1. Experimental data from sites in northern Alaska. *Chemosphere*, 26(1-4), pp. 591-594.

RISEBOROUGH, D.W. AND SMITH, M.W. (1993) Modeling permafrost response to climate change and climate variability. In: Lunardinai, V.J. and S.L. Bowen, eds. *Fourth International Symposium on Thermal Engineering and Science for Cold Regions, Proceedings.* U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, Special Report 93-22, pp. 179-187.

RIVKINA, E.M., SAMARKIN, V.A. AND GILICHINSKII, D.A. (1992) Metan v mnogoletnemerzlykh porodakh Kolymo-Indigirskoi nizmennosti. (Methane in permafrost sediments on the Kolyma-Indigirka lowland.) *Akademiia nauk SSSR. Doklady*, 323(3), pp. 559-562.

ROMANOVSKII, V.E., GARAGULIA, L.S. AND SEREGINA, N.V. (1991) Freezing and thawing of soils under the influence of 300- and 90-year periods of temperature fluctuation.. In:

International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol. 2. Fairbanks, University of Alaska, pp. 543-548.

ROMANOVSKII, V.E., MAKSIMOVA, L.N. AND SEREGINA, N.V. (1991) Paleotemperature reconstruction for freeze-thaw processes during the late Pleistocene through the Holocene. In: *International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol.* 2. Fairbanks, University of Alaska, pp. 537-542.

ROTHMAN, D.S. AND CHAPMAN, D. (1993) A critical analysis of climate change policy research. *Contemporary Policy Issues*, 11(1), pp. 88-98.

ROUSE, W.R., CARLSON, D.W. AND WEICK, E.J. (1992) Impacts of summer warming on the energy and water balance of wetland tundra. *Climatic Change*, 22(4), pp. 305-326.

SAND, K., HAGEN, J.O., REPP, K. AND BERNTSEN, E. (1990) Climate related research in Svalbard. In: Gjessing, Y. et al., eds. *Arctic Hydrology: Present and Future Tasks, (Longyearbyen, Svalbard, September 14-17, 1990), Proceedings.* Norwegian National Committee for Hydrology. Report No. 23, pp. 203-217.

SAND, K., HAGEN, J.O., REPP, K. AND BERNTSEN, E. (1991) Climate-related research in Svalbard. In: *International Conference on the Role of the Polar Regions in Global Change, (Fairbanks, AK, June 11-15 1990) Proceedings, Vol.* 2. Fairbanks, University of Alaska, pp. 525-531.

SCHMIDLIN, T.W. (1988) Alpine permafrost in eastern North America: a review. In: *Fifth International Conference on Permafrost (Trondheim, Norway, 2-5 August, 1988), Proceedings,* Vol. 1. Trondheim, Norway, Tapir Publishing, pp. 241-246.

SCHMITT, E. (1993) Global climatic change and some possible geomorphological and ecological effects in Arctic permafrost environments, Isfjorden and Liefdefjorden, northern Spitsbergen. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 544-549.

SCHOONMAKER, D. (1993) What makes permafrost permanent? *American Scientist*, 81(6), pp. 527-528.

SCHROTT, L. (1991) Global solar radiation, soil temperature and permafrost in the Central Andes, Argentina: a progress report. *Permafrost and Periglacial Processes*, 2(1), pp. 59-66.

SÉGUIN, M.K. AND DIONNE, J.-C. (1992) Modélisation géophysique et caractérisation thermique du pergélisol dans les palses de Blanc-Sablon, Québec. (Geophysical modeling and thermal properties of permafrost in palsas from Blanc Sablon, Québec.) *Geological Survey of Canada. Paper* 92-1E, pp. 207-216.

SHARKHUU, A. (1993) Permafrost in the Selenge River basin (on the Mongolian Territory). In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1223-1226.

SHAVER, G.R., BILLINGS, W.D., CHAPIN, F.S., III, GIBLIN, A.E., NADELHOFFER, K.J., OECHEL, W.C. AND RASTETTER, E.B. (1992) Global change and the carbon balance of Arctic ecosystems. *Bioscience*, 42, pp. 433-441.

SHI, Y. AND MI, D., EDS. (1988) Map of snow, ice and frozen ground in China. *Lanzhou*

Institute of Glaciology and Geocryology, Chinese Academy of Sciences. Scale 1:4,000,000.

SIGUNOV, I.A. AND FARTYSHEV, A.I. (1992) Investigation of evolution of the Arctic shelf cryolithozone by mathematical simulation. *Soviet Geology and Geophysics*, 32(8), pp. 13-19.

SLAUGHTER, C.W. AND HARTZMANN, R.J. (1993) Hydrologic and water quality characteristics of a degrading open-system pingo. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 574-579.

SLAUGHTER, C.W. (1993) Global warming considerations in northern boreal forest ecosystems, In: Wall, G., ed. *Impacts of Climate Change on Resource Management in the North, A Combined Fourth Canada-United States Symposium and Biennial AES/DIAND Meeting on Northern Climate*. Canadian Climate Centre, Environment Canada, *University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No. 16, , pp. 81-90.

SLAYMAKER, O. (1990) Climate change and erosion processes in mountain regions of western Canada. *Mountain Research and Development*, 10(2), pp. 171-182.

SMITH, M. (1990) Potential responses of permafrost to climatic change. *Journal of Cold Regions Engineering*, 4(1), pp. 29-37.

SMITH, M.W. (1990) The significance of climatic change for the permafrost environment. *Northern Engineer*, 22(1), pp. 21-26.

SONE, T. AND TAKAHASHI, N. (1993) Palsa formation in the Daisetsu Mountains, Japan. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1231-1234.

SPIVEY, D.B. (1990) Climate Change and Permafrost in the South Mackenzie Valley: A Methodological Approach. M.A. Thesis, Ottawa, Carleton University, Geotechnical Science Laboratories, 113 pp.

STARKEL, L. (1988) Global paleohydrology. *Polish Academy of Sciences. Bulletin. Earth Sciences*, 36(1), pp. 71-89.

TARNOCAI, C., ET AL. (1993) *International Tour of Permafrost Affected Soils: The Yukon and Northwest Territories of Canada.* Agriculture Canada, Ottawa, Canada. Center for Land and Biological Resources Research, Research Branch, , 197 pp.

TAYLOR, A. (1988) Deep ground temperatures in the Canadian Arctic archipelago: insight into paleogeography and paleoclimate in a permafrost environment. *EOS. Transactions, American Geophysical Union*, 69(44), p. 1210.

TEGART, W.J.M. AND SHELDON, G.W., EDS. (1992) *Climate Change 1992: The Supplementary Report to the IPCC Impacts Assessment.* Canberra, Australian Government Publishing Service.

THOMAS, G. AND ROWNTREE, P.R. (1992) The boreal forests and climate. *Quarterly Journal of the Royal Meteorological Society*, 118B(505), pp. 469-497.

TIMONEY, K.P., LA ROI, G.H., ZOLTAI, S.C. AND ROBINSON, A.L. (1992) The high subarctic forest-tundra of northwestern Canada: position, width, and vegetation gradients in relation to climate. *Arctic*, 45(1), pp. 1-9.

TORN, M.S. AND CHAPIN, F.S., III (1993) Environmental and biotic controls over methane flux from Arctic tundra. *Chemosphere*, 26(1-4), pp. 357-368.

TROMOBOTTO, D. AND STEIN, B. (1993) The latest Pleistocene cryomere in the region of "Kopjes" and the Big Mesetas, Patagonia, Argentina. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1238-1241.

TSAREV, W.P. AND POVILEIKO, R.P. (1990) Sever pered katastrofoi? Ekologicheskie posledstviia ozhidaemogo potepleniia. (Is the North facing a catastrophe? Ecological consequences of the expected warming.) *Stroitel'stvo truboprovodov*, No., pp. 15-19.

TUMURBAATER, D. (1993) Seasonal freezing and thawing grounds of Mongolia. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1242-1246.

ULRICH, R. AND KING, L. (1993) Influence of mountain permafrost on construction in the Zugspitze Mountains, Bavarian Alps, Germany. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 625-630.

VAIKMÏAE, R.A. (1991) Paleoenvironmental data from less-investigated polar regions. In: Weller, G., C.L. Wilson and B.A.B. Severin, eds. *Proceeding. International Conference on the Role of the Polar Regions in Global Change, Vol. II.* Fairbanks, University of Alaska, Geophysical Institute, pp. 611-616.

VANDENBERGHE, J. (1992) Introduction: Periglacial environments in relation to climatic evolution. *Permafrost and Periglacial Processes*, 3(4), 325 pp.

VANDENBERGHE, J. (1992) Periglacial phenomena and Pleistocene environmental conditions in the Netherlands: an overview. *Permafrost and Periglacial Processes*, 3(4), pp 363-374.

VANDENBERGHE, J. AND PISSART, A. (1993). Permafrost changes in Europe during the last glacial. *Permafrost and Periglacial Processes*, 4(2), pp. 121-135.

VASIL'CHUK, Y.K. (1993) Northern Asia cryolithozone evolution in late Quaternary. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 945-950.

VELICHKO, A.A. AND NECHAYEV, V.P. (1992) K otsenke dinamiki zony mnogoletnei merzloty v Severnoi Evrazii pri global'nom poteplenii klimata. (Estimating permafrost zone dynamics in northern Eurasia under global climatic warming.) *Akademiia Nauk. Doklady*, 324(3), pp. 667-671.

VINSON, T.S. AND HAYLEY, D.W. (1990) Editorial. Executive summary of the Workshop on Climate Change and Permafrost: Significance to Science and Engineering . *Journal of Cold Regions Engineering*, 4(1), pp. iv.

VLIET-LANOË, B.V. (1991) Les changements climatiques et leurs conséquences sur le milieu lors du dernier glaciaire dans le Massif Central. (Climatic changes and their environmental consequences during the last glaciation in the Massif Central.) *Association de Géographes Français. Bulletin*, 68(1), pp. 11-21.

VOURLITIS, G.L., OECHEL, W.C., HASTINGS, S.J. AND JENKINS, M.A. (1993) The effect of soil moisture and thaw depth on CH_4 flux from wet coastal tundra ecosystems on the North Slope of Alaska. *Chemosphere*, 26(1-4), pp. 329-337.

VTIURIN, B.I. (1989) Podzemnye l'dy Shpitsbergena. (Ground ice of Spitsbergen.) *Akademiia nauk SSSR. Institut Geografii. Materialy Gliatsiologicheskikh Issledovanii. Khronika obsuzhdeniia*, No.65, pp. 69-75. (In Russian with English summary).

VYALOV, S.S., GERASIMOV, A.S., ZOLOTAR, A.J. AND FOTIEV, S.M. (1993) Ensuring structural stability and durability in permafrost ground areas at global warming of the earth's climate. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 955-960.

WAELBROECK, C. (1993). Climate-soil processes in the presence of permafrost: a systems modeling approach. *Ecological Modelling*, 69(3-4), 185 pp.

WALKER, H.J. (1993) Lakes and permafrost in the Colville River Delta, Alaska. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1345.

WALL, G., ED. (1993) *Impacts of Climate Change on Resource Management in the North, A Combined Fourth Canada-United States Symposium and Biennial AES/DIAND Meeting on Northern Climate, (Whitehorse, Canada, 12-14 May, 1992), University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No. 16, , 253 pp.

WALSH, J.E. (1993) The elusive Arctic warming. *Nature*, 361(6419), pp. 300-301.

WALTERS, J.C. (1993) Sorted circle dynamics: 10 years of field observations from central Alaska. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1346.

WANG B. AND FRENCH, H.M. (1991) Soil wedge and ice-wedge pseudomorphs and their palaeoclimatic implications. *Journal of Glaciology and Geocryology*, 13(1), pp. 66-75.

WANG, B. (1993) A numerical simulation of coastal retreat and permafrost conditions, Mackenzie Delta Region, Canada. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 664-669.

WANG, B.L. (1992) Coastal retreat and permafrost thermal regimes, western Canadian Arctic. *Journal of Glaciology and Geocryology*, 14(1), pp. 55-62. (In Chinese with English summary.)

WANG, S.L. (1989) Formation and evolution of permafrost on the Qinghai-Xizang Plateau since the late Pleistocene. *Journal of Glaciology and Geocryology*, 11(1), pp. 69-75. (In Chinese with English summary.)

WANG, X.C. AND GEURTS, M.A. (1991) Post-glacial vegetation history of the Ittlemit Lake basin, southwest Yukon Territory. *Arctic*, 44(1), pp. 23-30.

WEIN, R.W. AND HOGG, E.H. (1990) Climate change moisture stresses on northern coniferous forests. *University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No., pp. 285-289.

WELLER, G. (1990) Role of the polar regions in global change. In: Louro, A., M.A. VanZele, and I. Velasco, eds. *First Latin American Conference on Antarctic Geophysics, Geodesy and Space Research, (Buenos Aires, July 30-*

Aug. 3, 1990) Proceedings. Buenos Aires, Centro Latinoamericano de Física, pp. 114-129.

WELLER, G. (1993) Global change and its implications for Alaska. In: *Impacts of Climate Change on Resource Management in the North, A Combined Fourth Canada-United States Symposium and Biennial AES/DIAND Meeting on Northern Climate*. Wall, G., ed. Canadian Climate Centre, Environment Canada, *University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No. 16, , pp 17-22.

WELLER, G., WILSON, C.L. AND SEVERIN, B.A.B., EDS. (1991) *International Conference on the Role of the Polar Regions in Global Change, Proceedings, (Fairbanks, Alaska, 11-15 June 1990), 2 Volumes.* Fairbanks, University of Alaska, Geophysical Institute, 778 pp.

WHALEN, S.C. AND REEBURGH, W.S. (1988) A methane flux time series for tundra environments. *Global Biogeochemical Cycles*, 2, pp. 399-410.

WHALLEY, W.B. (1992) Living with permafrost. *Geographical Magazine*, 64(10), pp. 45-49.

WIJEWEERA, H. AND JOSHI, R.C. (1992) Temperature-independent relationships for frozen soil. *Journal of Cold Regions Engineering*, 6(1), pp. 1-21.

WILLIAMS, P.J. (1990) Permafrost and other frozen ground. *Endeavour*, 14(3), pp. 117-123.

WOO, M.-K. (1990) Consequences of climatic change for hydrology in permafrost zones. *Journal of Cold Regions Engineering*, 4(1), pp. 15-20.

WOO, M.-K. (1992) Impacts of climatic variability and change on Canadian wetlands. *Canadian Water Resources Journal*, 17, pp. 63-69.

WOO, M.-K. AND WINTER, T.C. (1993) The role of permafrost and seasonal frost in the hydrology of northern wetlands in North America. *Journal of Hydrology*. 141(1-4), pp. 5-31.

WOO, M.-K., LEWKOWICZ, A.G. AND ROUSE, W.R. (1992) Response of the Canadian permafrost environment to climatic change. *Physical Geography*, 13(4), pp. 287-317.

WOO, M.-K., ROUSE, W.R., LEWKOWICZ, A.G. AND YOUNG, K.L. (1993) Adaptation to permafrost in the Canadian north: present and future. In: Wall, G., ed. *Impacts of Climate Change on Resource Management in the North, A Combined Fourth Canada-United States Symposium and Biennial AES/DIAND Meeting on Northern Climate*. Canadian Climate Centre, Environment Canada, *University of Waterloo, Department of Geography, Publication Series. Occasional Paper* No. 16, , pp. 51-54.

YARIE, J. AND VAN CLEVE, K. (1991) Changes in the source/sink relationships of the Alaskan boreal forest as a result of climatic warming. In: Weller, G., C.L. Wilson and B.A.B. Severin, eds. *International Conference on the Role of the Polar Regions in Global Change, Proceedings, (Fairbanks, Alaska, 11-15 June 1990), Vol. II.* Fairbanks, University of Alaska, Geophysical Institute, pp. 436-439.

ZENG, Z., SÉGUIN, M.K. AND HUANG, Y. (1992) Delineation of the high ice-content permafrost table along the Qinghai-Xizang (Tibet) highway. *EOS. Transactions, American Geophysical Union*, 73(14), pp. 120.

ZHANG, T. AND OSTERKAMP, T.E. (1993) Changing climate and permafrost temperatures in the Alaskan Arctic. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 783-788.

ZHANG, Q., ZHOU, Y., WANG, J., LIANG, L. AND GU, Z. (1993) Plant community ordination and its environmental interpretation following the disastrous fire in Amur area, Da Xingganling Prefecture, Northeastern China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 778-782.

ZHAO, L., QIU, G. AND JIN, H. (1993) Climate fluctuation and the process of permafrost formation since last glaciation in the source area of Urumqi River, Tianshan, China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 803-808.

ZHAO, X., GUO, D. AND HUANG, Y. (1993) The loess and its climate records in Kunlun Shan region since the late Pleistocene. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 1.* Wushan, China, South China University of Technology Press, pp. 809-812.

ZHOU, Z. (1993) Fossil periglacial landforms in the Shennongjia Mountains, China. In: *Sixth International Conference on Permafrost (Beijing, China, 5-9 July 1993), Proceedings, V. 2.* Wushan, China, South China University of Technology Press, pp. 1334-1337.

ZIMOV, S.A., ZIMOVA, G.M., DAVIODOV, S.P., DAVIODOVA, A.I., VOROPAEV, Y.V., VOROPAEVA, Z.V., PROSIANNIKOV, S.F., PROSIANNIKOVA, O.V., SEMILETOVA, I.V. AND SEMILETOV, I.P. (1993). Winter biotic activity and production of CO_2 in Siberian soils: a factor in the greenhouse effect. *Journal of Geophysical Research*, 98(D3), pp. 5017-5023.

ZIMOV, S.A., SEMILETOV, I.P., DAVIODOV, S.P., VOROPAEV, Y.V., PROSIANNIKOV, S.F., WONG, C.S. AND CHAN, Y.-H. (1993) Wintertime CO_2 emission from soils of Northeastern Siberia. *Arctic*, 46, pp. 197-204.

ZOLTAI, S.C. AND VITT, D.H. (1990) Holocene climatic change and the distribution of peatlands in western interior Canada. *Quaternary Research*, 33(2), pp. 231-240.

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*U.S. GOVERNMENT PRINTING OFFICE:1994-573-013/00027