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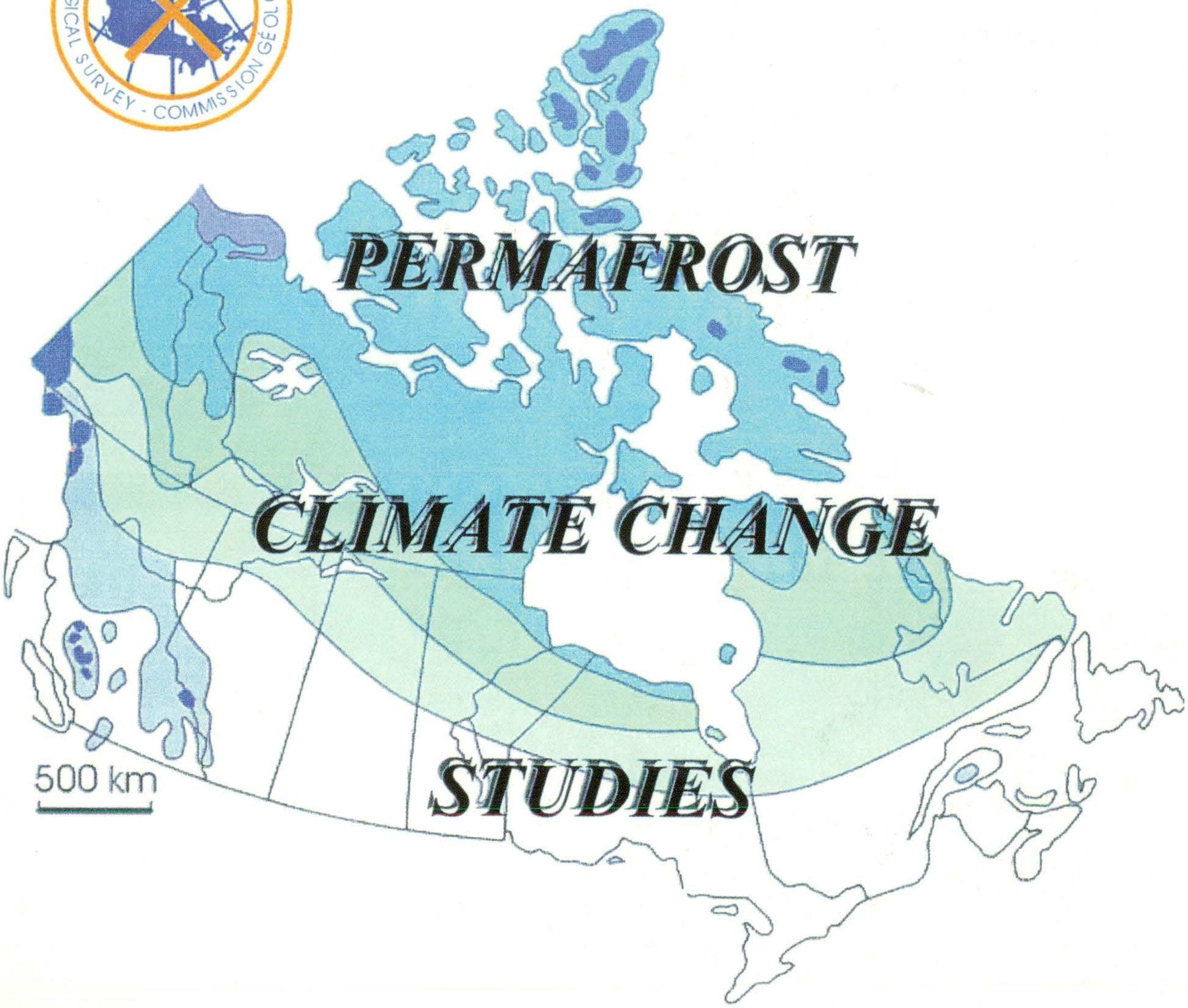
PERMAFROST CLIMATE CHANGE STUDIES



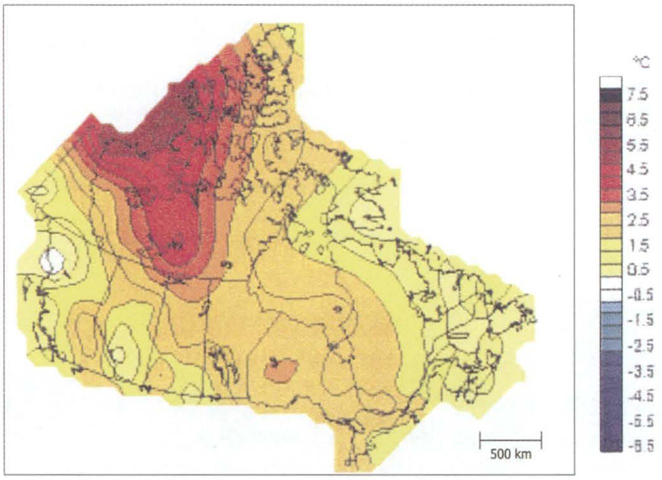
Canada

PERMAFROST CLIMATE CHANGE STUDIES

INTRODUCTION

Summary

The following document is a review of ongoing and newly proposed permafrost climate change studies directed by the Geological Survey of Canada (GSC). These studies represent the primary research areas undertaken by the GSC within the context of permafrost and climate change, and are summarized within four main research themes: **Physical Processes**, **Thermal Regimes**, **Carbon Sources and Sinks**, and **New Initiatives**. Many of the field investigations are located in the Mackenzie Valley and Delta. Historically, this area has experienced the greatest increase in air temperatures in Canada during the last century.



Temperature departures from normal anomalies
Annual (Jan – Dec) 1998

The Issue

Current General Circulation Models predict substantial warming in the high latitudes of North America as a consequence of increased atmospheric concentrations of anthropogenic greenhouse gases. Historical temperature trends show a warming of nearly 2°C during the last century in the western Canadian Arctic. In addition, extreme conditions such as the El Niño year of 1998 resulted in mean annual temperatures 5°C warmer than the average conditions. These data indicate that future warming in the western Canadian Arctic may be greater than other parts of Canada. This warming is expected to have a significant impact on the stability of permafrost. Therefore, it is essential to develop a sound understanding of the impact of climate change in permafrost regions and to provide this knowledge to decision-makers considering adaptations to climate change in the North.

Our Goal

To provide geoscientific knowledge of permafrost in Canada regarding the impacts of climate change. Specifically, to understand the role of the cryosphere in the global climate system and, conversely, the effects of climate change on permafrost processes, in order to: 1) detect the climate change signal in the cryosphere, 2) improve the formulation and evaluation of climate change impacts, and 3) facilitate the development of appropriate adaptation measures.

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Web sites:
To discover more about permafrost research at the GSC, please browse our web site at:
http://sts.gsc.nrcan.gc.ca/permafrost
For more information about climate change, visit the Government of Canada's climate change web site at:
http://climatechange.gc.ca/

Some of this research was funded in part by the Government of Canada's Climate Change Action Fund

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Geological Survey of Canada

PERMAFROST CLIMATE CHANGE STUDIES

1. PHYSICAL PROCESSES

A comprehensive understanding of regional geology and geomorphic processes is required in order to assess the impact of climate warming in northern Canada. This includes a knowledge of ground ice conditions, slope and coastal processes, and the role of disturbances such as fire. This also includes an understanding of how climate has shaped these conditions and processes in the past.

Ground ice studies

S.R. Dallimore, S.A. Wolfe

The occurrence of ground ice within permafrost soils is perhaps the single most important feature controlling ongoing geomorphic processes and the sensitivity of permafrost terrain to climate change. Transportation and development projects require a knowledge of the occurrence of massive ice, as it may represent potentially hazardous terrain conditions. In addition, engineering designs may require alternative approaches under warmer ground thermal conditions to maintain terrain stability. Field research by the GSC includes mapping the distribution of ground ice, assessment of the origin of thick, tabular, massive ground ice bodies, and studies of active geomorphic processes associated with ground ice formation and degradation. In addition, studies on wedge ice and pingo ice assist in determining Holocene climate history and change. Laboratory techniques include ice crystallography, stable isotope chemistry, and gas, ion and pollen analyses. These studies aid in determining the impacts of climate warming within ice-rich permafrost terrain.

Deformed massive ground ice at Nicholson Point, Tuktoyaktuk Coastlands. N.W.T.

2. THERMAL REGIME

Baseline knowledge of the past, present, and future ground thermal conditions in permafrost environments is critical for a sound understanding of the impact of climate change and for making realistic decisions regarding adaptations to climate change. Central to this understanding is a knowledge of changing active layer conditions, the thermal state of permafrost itself, and the ability to model and map existing conditions and potential changes.

Regional active-layer monitoring

F.M. Nixon, J.F. Wright

Thaw depth and active layer temperature monitoring in the Mackenzie Delta, N.W.T.

An extensive monitoring program in the Mackenzie Valley and Delta has been established to investigate the impacts of regional climate change upon the characteristics of permafrost and the active (thaw) layer. Annual maximum thaw penetration and surface movement are measured relative to thaw tubes anchored in permafrost. More than half of the sites are instrumented with automatic air and ground temperature recorders. Many sites, particularly in the Delta, include ground temperature cables extending 5 to 30 m into permafrost. Active layer probing grids have been established at a number of locations designated as CALM (Circumpolar Active Layer Monitoring) network sites, an initiative of the International Permafrost Association (IPA). Ground temperature data and information about the active layer are submitted annually to IPA's Global Geocryological Database. Additional linkages have been established with Agriculture Canada's Soil Climate Program, the National Hydrology Research Centre's Small Basin Study, and the University of British Columbia and Carleton University Drained Lake Experiment. In recent years, the Aurora Research Institute of Aurora College, N.W.T. has also increased its involvement in the GSC monitoring program in the Mackenzie Delta region.

3. CARBON SOURCES AND SINKS

Changes in the efficacy of natural carbon sources and sinks are an important source of uncertainty in determining future trends in atmospheric CO_2 concentrations and, ultimately, in climate change trends. The issue is made particularly complex because of the feedback mechanisms between the atmospheric CO_2 concentrations, climate change, and the natural carbon sources and sinks. Warming of permafrost could have two significant impacts; it could alter carbon sources and sinks in organic terrain, and it could result in the release of additional carbon, which is currently stored as methane in gas hydrates. Further knowledge of these issues is essential to understanding future climate change trends and impacts.

Organic terrain

S. Robinson, I. Kettles

A northern plateau bog surrounded by string bog, southern Mackenzie Valley, N.W.T.

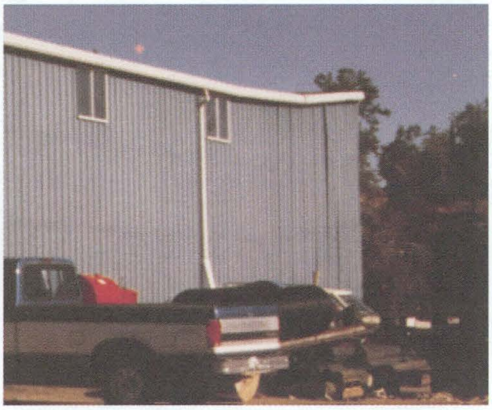
The terrestrial biosphere represents an important natural carbon sink of atmospheric CO_2. However, climate change may alter the behaviour of these natural sinks, to either enhance or reduce the efficiency, and therefore further affect the fate of greenhouses gases emitted from anthropogenic sources. The melting of permafrost associated with climate warming has the potential to drastically alter carbon sources and sinks in organic terrain. Recent results from the Fort Simpson area have suggested that carbon storage may double following permafrost thaw. In contrast, however, the increased frequency of forest and tundra fires may produce significant fluxes of carbon and particulate matter which may increase greenhouse gases. Field research in the Mackenzie River valley includes studies of peatland carbon storage and fluxes in relation to permafrost thaw, and an assessment of the role of fire in peatland dynamics.

4. RECENT INITATIVES

The study of climate change remains the study of uncertainties, and new initiatives are required within the issues of adaptation, monitoring, and impacts if we are expected to address these uncertainties. Such initiatives should address the need for adaptation measures to be based on realistic evaluations of the impacts of climate change and on the actual vulnerability to these changes. They should also address innovative techniques for conducting regional-scale monitoring of present-day processes. Where fundamental knowledge gaps still exist, they should also provide evaluations of the rates and controls of climate-influenced processes and should document the sensitivity to future climatic change based on ground-level research.

Community infrastructure impacts

S. Robinson, M.M. Burgess, R. Couture,



Damage to buildings can be caused by uplift of piles due to frost-jacking.

As much of the infrastructure in northern communities relies on the properties of frozen materials for stability, warming of the ground due to climate change could degrade the performance of many existing and future structures including roads, foundations, utilities, and embankments. Therefore, it is essential to evaluate the permafrost-affected infrastructure and assess the potential for climate change impacts in Arctic communities. This study is examining existing information concerning permafrost and surficial geology, conducting a geotechnical survey of construction types, foundations, and performance history, and will focus on a generic review of potential infrastructure issues related to permafrost thaw and a framework for adaptation strategies. Field work includes geophysical surveys such as ground penetrating radar, borehole sampling and instrumentation, and community consultation. Additional techniques include ground thermal modelling and analysis of soil geotechnical properties. Final reports are aimed at community-level decision-makers and other stakeholders, as well as non-technical documentation for public education.

Surficial landscape processes

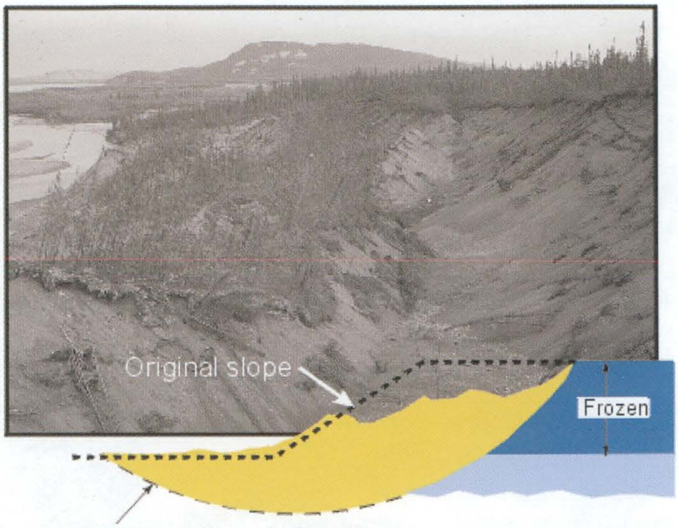
S.A Wolfe, S.R. Dallimore, F.M. Nixon

Retrogressive thaw flow slide caused by thawing of ice-rich sediments along the Yukon North slope.

Recent General Circulation Models (GCMs) consistently indicate that much of the northern Mackenzie Valley and Arctic Coastal Plain are likely to experience climate warming of a magnitude equal to or greater than any documented during the Holocene period. The area is also influenced by a wide range of active geomorphic processes which are highly sensitive to climate forcings, but where the relationships are still not well understood. Therefore, a systematic evaluation of landscape stability in the context of climate change is necessary in order to assess the biophysical and socioeconomic impacts in this region. The focus of this evaluation includes rates and controls of geomorphic processes such as mass wasting (thermokarst/thaw slides and active-layer detachments), lake basin development, and eolian processes. Future field work will include an assessment of past landscape evolution during the Holocene and documenting the sensitivity of the landscape to future climatic change. Techniques including conventional Quaternary methodologies, modelling, and laboratory analyses are required in order to undertake high resolution climate change assessments. These approaches are required in order to fill the significant knowledge gaps that still exist in our understanding of the potential climate change impacts that could occur within this region.

Landslides and stability of permafrost slopes in a warming climate

L.D. Dyke



Circular failure surface defined by head scarp and toe

Landslides and flows in ice-rich terrain are common in the Mackenzie Valley and are one of the most rapid and potentially destructive landscape-altering processes in permafrost regions. The sensitivity of such processes to climate warming must be determined if infrastructure adaptations are to be made in advance of projected climate changes. Examining the relationship between past slope failures and climate records aids in determining whether future climate warming will induce slope failures in permafrost. Forest fires are a major slope destabilizing mechanism in ice-rich terrain and may be a primary trigger for slides in the Mackenzie Valley. Fire-induced slides can subsequently contribute choking amounts of sediment to fish habitats. Analysis of lake bottom sedimentation records in watersheds affected by fires helps to establish the importance of this process. In addition, improved geotechnical analyses of slopes are required to provide for more accurate stability calculations. This includes a more realistic representation of thawing ice fabric in thaw-consolidation theory and more accurate measures of frozen ground mechanical properties for estimating the stability of high river banks subject to toe erosion.

Regional-scale thermal modelling

J.F. Wright

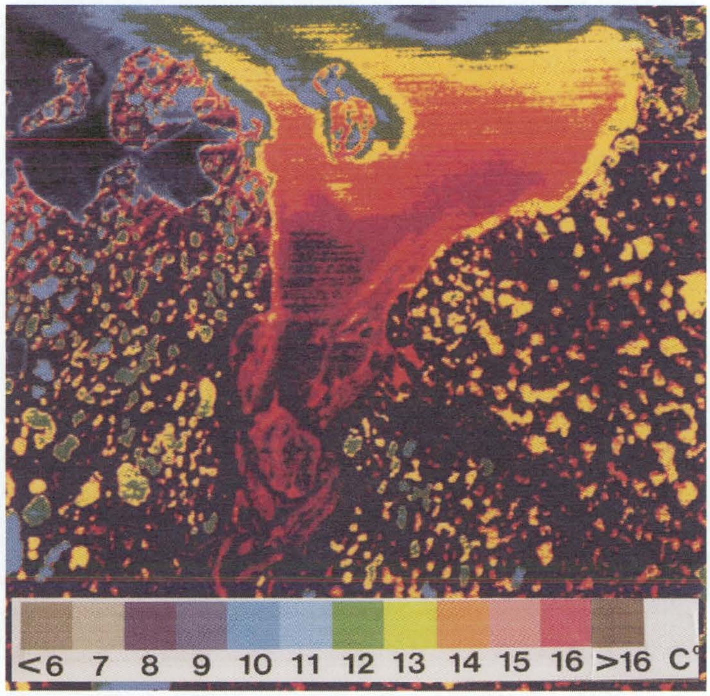
Thermal model showing occurrence of permafrost under present Mean annual air temperature conditions of –4° C, Fort Simpson, N.W.T. White areas depict permafrost.

Existing permafrost maps are generally inadequate for addressing climate change issues at a regional scale, as they provide little information about local and regional variations in ground temperatures and permafrost thickness. Such information is necessary for the development of models that may be used to predict potential impacts of climate change in permafrost regions, in support of the formulation of appropriate adaptation strategies. The GSC is developing a physically-based, regional-scale ground temperature modelling capability which utilizes generalized descriptions of climate and terrain to predict ground temperature conditions, and thus the occurrence and thickness of permafrost. Model calibration and validation are supported by data from an extensive GSC network of air/ground temperature and active layer monitoring sites within the Mackenzie Valley. The model links key properties and processes of climate and terrain, enabling the prediction of ground thermal responses to alternate climate scenarios. Modelling results support the evaluation of climate change impacts in permafrost regions, such as the identification of areas susceptible to severe ground subsidence, catastrophic slope failures, and to long-term ecological disturbance.

Geological Survey of Canada

Satellite applications for coastal geomorphology/hydrology/climate change studies, Mackenzie Delta/Beaufort Sea Coast, N. W. T.

S.R. Dallimore, P. Vachon, S. Solomon



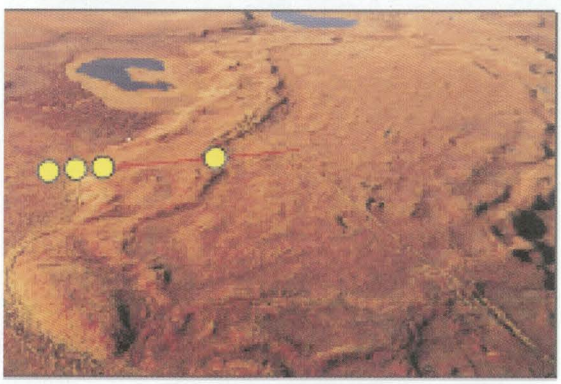
Satellite image of the Mackenzie Delta depicting plume of warm water and sediment from river.

Satellite remote sensing techniques offer great potential as relatively inexpensive, accurate tools for regional-scale applications in a variety of terrestrial environmental studies. Improvements in sensor technology, including enhanced spatial resolution and multispectral capabilities, have afforded an opportunity for development of increasingly site-specific applications, mapping of derivative variables, and assessment of temporal variations. The launch of Canada's RADARSAT has added a particularly valuable new remote sensing tool which is largely unaffected by weather variables and/or lack of solar illumination. In particular RADARSAT holds considerable potential for applications in coastal areas as it yields reliable and timely information about sea ice and open water conditions, hydrologic characteristics, and surface texture properties of terrestrial areas. A multidisciplinary project has been developed jointly by the Geological Survey of Canada and the Canada Centre for Remote Sensing to utilize newly developed remote sensing methods for coastal geology, permafrost and hydrology studies in an Arctic setting. The Mackenzie Delta/Beaufort Sea coast region has been chosen as the primary research area. This region is characterized by a wide diversity of terrestrial ecosystems which, as a whole, are particularly vulnerable to climate change.

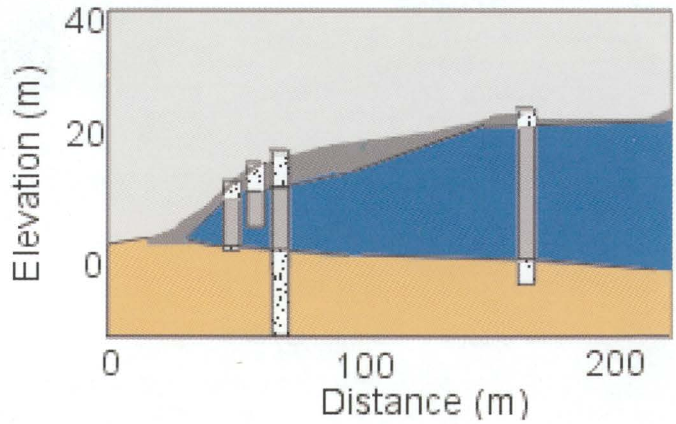
Creep deformation of ice-rich permafrost slopes

S.R. Dallimore, F.M. Nixon, P.A. Egginton

Characterization of the internal deformation of hill slopes is critical to evaluating geomorphic processes associated with the ice-cored landscape of the Tuktoyaktuk Coastlands. In addition, knowledge of long-term creep rates under present and future climate conditions are needed for the assessment of the stability of engineering structures in this environment. Monitoring of four slopes in the Tuktoyaktuk Coastlands has produced a decade long record of creep deformation of ice-rich permafrost. Future work will concentrate on evaluating hill slope response to environmental change, including climate warming, by establishing the relationship between deep-seated processes and shallow movements associated with the active layer. Each site is instrumented with slope inclinometers, installed through the ice body into underlying sediments, to measure slope movements and their annual and/or seasonal variation. Recently, in-place recording instrumentation was installed to produce a high frequency and high quality time series of movement at selected depths. Movement is being related to seasonal variations in ground and surface temperatures measured at the sites and incorporated into process models.



Involuted Hill, Tuktoyaktuk Peninsula, N.W.T. showing the characteristic "wrinkled" surface topography.

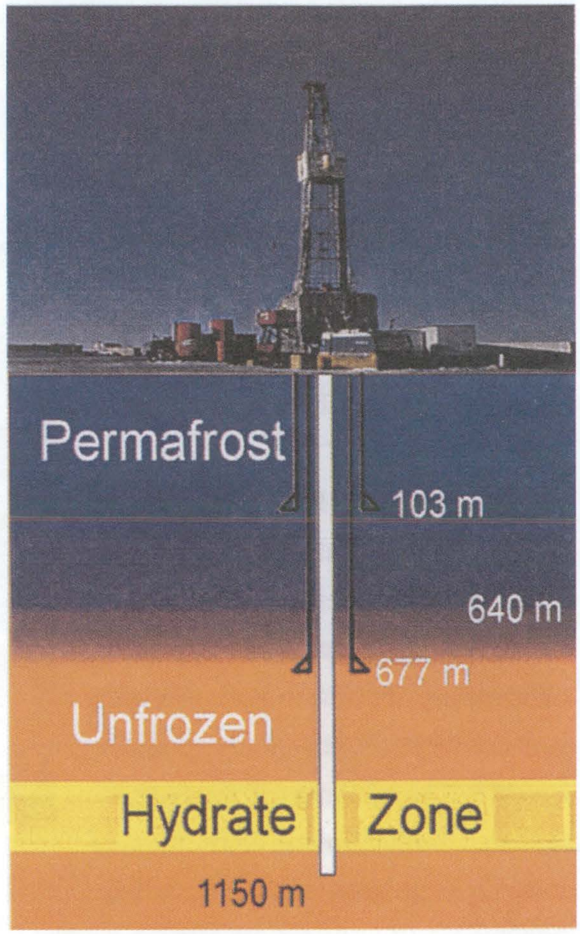


Coreholes indicate that the hill is underlain by massive ice that is undergoing creep deformation.

Gas hydrates

S.R. Dallimore, J.F. Wright, F.M. Nixon

Gas hydrates occurring beneath the continental shelves of the world and associated with deep permafrost represent the single largest known source of mobile carbon. Methane hydrate, thought to be the most common form of gas hydrate, is only stable under specific conditions of low temperature and moderate pressures. When these conditions are changed by processes such as climate warming or fluctuations in sea level, there is a significant risk of an increased flux of methane into the atmosphere. Research in the Mackenzie Delta/Beaufort Sea and Arctic Islands is focussed on assessing the distribution of methane hydrate and its sensitivity to climate warming.



Cross-section of Mallik 2L-38, Mackenzie Delta, drill hole showing gas hydrate zone.

Sample of drill core showing visible gas hydrates.

Coastal process studies

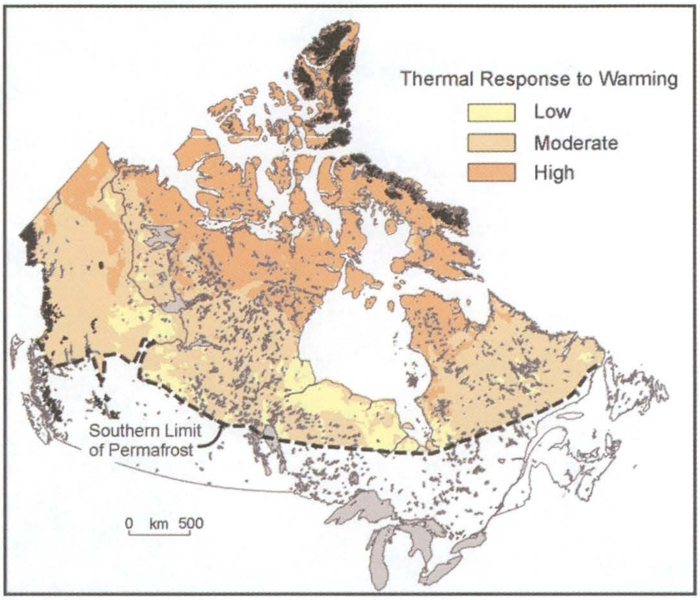
S. Solomon, B. Taylor, S.R. Dallimore, S.A. Wolfe

Coastal erosion in the form of block failures is caused by waves undercutting the frozen soil.

Significant segments of the Canadian Arctic coast are subject to rapid rates of change. In the Beaufort Sea region, more than 10 m of erosion can occur in a single year, despite seas that are ice-covered more than three quarters of the year. Warming in high latitudes will likely be accompanied by increasing rates of thawing of coastal permafrost, longer open water seasons, higher sea levels, and changing spatial and temporal patterns of storms, which will alter the rates of erosion and degradation of coastal regions. These changes may pose hazards to navigation and offshore development and will affect coastal communities and indigenous uses of coastal resources. The GSC is presently investigating the magnitude and variability of coastal change in the Arctic, and the relationships between these changes and environmental forces such as wind, temperature, waves, and storm surges. Field investigations include coring, sediment and thermal monitoring, coastal/nearshore profiling, and geophysical surveys. Laboratory studies consist of sediment, ice and palynological analyses, air photo and satellite image analyses, along with analysis of oceanographic and climate data collected by other organizations. Results from these studies may improve our ability to predict the location and intensity of coastal impacts and to develop appropriate adaptation strategies in a region where climate changes are likely to be most pronounced.

National-scale permafrost sensitivity mapping and national databases

S.L. Smith, M.M. Burgess

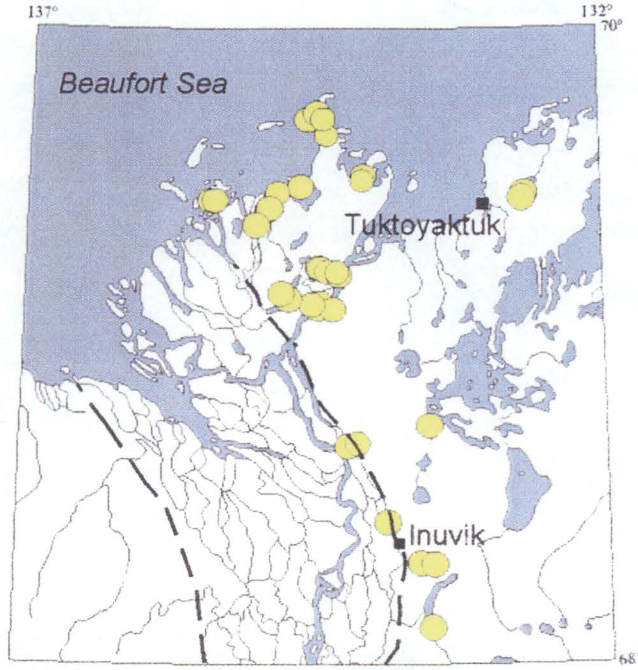


The relative thermal response of permafrost to climate warming.

Climate change is a national-scale issue, and permafrost underlies more than 50% of the landmass of Canada. Therefore, understanding the potential changes to permafrost in Canada is, from a strictly geographic and ecosystem perspective, of national relevance. Maps characterizing the sensitivity of permafrost to climate warming in Canada are currently being developed as part of a series of national syntheses of geological responses to climate change. The study considers the main factors (snow cover, vegetation, organic layer, surficial materials) that determine the response of the permafrost thermal regime to warming and the impact of any permafrost thaw that occurs. Digital data layers of the relevant factors have been compiled and GIS techniques are being used to produce maps which classify areas according to the thermal and physical responses to warming. These maps provide information on the relative rate and magnitude of ground temperature change and the relative magnitude of impact of permafrost thaw. National permafrost thickness and temperature databases are also being developed and maintained. Information on the current permafrost thermal regime extracted from these databases are being combined with the maps characterizing the thermal and physical response to warming to produce a national-scale sensitivity map. The variability and extremes of climatic parameters under climate warming scenarios and the response of the permafrost environment are also being considered.

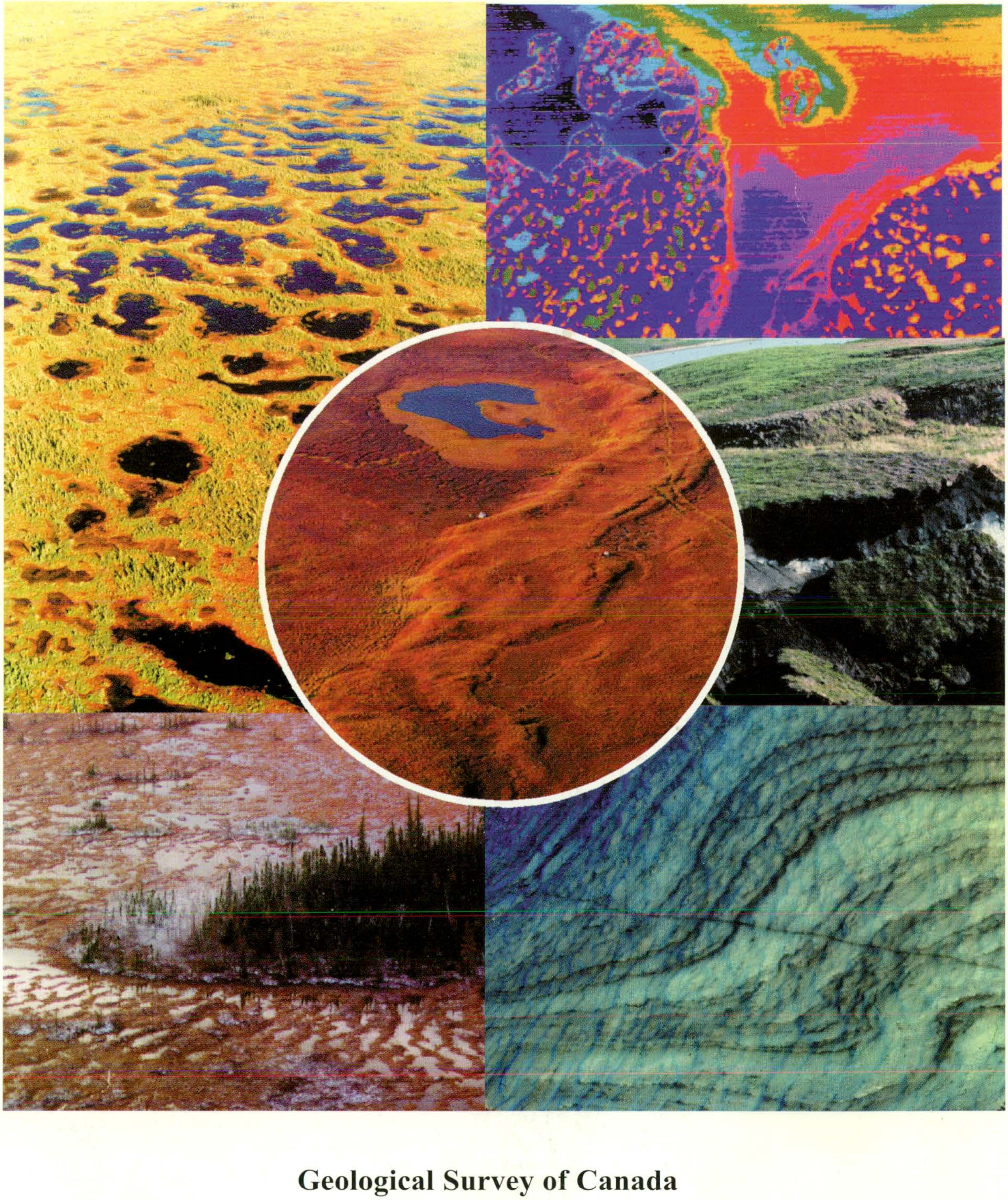
Permafrost thermal monitoring

M.M. Burgess, F.M. Nixon, J.F. Wright



Location of permafrost and active layer monitoring stations in the Mackenzie Delta region.

The World Climate Research Program (WCRP) has identified the "permafrost thermal state" as a key cryospheric variable for monitoring under their global network. The response of permafrost terrain to a warming climate depends on the nature and temperature of subsurface materials, as well as ground ice conditions, and is a function of changes in air temperature, precipitation, snow cover, and surface vegetation. Local and regional variability of these responses are expected to be great. Within the past two decades, the GSC has established a significant number of ground temperature monitoring sites, principally in the Mackenzie Valley and Delta, in conjunction with regional active layer monitoring and pipeline corridor studies. Several sites have been established through co-operation with Environment Canada and Agriculture Canada. In order to provide a comprehensive evaluation of anticipated changes, it is necessary to establish a nationally extensive ground temperature and active layer monitoring program. An effective monitoring strategy will provide field observations essential for the detection of the terrestrial climate change signal, for the assessment of its lag (rate of change) and attenuation (magnitude of change), and will provide indications of the spatial variability of change across the Arctic. This information is critical to the improvement of predictive models, for the reliability of impact assessments, and for appropriate adaptation measures to be taken.



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