Great Bear Lake Climate Change Analysis

An Assessment of Climate Change Variables
in the
Great Bear Lake Region, Canada

Prepared for

Déline Renewable Resources Council

by the

Scenarios Network for Arctic Planning (SNAP)

University of Alaska Fairbanks

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Introduction

Northern Canada is undergoing rapid changes. Substantial warming has occurred at high northern latitudes over the last half-century. Fire patterns are changing, permafrost is thawing, and Arctic summers are now warmer than at any other time in the last 400 years. Most climate models predict that high latitudes will experience a much larger rise in temperature than the rest of the globe over the coming century. At the same time, the region is undergoing changes in human population and demands on natural resources. These changes mean that maintaining the status quo in operations and management of resources and growth may result in increased costs, risk, and resource damage. Future planning that accounts for these changes can avoid or reduce these potential liabilities.

Déline Renewable Resources Council (DRRC) is working on a project to assess the impacts of climate change on the aquatic ecosystems of Great Bear Lake and its watershed. Great Bear Lake lies between the Kazan Uplands portion of the Canadian Shield and the Interior Plains. The lake empties through the Great Bear River (Sahtúdé) into the Mackenzie River. The community of Deline is at the southwest end of the lake. The lake is renowned for its Lake Trout, Arctic Grayling. Lake Whitefish, and Arctic Char.

For this project, the Scenarios Network for Alaska Planning (SNAP: www/snap.uaf.edu), a program within the University of Alaska Geography Program, provided objective scenarios based on climate projections and associated models of future landscape conditions. SNAP is a collaborative network that includes the University of Alaska, state, federal, and local agencies, NGO's, and industry partners. The SNAP network provides timely access to scenarios of future conditions in Arctic regions for more effective planning by communities, industry, and land managers. The network meets stakeholders' requests for specific information by applying new or existing research results, integrating and analyzing data, and communicating information and assumptions to stakeholders. SNAP's goal is to assist in informed decision-making.

The projections used in this project were for a range of modeled data, including baseline (1961-1990), current, and future years extending to 2099. These data provided measurements of change as they are likely to manifest themselves in the Great Bear Lake region, and estimating the uncertainty associated with each projection. SNAP provided data on the effects of climate change on the following environmental factors: temperature, precipitation, dates of freeze, and summer season length. SNAP also provided measures of active layer depths and permafrost dynamics based on collaborative modeling with researchers from the UAF Geophysical Institute Permafrost Lab. Measures of change were, where appropriate, specific to season. The full results of this assessment are presented below.

Modeling climate change

SNAP climate models

SNAP climate projections are based on downscaled regional Global Circulation Models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC). The IPCC used fifteen different GCMs when preparing its Fourth Assessment Report released in 2007. SNAP collaborator Dr. John Walsh and colleagues analyzed how well each model predicted monthly mean values for three different climate variables over four overlapping northern regions for the period from 1958 to 2000.[1]

For this project, SNAP used mean (composite) outputs from the five models that provided the most accurate overall results.[2] For each of these five models, results relied on model runs based on midrange (A1B) predictions of greenhouse gas emissions, as defined by the IPCC. The A1B scenario was selected

[1] Model selection and downscaling methods are described here http://www.snap.uaf.edu/about

[2] The models used to form the composite are Echam5, Gfdl2.1, Miroc3.2MR, HadCM3, and CGCM3.1 from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment, published in 2007.

because it offers a balanced and somewhat conservative perspective on the future of human population growth, technology, and energy use; results from this scenario are unlikely to overstate the severity of projected change,[3] given recent climate and emission trends.[4] SNAP model outputs based on these GCMs cover the time period from 1980 to 2099, with baseline climatologies for 1961-1990.

Model downscaling

GCMs generally provide only large-scale output, with grid cells typically 1°-5° latitude and longitude. SNAP scaled down these outputs to a resolution of ten minutes lat/long (approximately 10 km), using baseline climatology grids available from the Climate Research Unit (CRU)[5], University of East Anglia. These grids represented mean monthly values for precipitation and temperature for the years 1961-1990 (New et al. 2002)[6]. CRU uses point data from climate stations, other spatial data sets, and multi-variate interpolation to generate gridded estimates of monthly climatic parameters, including precipitation and temperature. SNAP calculated the differences between baseline CRU grids and GCM grids for the same time period, and used the resulting grids to both correct for model biases and downscale future projections.

Model uncertainty

Greenhouse-driven climate change represents a response to the radiative forcing associated with increases of carbon dioxide, methane, water vapor and other gases, as well as associated changes in cloudiness. The response varies widely among GCMs because it is strongly modified by feedbacks involving clouds, the cryosphere, water vapor and other processes whose effects are not well understood. The ability of a model to accurately replicate seasonal radiative forcing is a good test of its ability to predict changes in radiative forcing associated with increasing greenhouse gases. SNAP models have been assessed using backcasting[7] and comparison to historical conditions, and have proven to be robust in predicting overall climate trends.

Model projections are available as monthly average values. While trends are relatively clear, precise values for any one year or month for any single model cannot be considered reliable weather forecasts. Each model incorporates the same degree of variability found in normal weather patterns.

The downscaling process introduces further uncertainty. While CRU offers the best available algorithms for linking climate variability to weather station interpolation, the connection is not perfect. Weather stations are sparse in northern Canada, which tends to lower model reliability. Overall, model validation has shown that SNAP projections are more robust for temperature than for precipitation.

Some of this uncertainty can be dampened by using average values across time, space, and GCMs. All three kinds of averaging have been used in this analysis. Averaging increases the reliability of projections, but makes it impossible to make predictions about extreme events such as heat waves, cold snaps, and floods. Since such events are likely to have less impact than more broad-based shifts in the Great Bear Lake area, an averaging approach was selected for this project.

As described below, additional uncertainty is introduced when SNAP climate models are linked with additional parameters such as or permafrost thaw.

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[3] Nakicenovic, N., et al., *Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge Univ. Press, New York, 2000.
[4] *Climate Change Science Compendium 2009*, United Nations Environment Programme, 2009.
[5] Climate Research Unit, http://www.cru.uea.ac.uk/
[6] New, M., Lister, D., Hulme, M. and Makin, I., 2002: A high-resolution data set of surface climate over global land areas. *Climate Research* **21**
[7] Validating SNAP Climate Models http://www.snap.uaf.edu/downloads/validating-snap-climate-models

Selection of variables and data

The project focused on projections for two selected decades, 2030-2039 and 2090-2099, in order to provide shorter-term and long-term analysis of climate trends. For most variables, these future decades were compared to the standard baseline climatology used by SNAP, CRU, and the IPCC: 1961-1990. Temperature and precipitation were assessed in terms of seasonal averages for those decades. Additional variables were assessed based on appropriate time steps and seasons, as described in each section below. These variables were selected by DRRC in conjunction with SNAP scientists, and were analyzed by researchers at SNAP in collaboration with the UAF Geophysical Institute Permafrost Lab. They included depth of active layer and changes in dates of winter freeze and summer season length. Modeling methods were different for each of these variables, and sources and magnitude of uncertainty vary. The results of each assessment are presented and discussed below.

Projection Results for the Great Bear Lake Area

Temperature

Both summer and winter temperatures are expected to increase around Great Bear Lake throughout the century, with the greatest increases in winter (Table 1). Summer (June-August) temperatures are projected to rise by approximately 1°C by the 2030s, and by approximately 3-4°C by the 2090s. Average winter temperatures (December-February) are likely to increase by as much as 8-9°C by the 2090s, as compared to historical averages.

As can be seen in Figure 1, summer temperatures characteristic of the southernmost portions of the watershed are likely to increase from about 14°C to about 17 °C, while summer temperatures in the coldest (northeastern) areas of the watershed are projected to rise from about 6°C to about 8°C. Figure 2 shows that although autumn temperatures have historically averaged wll below freezing, above-freezing temperatures are likely by the 2090s. In winter (Figure 3) change may become apparent even sooner, particularly to the north and west. SNAP models do not predict a significant change in temperature variabilty, meaning that on average warming trends are likely to reduce the number of extreme cold days, and increase the number of extreme warm events in every season (based on historical standards of extreme events). Warmer spring temperatures (Figure 4) are linked to earlier spring thaw, as will be discussed below.

Table 1: Temperature projections by decade. "Winter" refers to averages for December through February, "Spring" is March through May, "Summer" June through August, and "Autumn" is September through November.

TEMPERATURE (°C)	1961-1990	2030-2039	2090-2099
ANNUAL	-8.36	-6.15	-2.59
WINTER	-27.22	-23.96	-18.79
SPRING	-10.75	-8.63	-5.05
SUMMER	11.04	12.09	14.47
AUTUMN	-6.50	-4.12	-0.98
	Change in Temperature (°C) from 1961-1990		
ANNUAL	X	2.21	3.26
WINTER	X	3.26	8.43
SPRING	X	2.12	5.70
SUMMER	X	1.05	3.43
AUTUMN	X	2.38	5.52

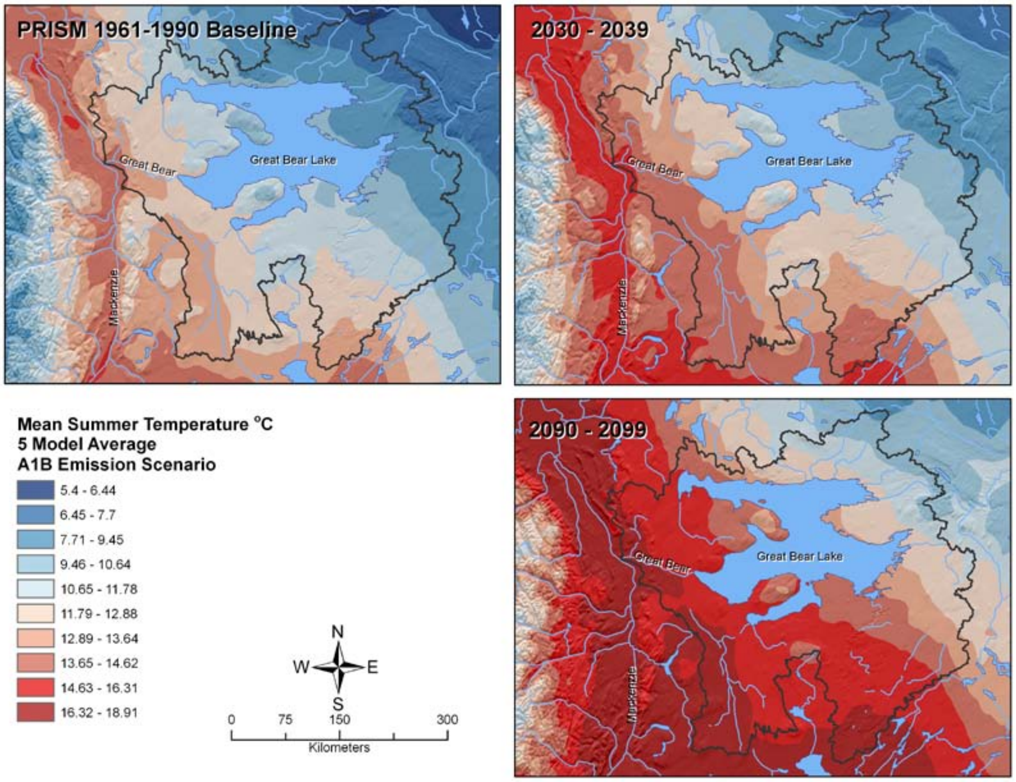

Figure 1: Summer Temperature Projections. "Summer" refers to averages for June through August.

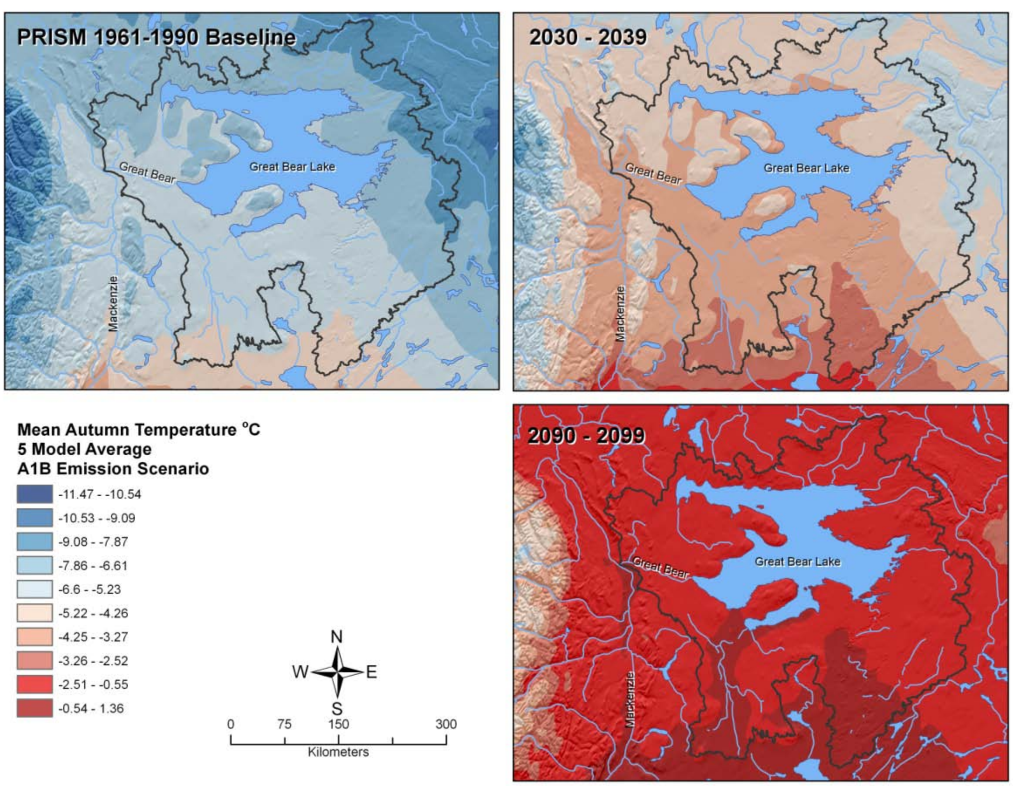

Figure 2: Autumn Temperature Projections. "Autumn" refers to averages for September through November.

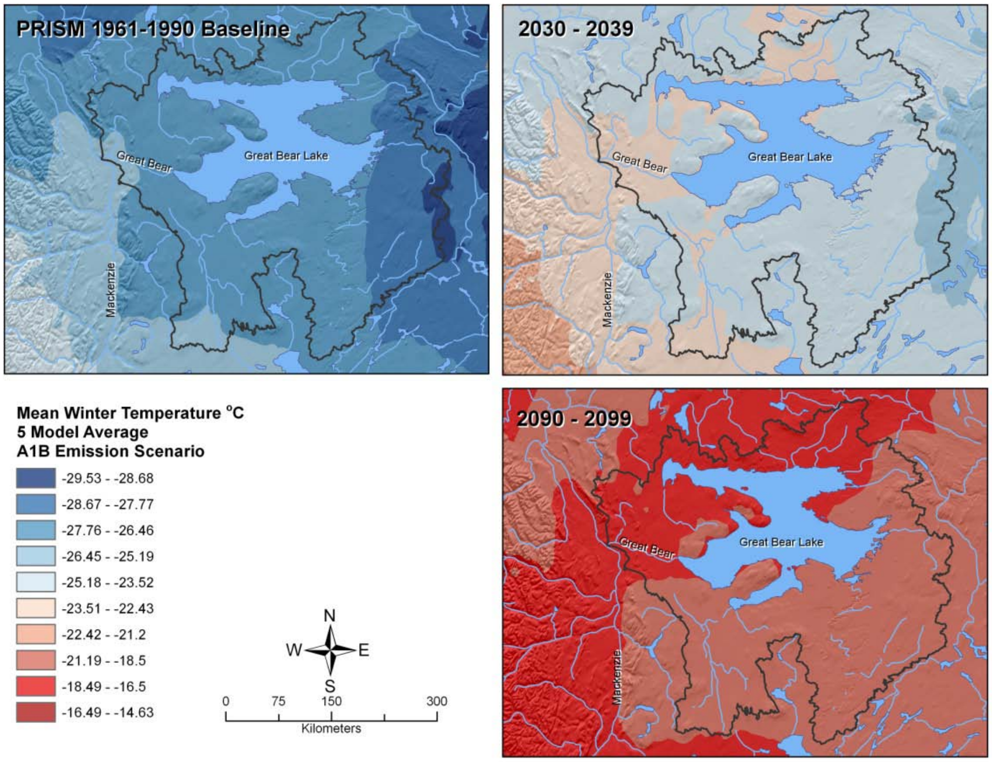

Figure 3: Winter Temperature Projections. "Winter" refers to averages for December through February.

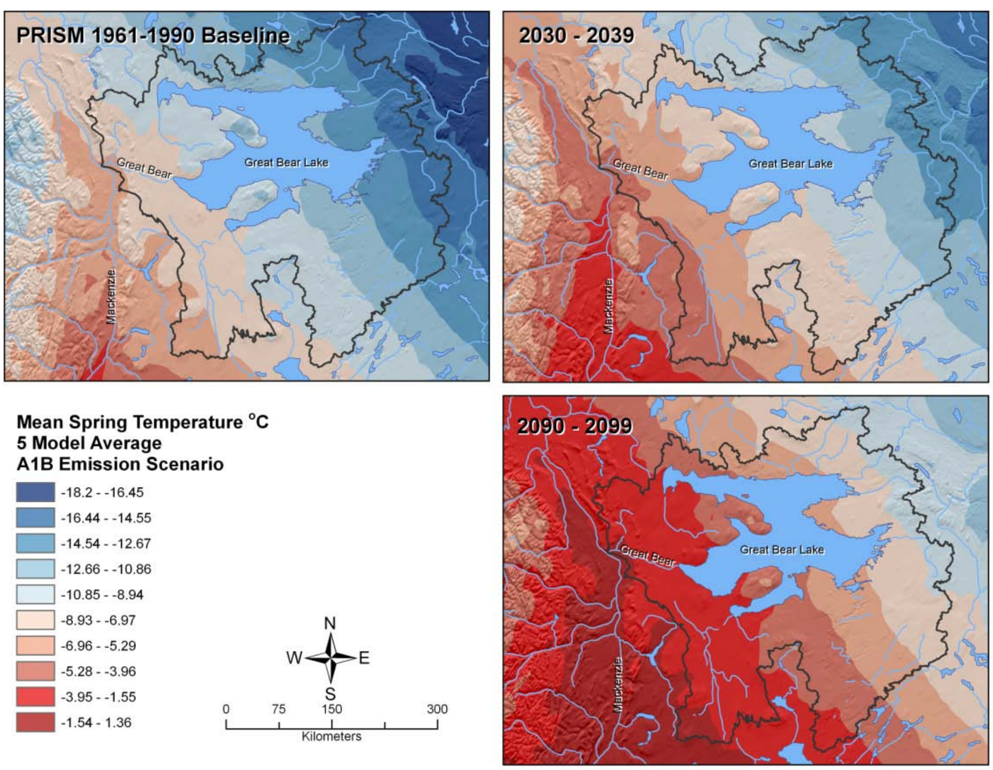

Figure 4: Spring Temperature Projections. "Spring" refers to averages for March through May.

Precipitation

Precipitation is projected to increase in all seasons (Table 2). The greater increases are expected in spring and autumn, with increases of 15-20% projected by the 2040s, and about 40% by the 2090s. However, it should be noted that warmer temperatures may result in some of this precipitation occurring as rain during the shoulder seasons. Precipitation is not divided into rainfall and snowfall, but is reported uniformly as rain-water equivalent. Moreover, the greatest absolute increase in precipitation is expected in the summer months, given that this is the wettest portion of the year to start with.

Table 2: Precipitation projections by decade and region. "Winter" refers to averages for December through February, "Spring" is March through May, "Summer" June through August, and "Autumn" is September through November.

PRECIPITATION (mm)	1961-1990	2030-2039	2090-2099
ANNUAL	268.1	310.4	367.6
WINTER	44.6	51.9	59.6
SPRING	40.2	48.5	56.0
SUMMER	109.7	124.6	146.5
AUTUMN	73.6	85.3	105.5
	Change in Precipitation (mm) from 1961-1990		
ANNUAL	X	42.3	99.5
WINTER	X	7.3	15.0
SPRING	X	8.3	15.7
SUMMER	X	15.0	36.9
AUTUMN	X	11.7	31.9
	Change in Precipitation (%) from 1961-1990		
ANNUAL	X	15.78	37.11
WINTER	X	16.34	33.58
SPRING	X	20.64	39.14
SUMMER	X	13.67	33.61
AUTUMN	X	15.94	43.31

Historically, SNAP models show the eastern side of the watershed as being driest in the summer (Figure 5) and the northeast being driest in all other seasons (Figures 6-8). In general, the existing precipitation gradient is expected to remain in coming decades.

The Great Bear Lake Watershed, like much of Canada's Arctic, is a relatively dry region. However, a great number of lakes and wetlands persist in the Arctic due to several factors, including flat topography, limited drainage caused by shallow permafrost, and limited evapotranspiration, due to cool temperatures, low biomass, and short growing season. Predicting changes in overall water availability and drainage in this area is complex, because each of the above factors affects the others, sometimes in unpredictable ways.

Preliminary analysis of the overall moisture balance between precipitation (P) and potential evapotranspiration (PET) shows an overall drying trend in the arctic, indicated by increases in PET and decreases in P-PET. However, not only are these estimates subject to the uncertainty associated with all SNAP models, as described above; they also involve a choice of additional algorithms and input variables such as cloud cover data. Although a great deal of ground water is generally available in the arctic, and some soils are fully saturated, it is likely that during the growing season loss of water through evaporation and plant uptake will increase relative to inputs through precipitation. While this may mean that lakes and wetlands will tend to shrink in the long term, this is difficult to predict.[8] Draining of lakes is also strongly controlled by permafrost and active layer depth, which will be discussed below.

[8] Jones, BM, Arp C, Hinkel K, Beck R, Schmutz J, Winston B (2009). Arctic Lake Physical Processes and Regimes with Implications for Winter Water Availability and Management in the National Petroleum Reserve Alaska. Environmental Management. Vol.43, 1071-1084

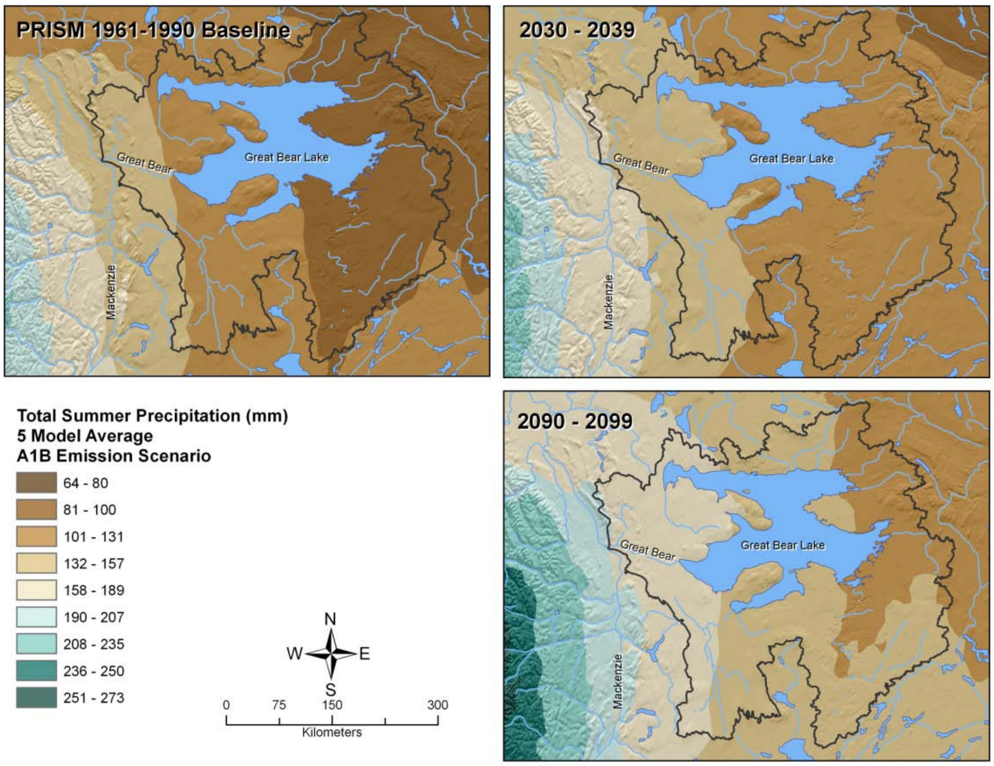

Figure 5: Summer Precipitation Projections. "Summer" refers to averages for June through August.

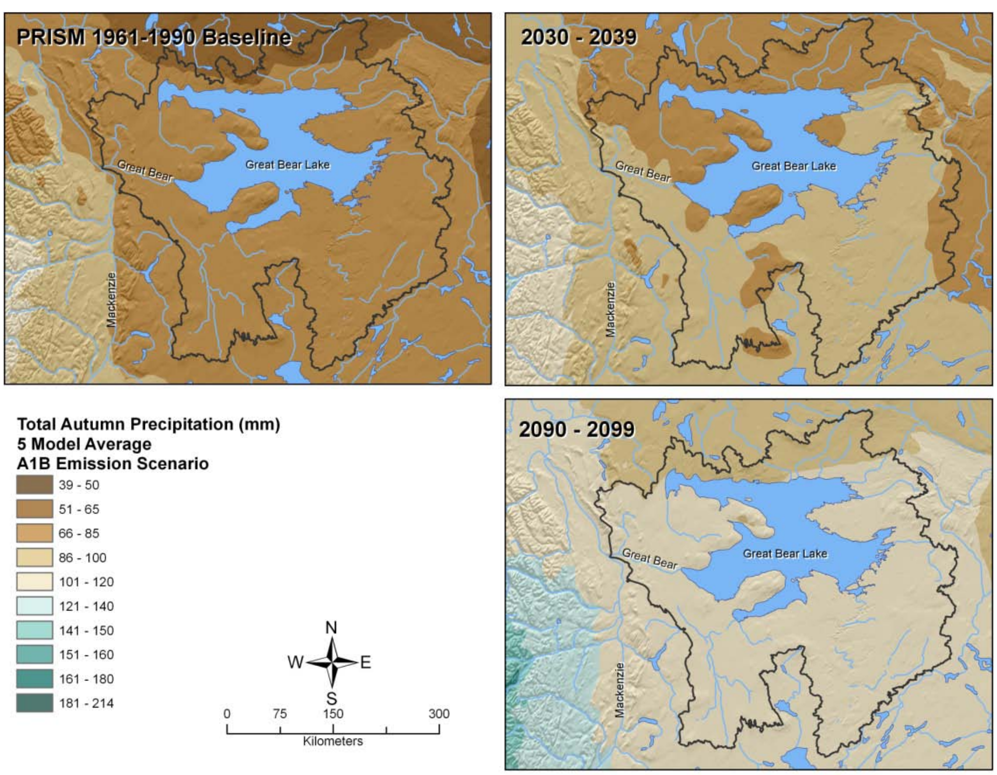

Figure 6: Autumn Precipitation Projections. "Autumn" refers to averages for September through November.

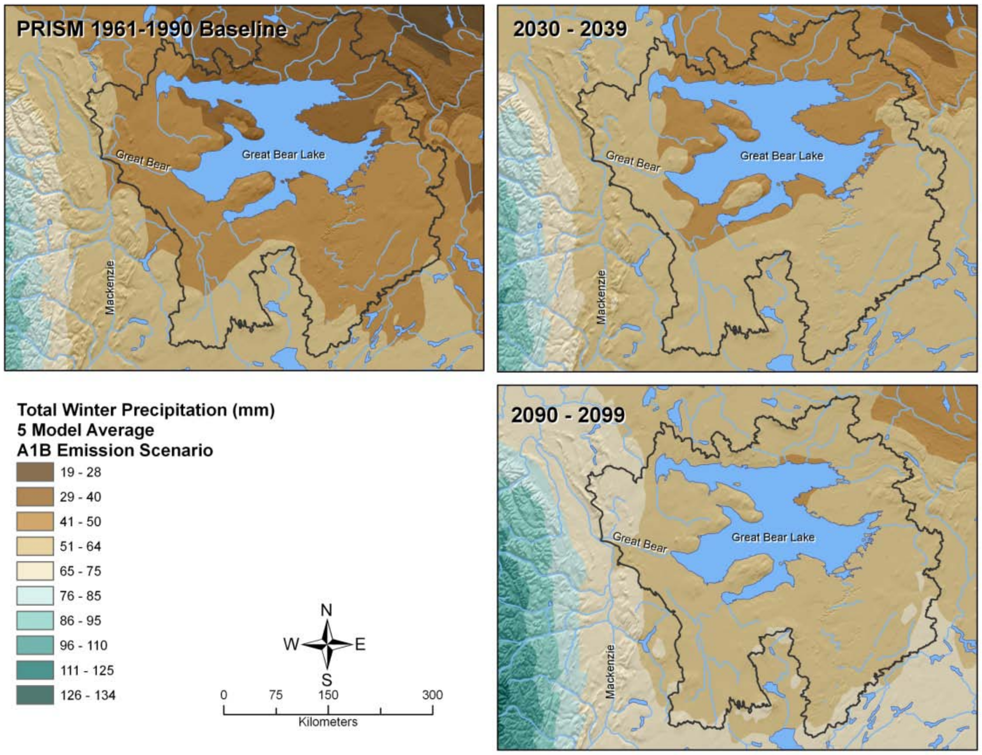

Figure 7: Winter Precipitation Projections. "Winter" refers to averages for December through February.

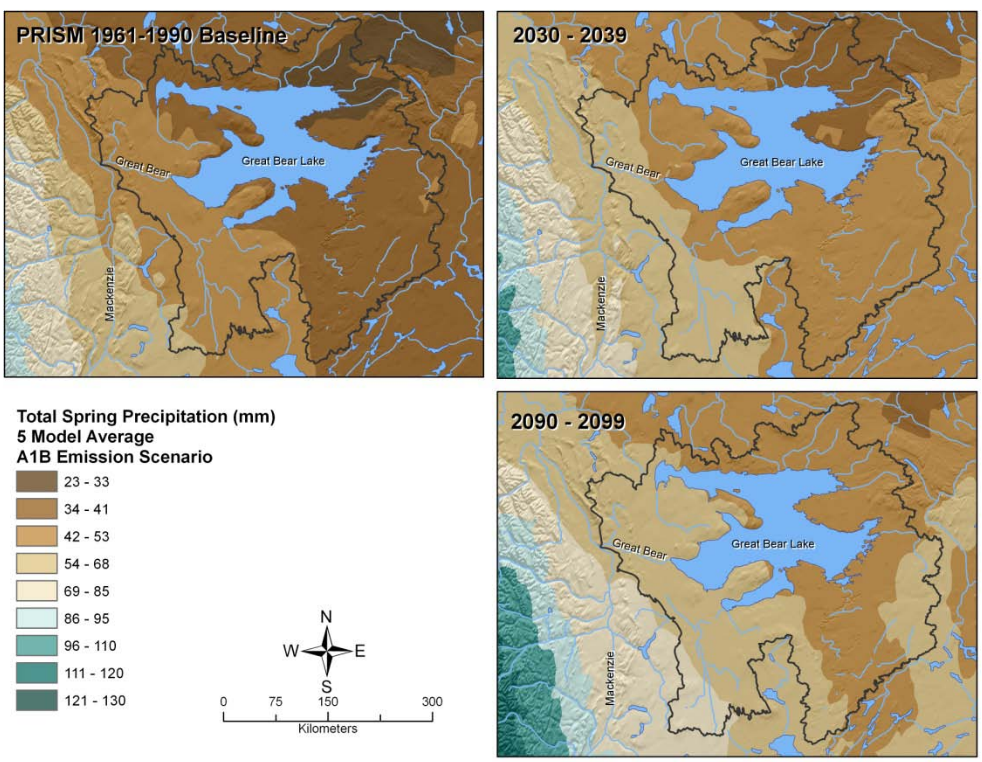

Figure 8: Spring Precipitation Projections. "Spring" refers to averages for March through May.

Freeze date and growing season length

SNAP uses monthly temperature and precipitation projections to estimate the dates at which the freezing point will be crossed in the spring and in the fall, via interpolation. The intervening time period is defined as summer season length or growing season length. It should be noted that these dates do not necessarily correspond with other commonly used measures of "thaw", "freeze-up" and "growing season". Some lag time is to be expected between mean temperatures and ice conditions on lakes or in soils. However, analyzing projected changes in these measures over time can serve as a useful proxy for other season-length metrics.

Perhaps because of the buffering effect of large bodies of water, the Great Bear Lake watershed experiences slightly later freeze dates than the surrounding area.

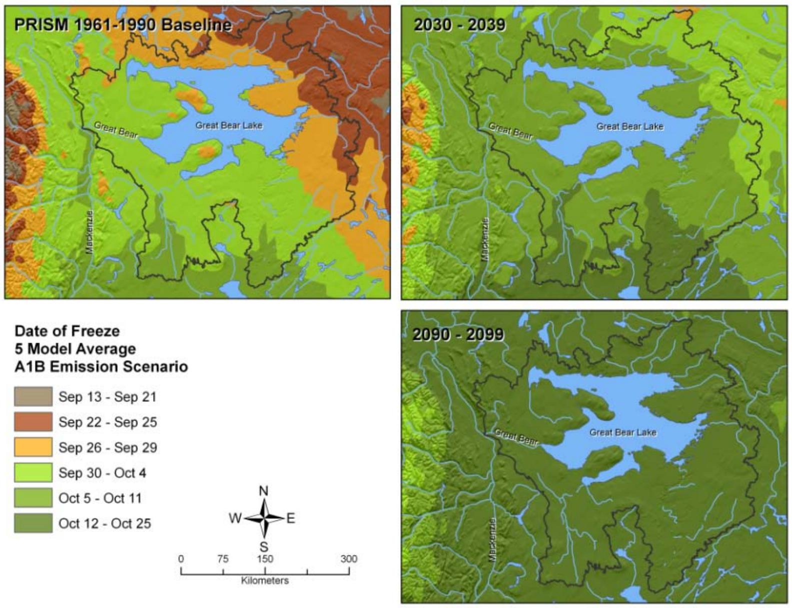

Figure 9: Autumn freeze-up projections. Freeze date is defined, for the purposes of this analysis, as the day at which the running mean temperature crossed the freezing point of fresh water (0°C)

Figure 9 shows projected changes in freeze dates for the baseline period as well as for the 2030s and 2090s. A northward shift in freeze dates is expected over the course of the century. Historically, the lakeshore crossed the freezing point in about the last week of September of the first week of October. However, these areas are projected to reach 0°C in the second week of October in the 2030s, and as late as October 25th by the 2090s. Ice formation on the lake itself would be expected to be delayed by a similar time period, impacting ecological processes and human users.

Likewise, summer season length in the watershed is expected to increase dramatically. Figure 10 shows a historical season length of 121-154 days along the lakeshore, with outlying parts of the watershed having as few as 106 or any many as 162 days with mean temperatures above freezing. By the 2030s, projections show the warm

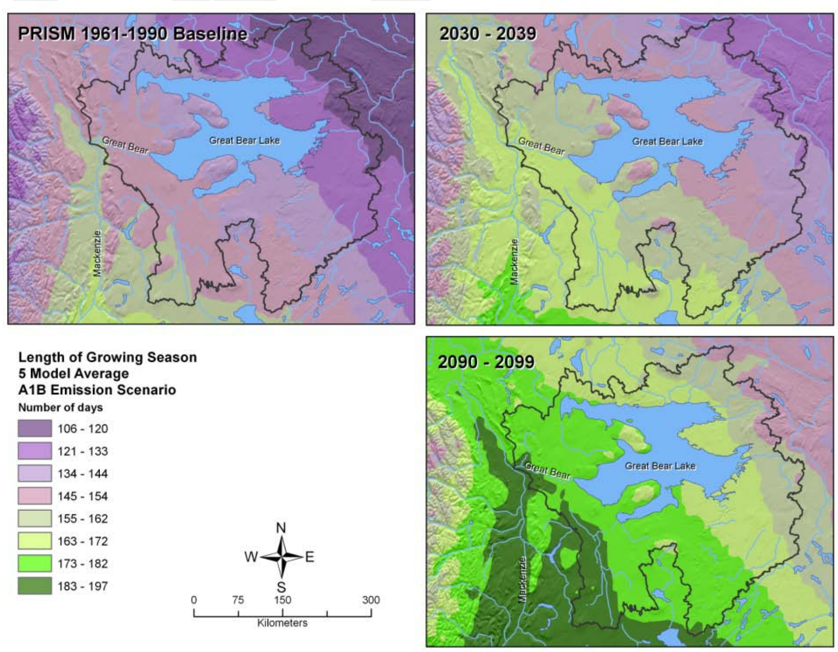

Figure 10: Summer season lenght projections. Growing season is defined, for the purposes of this analysis, as the number of days between the point at which the running mean temperature crosses the freezing point of fresh water in the spring and in the fall.

season increasing by about ten days. By the 2090s, the expected increase is about 25 days across the watershed, meaning that the conditions that currently prevail in the southwest (the warmest area) would become the norm in the northeast (the coldest area). Such changes might be expected to have marked effects on a wide range of ecosystem components, including vegetation, fish populations, migratory waterfowl, and endemics, as well and making the area more hospitable to invasive species.

Permafrost and depth of active layer

All of the Great Bear Lake watershed is currently underlain by permafrost (permanently frozen soils). During the summer season, the surface layer of the soil thaws, and then refreezes again in the autumn. The depth to which this thaw occurs (active layer thickness, ALT) is an important factor in determining what plant species can thrive here.

This portion of the project was undertaken by Dr. Sergei Marchenko, and used permafrost models developed by Dr. Vladimir E. Romanovsky and his colleagues at the Geophysical Institute Permafrost Lab (GIPL) at UAF.[9] GIPL used complex models and extensive monitoring stations and field measurements to address scientific questions related to circumpolar permafrost dynamics and feedbacks between permafrost and global change. Their models take into account the insulation properties of various soil types and ground covers in order to estimate the lag time between air temperature change and permafrost change. For these projections, GIPL models were linked with SNAP climate projections to produce projections for the 2030s and the 2090s, as compared to the time period between 2000 and 2009 (note that this baseline is different from the 1961-1990 climatology used in other portions of this assessment).

Results show increases in ALT across the watershed (Figure 11). Contemporary active layer thickness shows a complex spatial pattern, with values ranging from only approximately 1-2 centimeters to more than a meter and a half. The areas with the greatest ALT are generally to the south and west of the lake.

Future projections for 2030s show modest but significant increases in sesonal thaw depth, with overall spatial patterns remaining the same. By the 2090s, summer thaw depths may increase more dramatically, with increases of about 40-50 cm. Figure 12 shows the mean annual ground temperature (MAGT), which is expected to increase across the entire area for the same time periods. The most striking change is the projection that this temperature will rise above freezing for a significant portion of the watershed, implying loss of shallow permafrost.

As previously noted, changes in active layer depth and permafrost thaw can have profound effects on vegetation. Where permafrost is very shallow, soils tend to remain saturated throughout the growing season unless on slopes, and only shallow-rooted plants can persist. Conversely, deeper thawed soils allow for better drainage and the growth of woody plants species. The loss of permafrost can lead to thermokarst, slumping, and other major changes in hydrology and land morphology. These regions might be expected to undergo more extreme changes than other parts of the watershed.

Effects on permafrost thaw on vegetation are expected to be complex, since vegetation strongly effects the insulation of soils[10]. In some cases, a shift to denser and woodier plant canopies and thicker organic soils may offset the effects of warmer air temperatures. These changes are further complicated and by positive feedbacks between summer warming, increased vegetation, decreased snow cover, and decreased ice extent.[11]

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[9] http://permafrost.gi.alaska.edu/

[10] D. A. Walker et al. (2003). Vegetation-soil-thaw-depth relationships along a low-arctic bioclimate gradient, Alaska: synthesis of information from the ATLAS studies. Permafrost and Periglacial Processes. Vol. 14, Issue 2, pp 103–123.

[11] Chapin, F.S. et al. 2005. Role of Land-Surface Changes in Arctic Summer Warming. Science. Published online September 22 2005; 10.1126/science.1117368 (Science Express Reports).

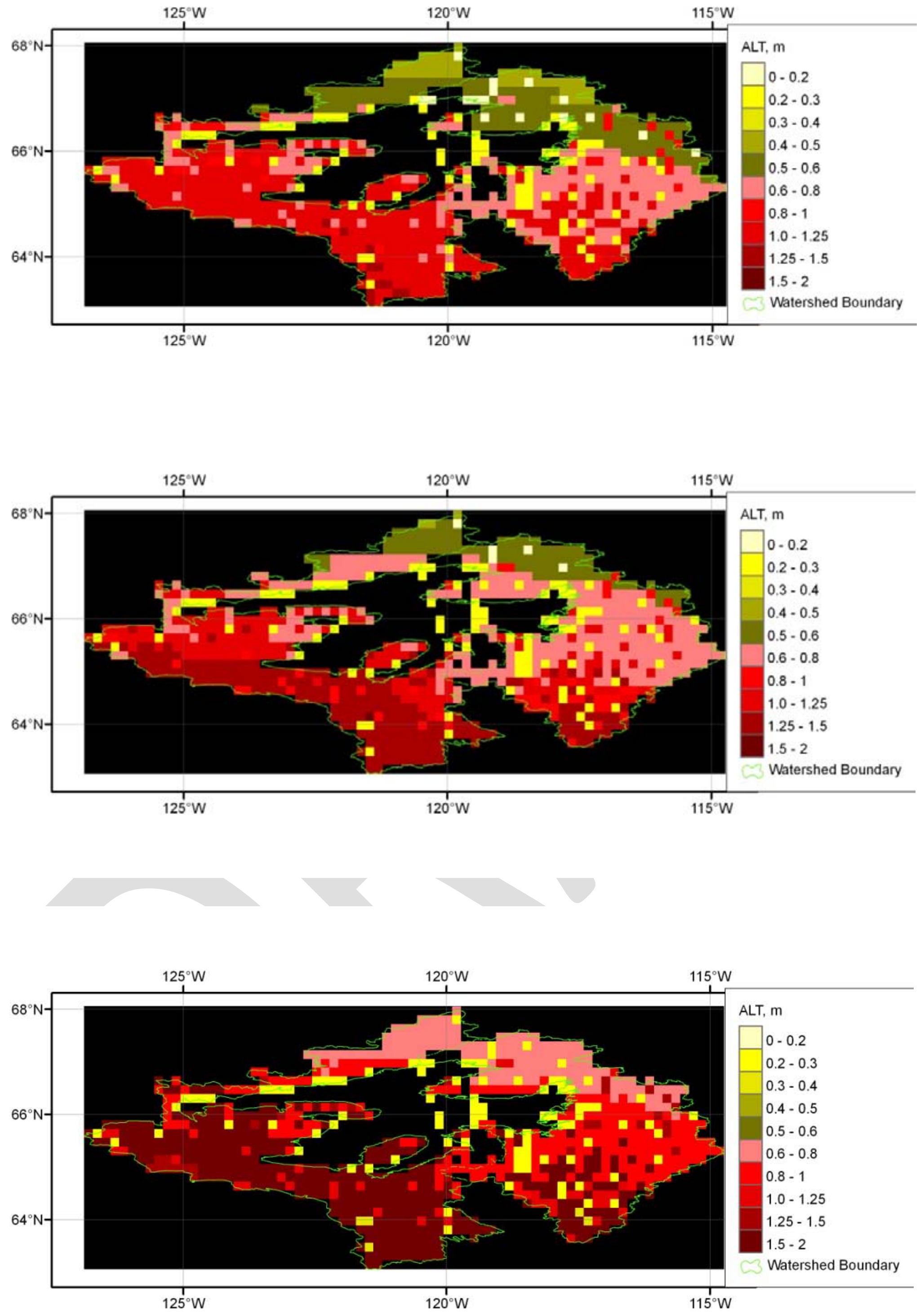

Figure 11 –Projections for active layer thickness (ALT), 2000s, 2030s, and 2090s. An increase of 20-50 cm is expected across the region, although changes are likely to be variable and site-specific.

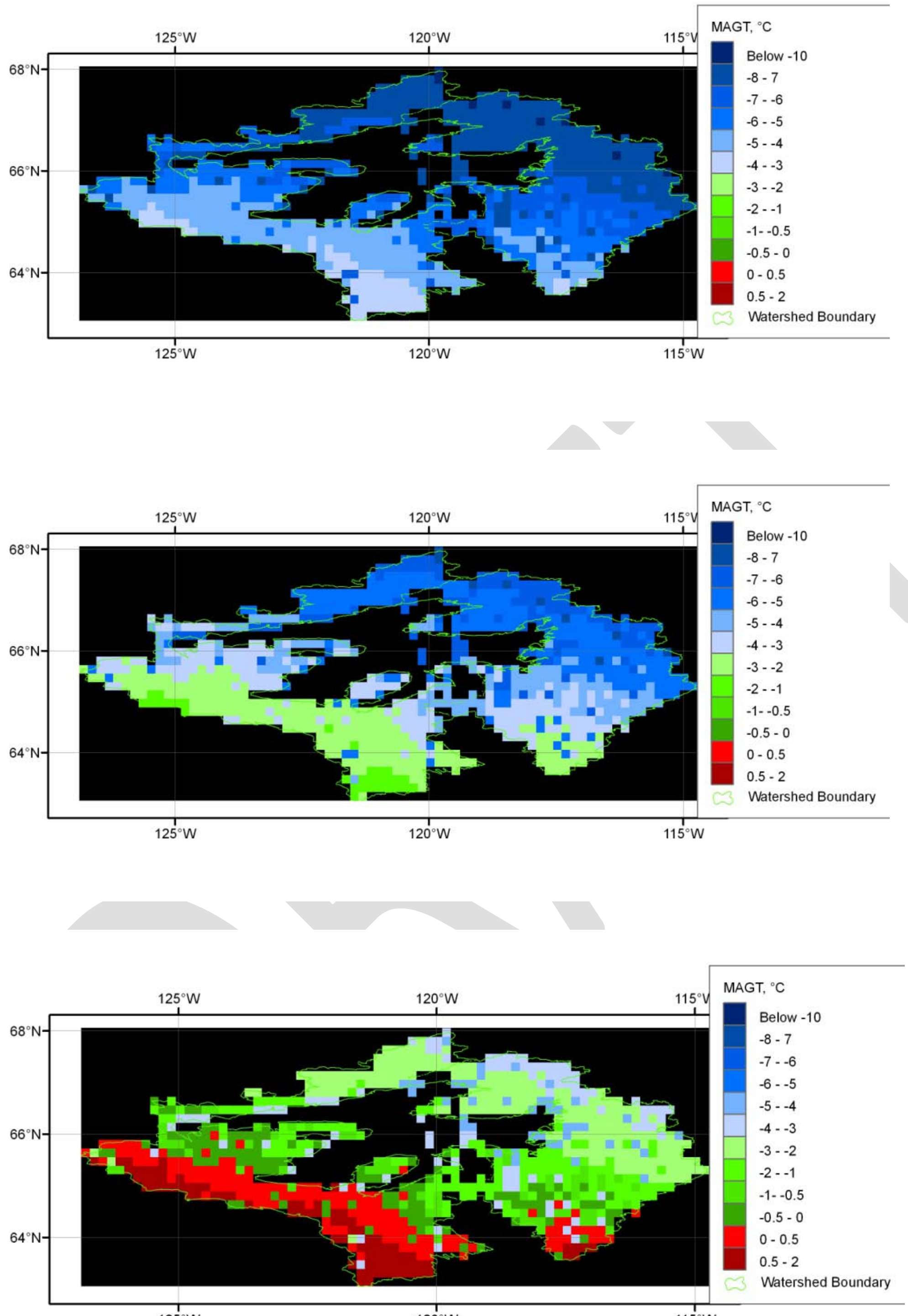

Figure 12 –Projections for mean annual ground temperature (MAGT), 2000s, 2030s, and 2090s. In some areas of the watershed, mean annual ground temperatures are projected to be above freezing by the 2090s, leading to thawing of shallow permafrost.

Summary and Conclusions

Overall, the Great Bear Lake watershed is expected to become much warmer in the middle and latter portion of this century, with a longer growing season, shorter less severe winters, and a deeper active layer in soils. Some increases in precipitation are likely, and complete permafrost thaw may occur in limited areas.

Due to the complex interrelationships between variables, it is not entirely clear how these changes will play out in terms of changes in drainage, water availability, vegetation, fish, wildlife, and human uses of the landscape. However, it is likely that most, if not all, of the watershed will experience some degree of stress to existing plant and animal species due to climate changes, and in some regions significant shifts in biome may occur. Some species, including cold-limited fish, may be able to expand their ranges. New species, including invasive species, may encroach. Cold winter temperatures and short summer seasons currently place a natural bar on many invasives, but with summers up to a month longer and winter temperatures up to 9°C warmer, this protection would be lessened.

The combination of thawing permafrost and increased potential evapotranspiration both point toward losing water from the landscape, especially if shifting biomes bring in plant species with higher biomass and a greater capacity for transpiration. A drier landscape may point to fewer wetlands, and a corresponding increase in upland habitat types. It is unclear whether Great Bear Lake would be expected to shrink, since increased drainage from thawing permafrost is difficult to forecast.

Other possible changes include, for example, a potentially negative impact on many bird species due to decreased wetlands. However, this loss might result in a corresponding increase in forage and improved habitat for grazers, or might even introduce new habitat for browsers. Many wildlife species are affected, either positively or negatively, by snow cover. While it is hard to predict whether seasonal snowpack would be deeper, it is likely that the snow season would start later and end earlier. Rain on snow events might become more common.

Warmer waters may impact resident fish populations, either positively or negatively[12,13], although the vast water volume of the lake would be expected to result in lag times in warming effects[14].

All of the above changes are pertinent to human uses of the landscape. Impacts to vegetation and wildlife directly impact hunting and gathering. Changes in season length affect hunting seasons and food storage, and changes to the depth and duration of frozen soils impact winter travel, including the Déline ice road.

Due to the uncertainty of these predictions – and all climate predictions – users and managers of the lands and waters of the Great Bear Lake area would be best advised to increase efforts to measure and assess change as it occurs, and to remain as flexible and adaptive as possible in their planning over the coming years.

For more information please visit the SNAP website at www.snap.uaf.edu or contact: Dr. Nancy Fresco, Network Coordinator, Scenarios Network for Alaska Planning, University of Alaska, 907-474-2405; nlfresco@alaska.edu

[12] Johnson, L. (1966) Temperature of maximum density and its effect on the circulation in Great Bear Lake. J. Fish. Res. Board Can., 23: 963-973.

[13] Yaremchuk, G. C. B. (1986) Results of a Nine-year Study (1972-80) of Sport-fishing Exploitation of Lake Trout (Salvelinus namaycush) on Great Slave and Great Bear Lakes, NWT: the Nature of the Resource and Management Options. Can. Tech. Rep. Fish. Aquat. Sci. no. 1436.

[14] Barbour, C. L., & Brown, J. H. (1974) Fish species diversity in lakes. Amer. Nat., 108: 473-489.