

SNAP

Scenarios Network for Alaska Planning



PRELIMINARY REPORT TO THE GOVERNOR'S SUB-CABINET ON CLIMATE CHANGE



2 Scenarios Network for Alaska Planning

COVER PHOTOS, CLOCKWISE FROM TOP LEFT:

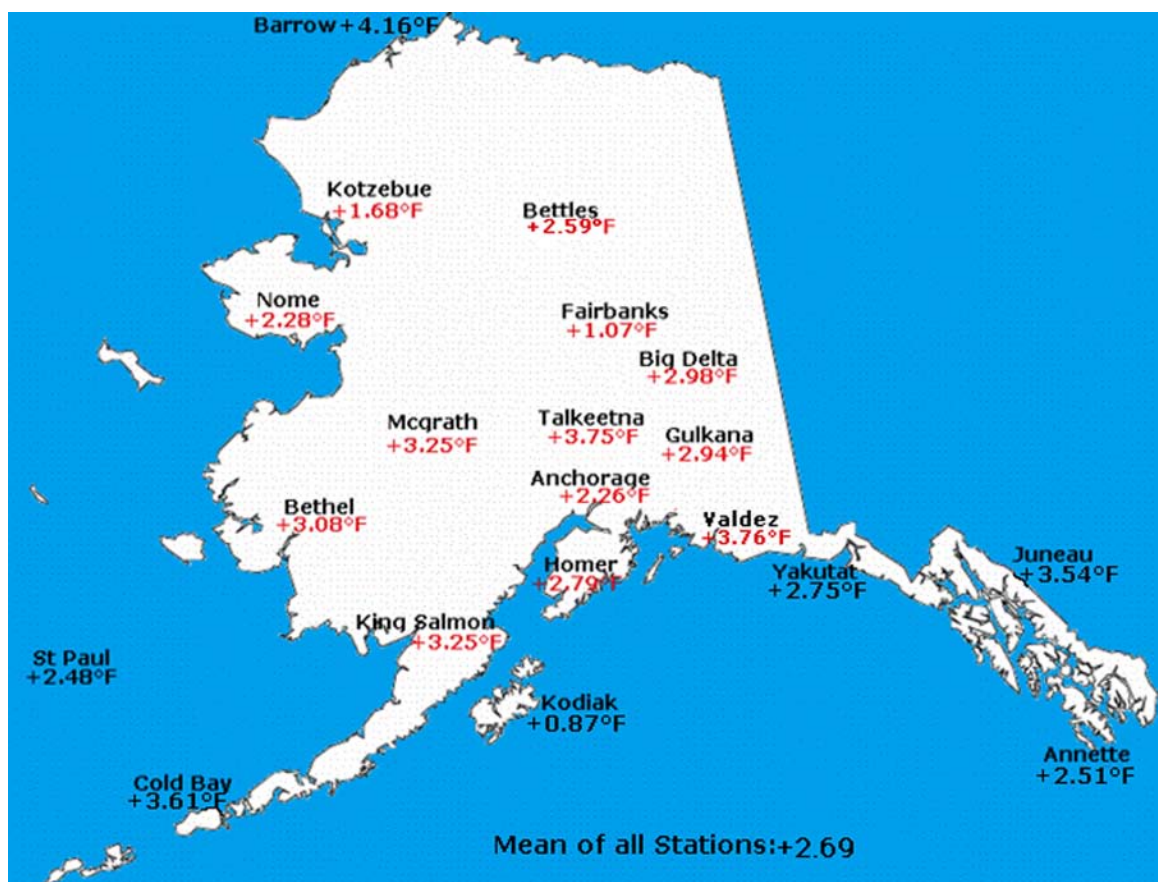
A Shishmaref house undermined by coastal erosion:
www.aaas.org/news/releases/2006/1206alaska.shtml

A young boy takes pride in a good harvest:
<http://community.adn.com/adn/blog/69017>

The Mendenhall Glacier near Juneau
http://commons.wikimedia.org/wiki/Image:Mendenhall_Glacier.jpg

Highway collapse following thawing of an underlying ice lens:
USDA-NRCS by Joe Moore http://soils.ag.uidaho.edu/soilorders/gelisols_07.htm

Deer Creek Fire, Alaska, 2004:
http://earthobservatory.nasa.gov/Study/ContributionPollution/Images/deercreek_fire_nps.jpg



Temperature Change in Alaska 1971-2000. Despite considerable inter-annual variability, mean annual temperatures have increased statewide.

(Alaska Climate Research Center,
University of Alaska Geophysical Institute)



INTRODUCTION

SNAP'S MISSION

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 Alaska for more effective planning by communities, industry, and land managers. We meet stakeholders' requests for specific information by applying new or existing research results, integrating and analyzing data, and communicating information and assumptions to stakeholders. Our goal is to assist in informed decision-making.

WHY PLAN FOR THE FUTURE?

SUBSTANTIAL WARMING HAS occurred at high northern latitudes over the last half-century. Sea ice is retreating, 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, Alaska is undergoing rapid 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.

CURRENT SERVICES AND PRODUCTS

IN COLLABORATION WITH stakeholders, SNAP produces projections of future conditions in Alaska. We also provide objective interpretations of potential future scenarios, including detailed explanations of assumptions, models, methods, and uncertainties. SNAP scenarios and the data used to produce them are openly available to all potential users. Data can

be accessed by contacting SNAP personnel (see back page) or via our website at <http://www.snap.uaf.edu>. Data are available in tabular form, as graphs, or as maps (ArcGis, ASCII and KML format) depicting the whole state of Alaska or part of the state at 2km resolution. Climate maps and graphs can be created for any time period from 1901 to the year 2099, based on historical back-casting and future projections. However, daily outputs are only available for a subset of this time period. For other times, mean monthly output is available.

LINKING CLIMATE TO RESOURCES

ESTIMATING FUTURE AIR temperature, precipitation, and other climate parameters is the first step towards planning for change. Stakeholders who want more detailed information can create collaborative agreements with SNAP in order to work on projects that link climate data to a wide range of variables such as permafrost thaw; timing of autumn freeze-up and spring breakup; frequency of flooding events; sea level change; and changes in evapotranspiration. These changes can, in turn, be linked to factors of direct concern to communities and land planners, such as transportation opportunities; ecosystem shifts; forest fires; agricultural prospects; risks to infrastructure; and movement of game animals.

DERIVATION OF SNAP CLIMATE PROJECTIONS

USE OF GCMs TO MODEL FUTURE CLIMATE

GENERAL CIRCULATION MODELS (GCMs) are the most widely used tools for projections of global climate change over the timescale of a century. Periodic assessments by the Intergovernmental Panel on Climate Change (IPCC — www.ipcc.ch) have relied heavily on global model simulations of future climate driven by various emission scenarios.

The IPCC uses complex coupled atmospheric and oceanic GCMs. These models integrate multiple equations, typically including surface pressure; horizontal layered components of fluid velocity and temperature; solar short wave radiation and terrestrial infra-red and long wave radiation; convection; land surface processes; albedo; hydrology; cloud cover; and sea ice dynamics.

GCMs include equations that are iterated over a series of discrete time steps as well as equations that are evaluated simultaneously. Anthropogenic inputs such as changes in atmospheric greenhouse gases can be incorporated into stepped equations. Thus, GCMs can be used to simulate the changes that may occur over long time frames due to the release of excess greenhouse gases into the atmosphere.

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 models because it is strongly modified by feedbacks involving clouds, the cryosphere, water vapor and other processes whose effects are not well understood. Changes in the radiative forcing associated with increasing greenhouse gases have thus far been small relative to existing seasonal cycles. Thus, the ability of a model to accurately replicate seasonal radiative forcing is a good test of its ability to predict anthropogenic radiative forcing.

MODEL SELECTION

DIFFERENT COUPLED GCMs have different strengths and weaknesses, and some can be expected to perform better than others for northern regions of the globe.

SNAP collaborator Dr. John Walsh and colleagues evaluated the performance of a set of fifteen global climate models used in the Coupled Model Intercomparison Project (www.pcmdi.llnl.gov/projects/cmip/index.php) Using the outputs for the A1B (intermediate) emission scenario, they calculated the degree to which each model's output concurred with actual climate data for the years 1958-2000 for each of three climatic variables (surface air temperature, air pressure at sea level, and precipitation) for three overlapping regions (Alaska only, 60-90 degrees north latitude, and 20-90 degrees north latitude.)

The core statistic of the validation was a root-mean-square error (RMSE) evaluation of the differences between mean model output for each grid point and calendar month, and data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis, ERA-40. The ERA-40 directly assimilates observed air temperature and sea level pressure observations into a product spanning 1958-2000. Precipitation is computed by the model used in the data assimilation. The ERA-40 is one of the most consistent and accurate gridded representations of these variables available.

To facilitate GCM intercomparison and validation against the ERA-40 data, all monthly fields of GCM temperature, precipitation and sea level pressure were interpolated to the common $2.5^{\circ} \times 2.5^{\circ}$ latitude-longitude ERA-40 grid. For each model, Walsh et al. calculated RMSEs for each month, each climatic feature, and each region, then added the 108 resulting values (12 months \times 3 features \times 3 regions) to create a composite score for each model. A lower score indicated better model performance.

The specific models that performed best over the larger domains tended to be the ones that performed best over Alaska. Although biases in the annual mean of each model typically accounted for about half of the models' RMSEs, the systematic errors differed considerably among the models. There was a tendency for the models with the smaller errors to simulate a larger greenhouse warming over the Arctic, as well as larger increases of Arctic precipitation and decreases of Arctic sea level pressure when greenhouse gas concentrations are increased.

Since several models had substantially smaller systematic errors than the other models, the differences in greenhouse projections implied that the choice of a subset of models might offer a viable approach to narrowing the uncertainty and obtaining more robust estimates of future climate change in regions such as Alaska. Thus, SNAP selected the five best-performing models out of the fifteen: MPI_ECHAM5 (Germany), GFDL_CM2_1 (United States), MIROC3_2_MEDRES (Japan), UKMO_HADCM3 (United Kingdom), and CCCMA_CGCM3_1 (Canada). These five models are used to generate climate projections independently, as well as in combination, in order to further reduce the error associated with dependence on a single model.

DOWNSCALING MODEL OUTPUTS

BECAUSE OF THE mathematical complexity of GCMs, they generally provide only large-scale output, with grid cells typically 1°-5° latitude and longitude. For example, the standard resolution of HadOM3 is 1.25 degrees in latitude and longitude, with 20 vertical levels, leading to approximately 1,500,000 variables.

Finer scale projections of future conditions are not directly available. However, local topography can have profound effects on climate at much finer scales, and almost all land management decisions are made at much finer scales. Thus, some form of downscaling is necessary in order to make GCMs useful tools for regional climate change planning.

Historical climate data estimates at 2km resolution are available from PRISM (Parameter-elevation Regressions on Independent Slopes Model — www.prism.oregonstate.edu), which was originally

developed to address the lack of climate observations in mountainous regions or rural areas. PRISM uses point measurements of climate data and a digital elevation model to generate estimates of annual, monthly and event-based climatic elements. Each grid cell is estimated via multiple regression using data from many nearby climate stations. Stations are weighted based on distance, elevation, vertical layer, topographic facet, and coastal proximity.

PRISM offers data at a fine scale useful to land managers and communities, but it does not offer climate projections. Thus, SNAP needed to link PRISM to GCM outputs. This work was completed by John Walsh, Bill Chapman, and the SNAP integration team. They first calculated mean monthly precipitation and mean monthly surface air temperature for PRISM grid cells for 1961-1990, creating PRISM baseline values. Next, they calculated GCM baseline values for each of the five selected models using mean monthly outputs for 1961-1990. They then calculated differences between projected GCM values and baseline GCM values for each year out to 2099 and created "anomaly grids" representing these differences. Finally, they added these anomaly grids to PRISM baseline values, thus creating fine-scale (2 km) grids for monthly mean temperature and precipitation for every year out to 2099. This method effectively removed model biases while scaling down the GCM projections. In order to create equally fine-scale maps of historical climate data—thus improving the potential for comparison between past, current, and future conditions—SNAP used the same methodology to downscale Climate Research Unit (CRU) datasets for the state of Alaska.

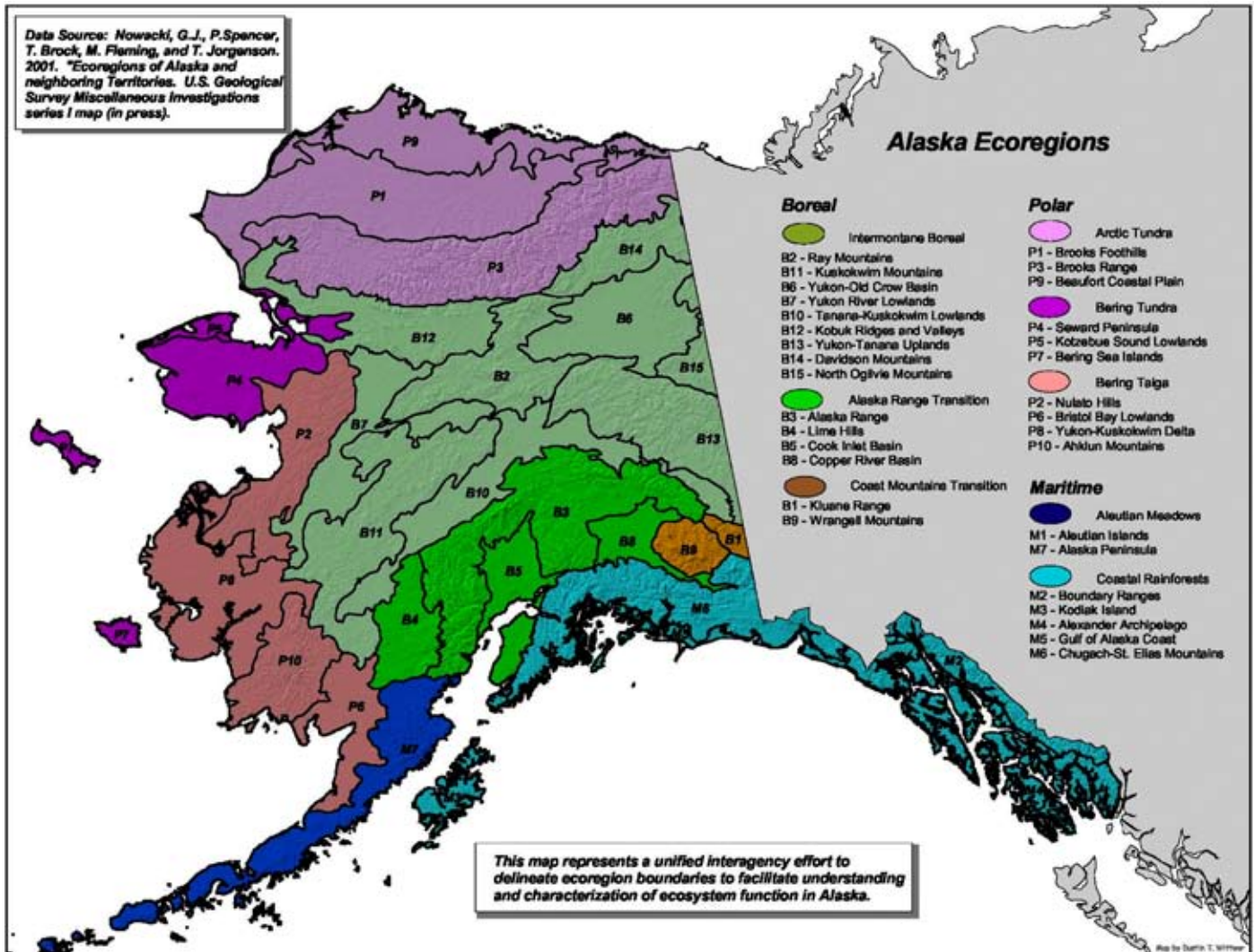
SNAP now has spatially explicit data (maps) of mean monthly temperature and precipitation projections for three different emissions scenarios, including the A2 scenario, which predicts rapid and unchecked increases in anthropogenic greenhouse gas emissions, the B1 scenario, which predicts swift leveling followed by significant decline of emissions, and the A1B scenario, which falls between the other two. For each emission scenario, SNAP has mapped outputs from each of the five selected models as well as a composite of all five. SNAP has also created maps showing the standard deviations between the outputs of the five models, in order to provide information on the spatial distribution of model uncertainty.

STATEWIDE AND REGIONAL CLIMATE PROJECTIONS

SNAP IS NOW working on making maps and data sets more readily available to the public by converting selected data sets from ASCII format to static maps and to KML (Google Earth) format. These KML maps allow users to select maps, view time series, and to zoom in on areas of interest. For researchers interested in using the full breadth of SNAP data, all of our ASCII files can also be downloaded from our website.

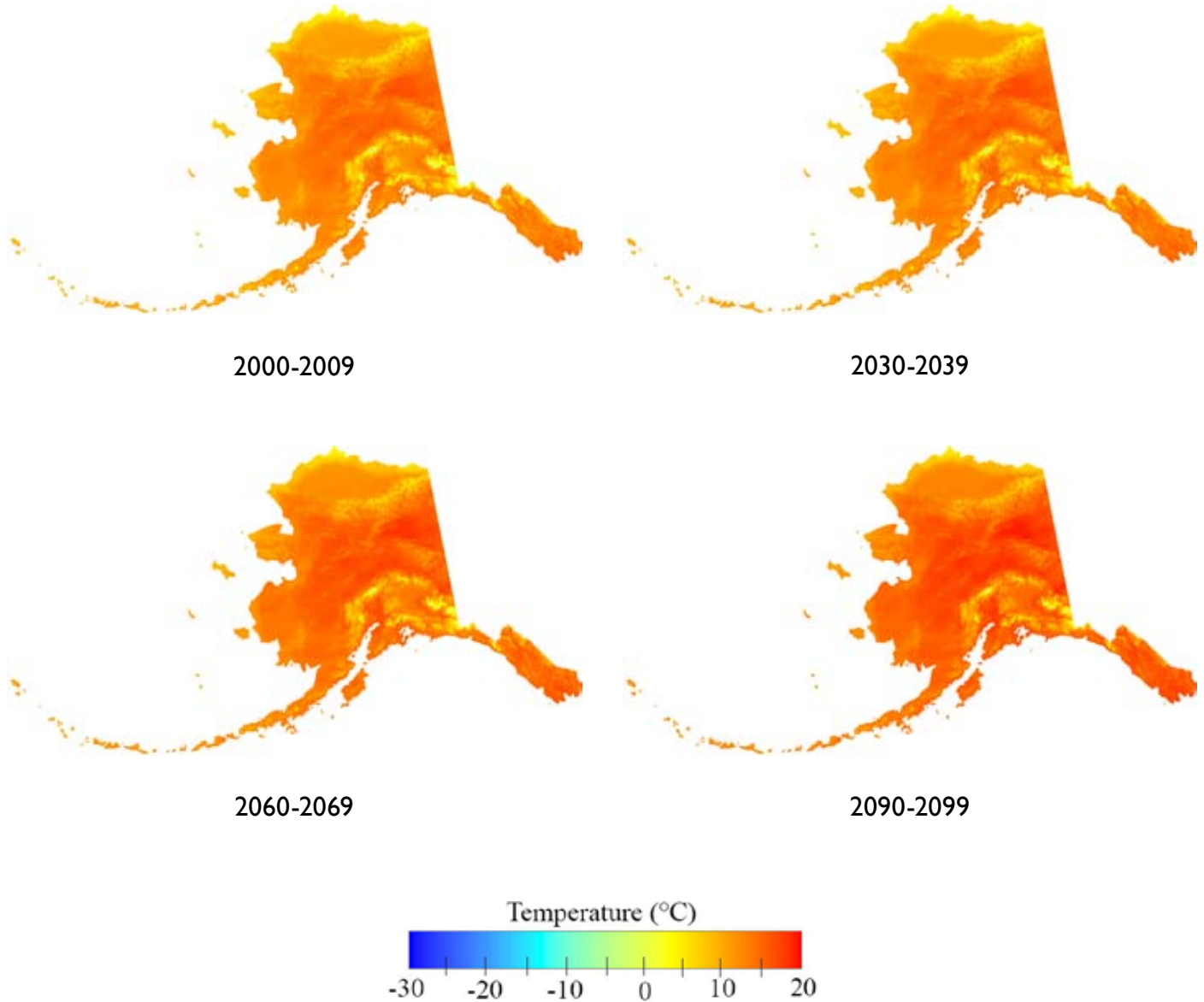
The maps shown on the following pages represent a small subsample of available data. They focus primarily on mean model output for the AIB emissions scenario, and on four time slices within this

century, although similar data are available for the A2 and B1 scenarios and for intervening decades. The 2km resolution of SNAP maps allows for unprecedented fine-scale analysis. Indeed, community-specific data are available for 353 communities statewide. However, this document addresses climate scenarios at the statewide level. As such, all maps and graphs represent either the whole state or one of eight primary sub-regions (shown below). Based on the needs and requests of the State of Alaska and other stakeholders, SNAP can alter the range, depth, and scale of data available in KML format, static maps, and graphs, as well as providing explanatory text and metadata for all of our outputs.



TEMPERATURE PROJECTIONS: SUMMER

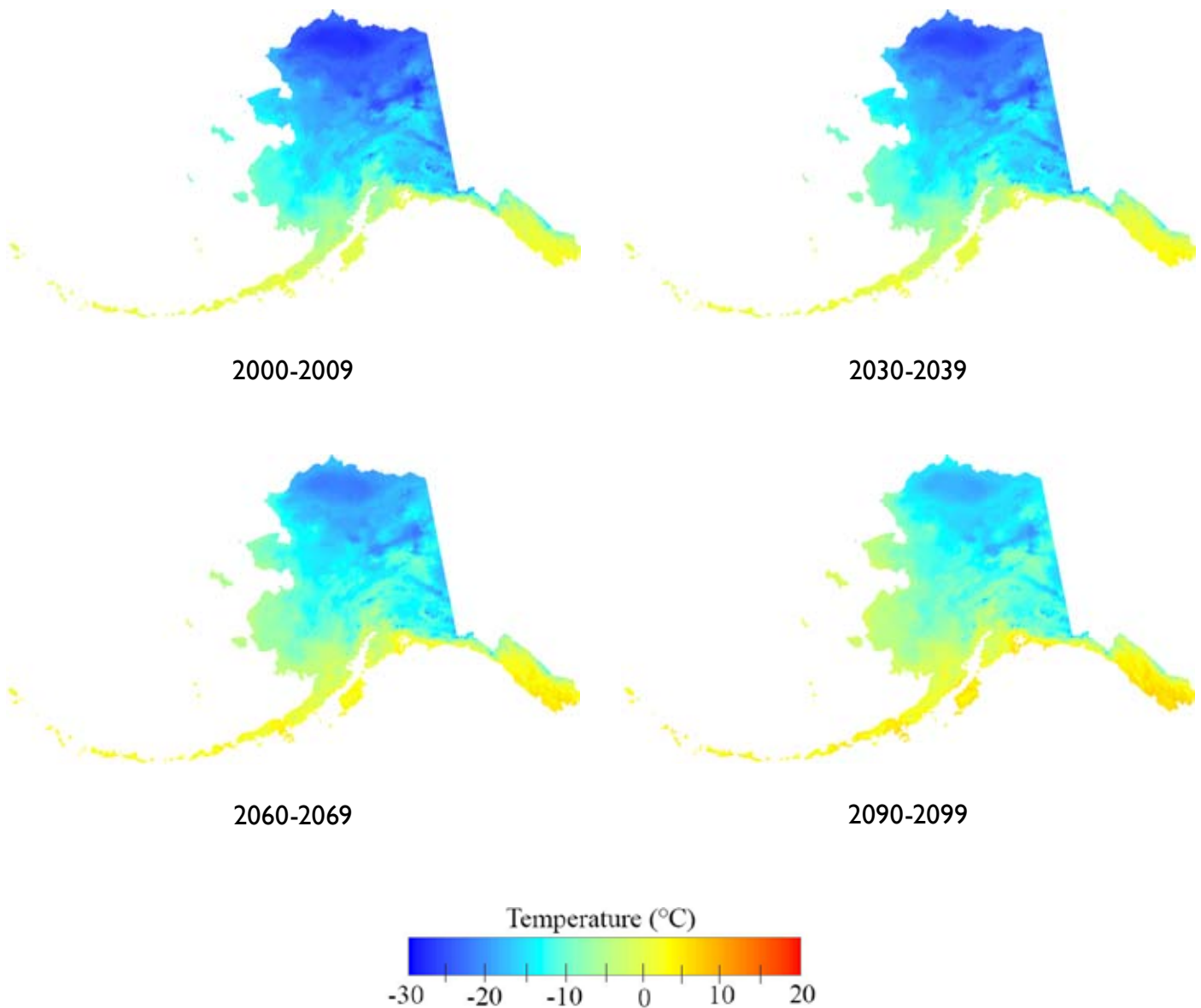
THE PROJECTIONS BELOW show mean temperatures for June, July, and August for selected decades. SNAP models project that summer temperatures will increase across all regions of Alaska. Temperature increases are predicted for every month, and increases are expected to continue throughout the century.



*Projections of statewide mean summer temperatures (June-August).
These maps are based on mean monthly outputs from five downscaled GCMs.*

STATEWIDE TEMPERATURE PROJECTIONS: WINTER

IN GENERAL, SNAP models project that temperature increases will be greater during winter months (December, January, and February) than summer months. The maps below show particularly marked increases in the state's interior and far north.

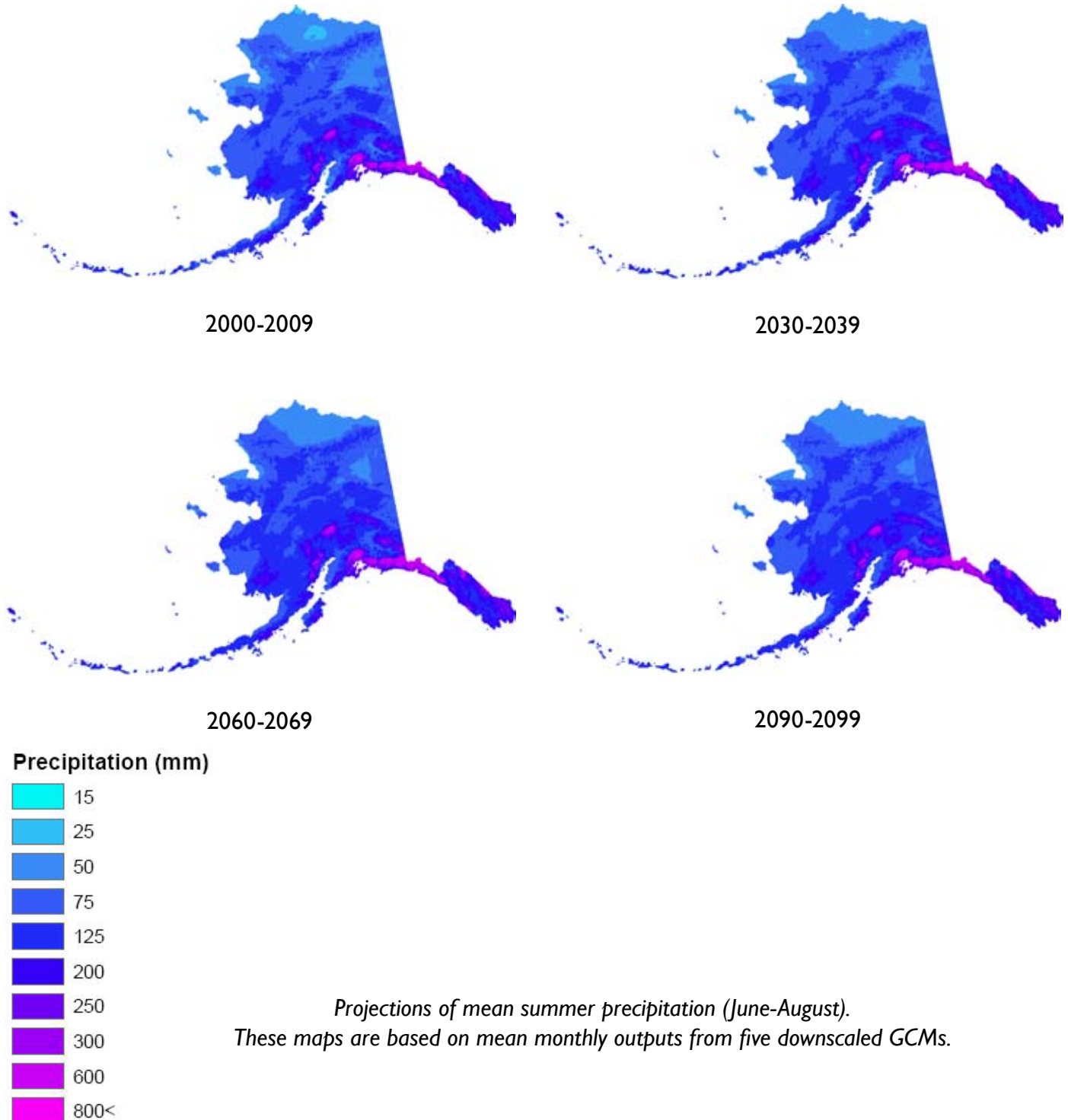


*Projections of mean winter temperatures (December-February).
These maps are based on mean monthly outputs from five downscaled GCMs.*

STATEWIDE PRECIPITATION PROJECTIONS: SUMMER

PRECIPITATION DURING SUMMER months (June, July, and August) is projected to increase statewide. However, it is important to note that precipitation alone does not predict ecosystem moisture limitations. In some areas, increased plant growth and increased evapotranspiration due to higher temperatures may more than offset the additional precipitation, resulting

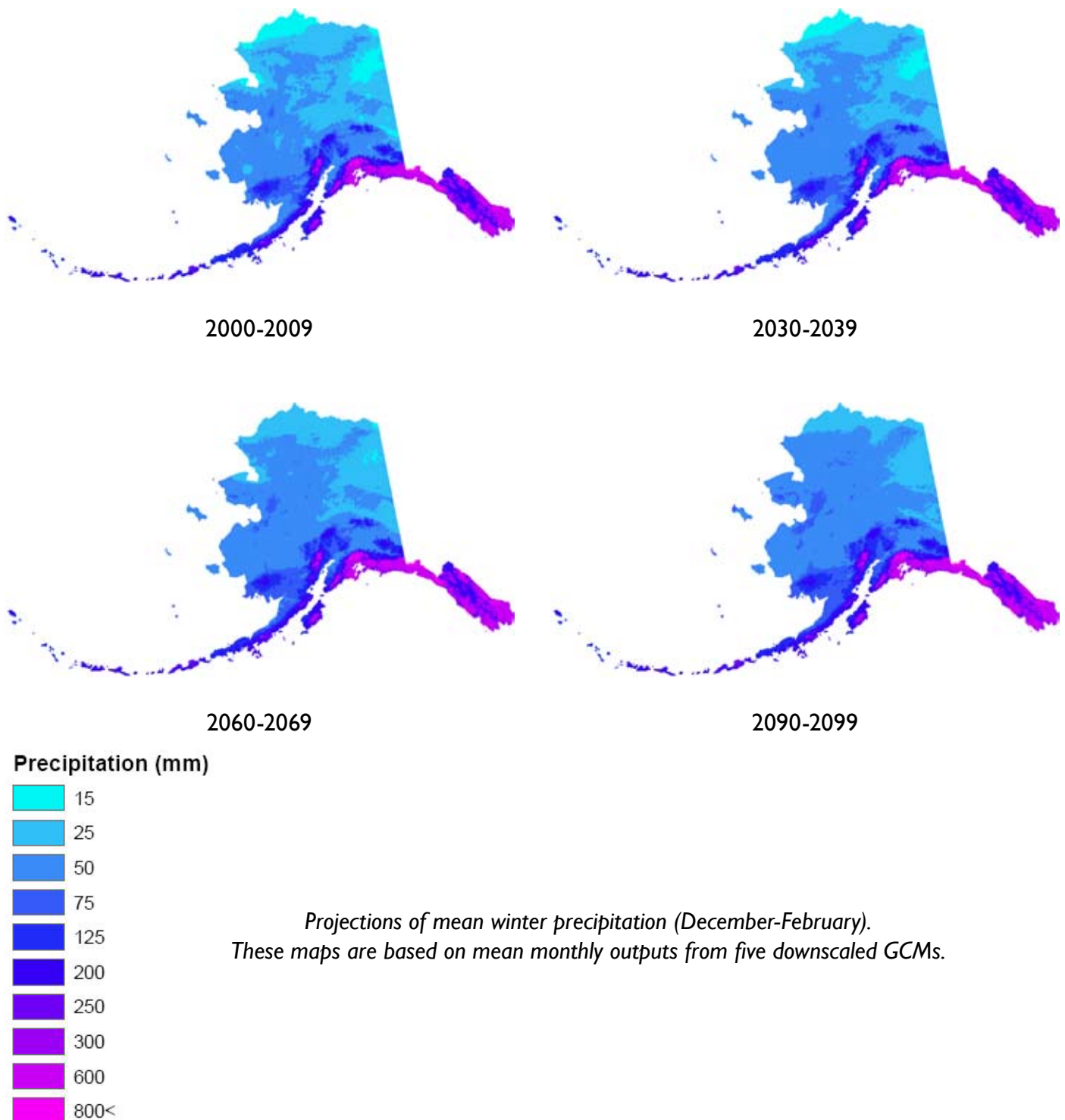
in overall drying of soils. In addition, the timing of precipitation can greatly affect its impacts. For example, low spring rainfall or early loss of snowpack can cause drought stress even if annual rainfall is relatively high.



*Projections of mean summer precipitation (June-August).
These maps are based on mean monthly outputs from five downscaled GCMs.*

STATEWIDE PRECIPITATION PROJECTIONS: WINTER

WINTER (DECEMBER, JANUARY, and February) precipitation is projected to increase statewide. However, concurrent increases in temperature may result in a smaller percentage of winter precipitation occurring as snow, and may reduce the time in which snowpack remains on the ground. Large storms or rain-on-snow events can trigger flooding or erosion.

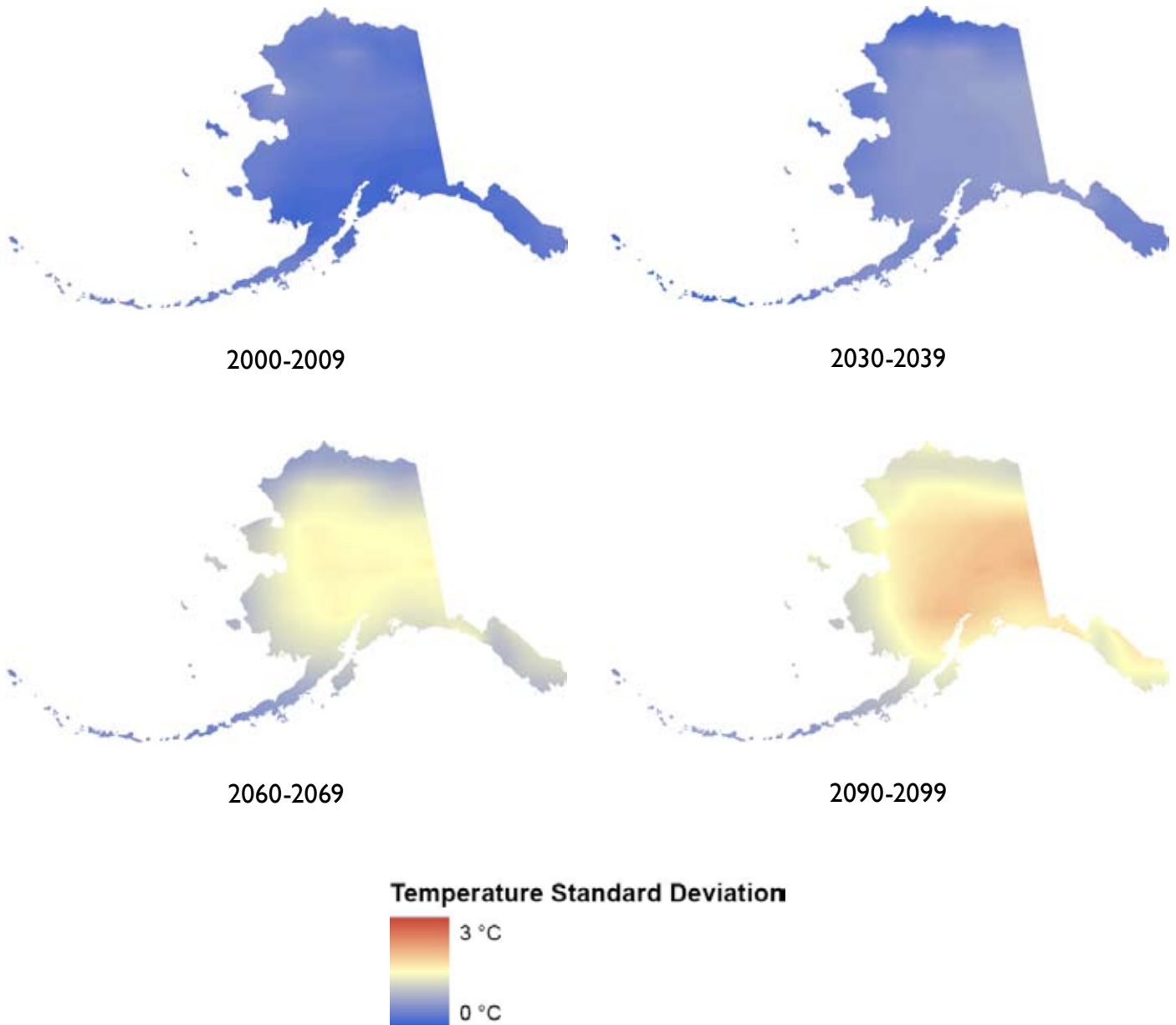


*Projections of mean winter precipitation (December-February).
These maps are based on mean monthly outputs from five downscaled GCMs.*

UNCERTAINTY: SUMMER TEMPERATURE

ALTHOUGH SNAP’s CLIMATE projections are based on the best available models, they are estimates only. Variation between model outputs is to be expected. Each of the five GCMs used is based on different algorithms. In addition, annual variation within each model mimics the stochastic nature of weather patterns.

The maps on the preceding pages are based on mean values from the five best-performing GCMs identified by SNAP. The maps below and on the following page show a spatial representation of the variability (standard deviation) among the outputs of these five models. Concurrence among models is relatively high for short-term projections, but uncertainty tends to increase as projections move further into the future.

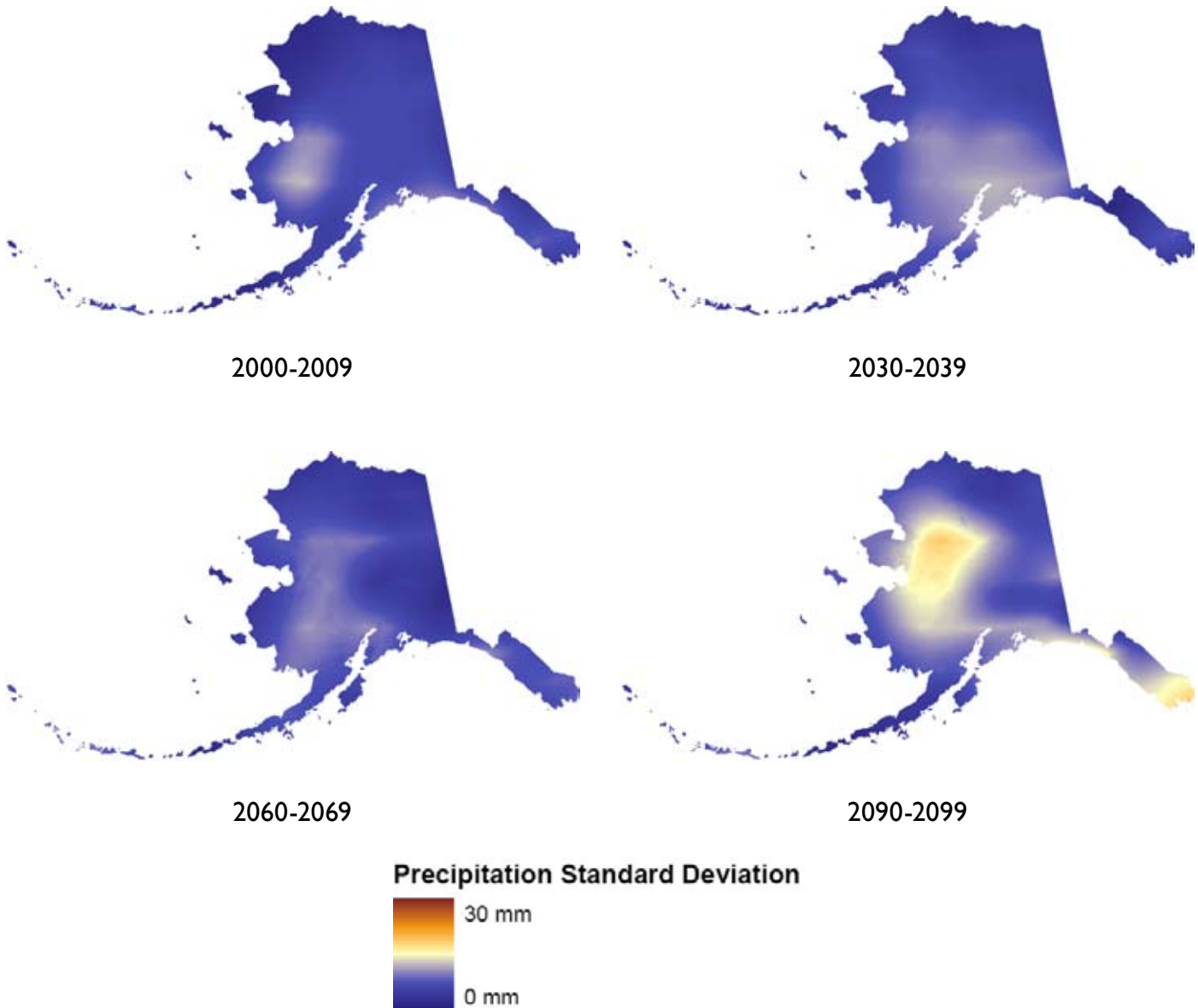


Standard deviation of values for summer temperature among outputs from five downscaled GCMs.

UNCERTAINTY: SUMMER PRECIPITATION

AS WITH TEMPERATURE projections, the standard deviation among model outputs for precipitation projections increases as the length of the timeframe increases. In general, the percentage of uncertainty is higher for precipitation than for temperature, particularly for dry regions where small differences can represent large percentage changes. While

a standard deviation of 10-15mm is relatively small in southeast Alaska, where summer precipitation can be as high as 800mm, it is relatively high in the interior and northern regions of the state, where summer precipitation can be as low as 15-25mm.



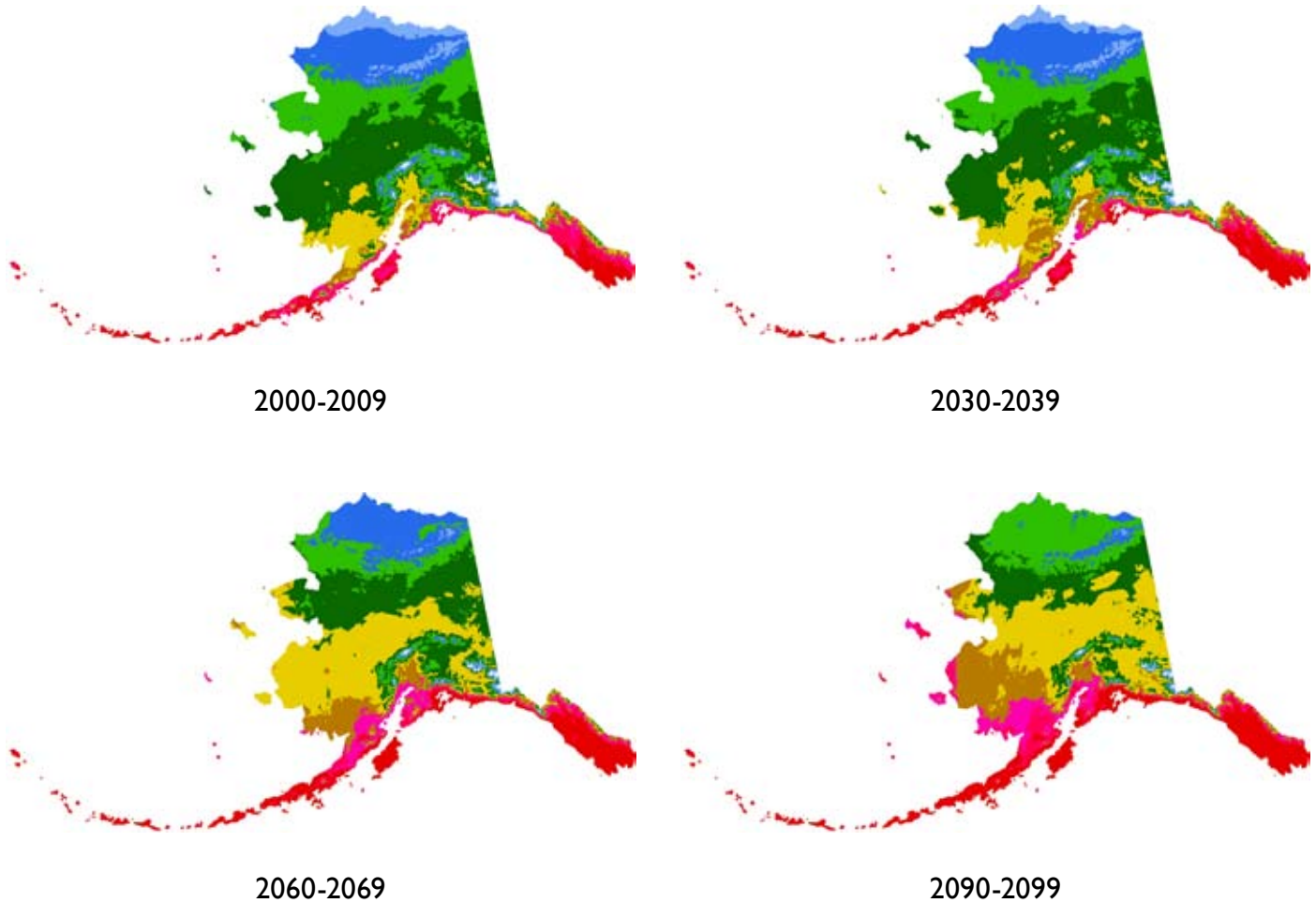
Standard deviation of values for summer precipitation among outputs from five downscaled GCMs.

SEASON LENGTH: DAYS FROM THAW TO FREEZEUP

ACROSS THE STATE, length of summer season is projected to increase, and winters conversely are projected to shorten. The maps below depict the time interval between spring thaw and autumn freeze-up, as defined by the time at which mean temperatures cross 0°C. These data were derived by interpolating daily temperature values based on linear temperature

ramps between monthly means. Mean values were assumed to occur in the middle of each month.

Areas which do not experience mean temperatures below freezing appear in red on these maps. Striking increases in growing season length are projected across the southcentral, interior, and northern regions of the state.



Growing Season Length (days)

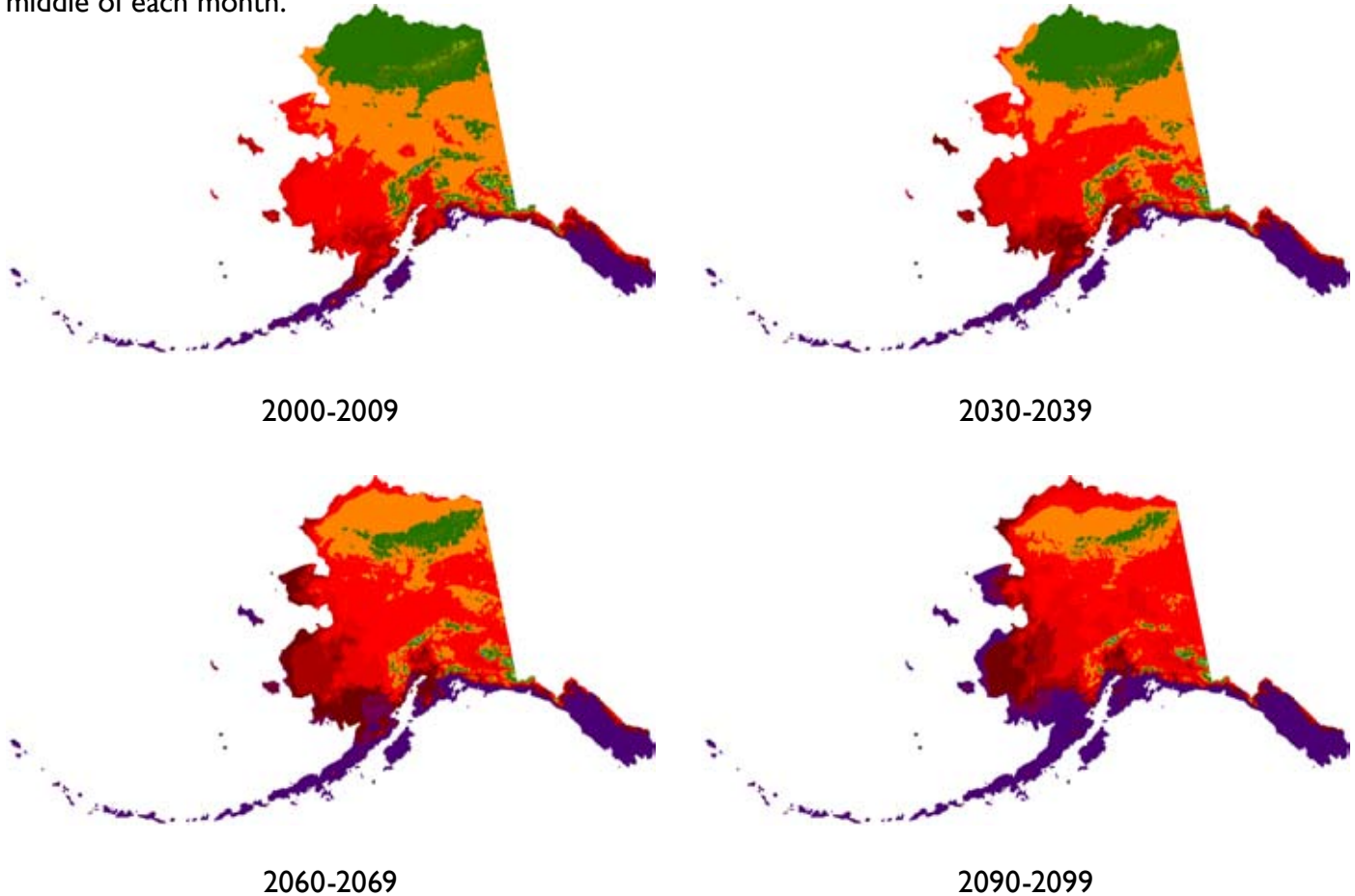
- 0
- 70
- 120
- 140
- 160
- 185
- 215
- 250
- 295
- 335

Projection of the number of days between the times when mean temperature will cross the freezing point (0°C) in spring and in fall. These values were derived via interpolation of mean monthly temperatures.

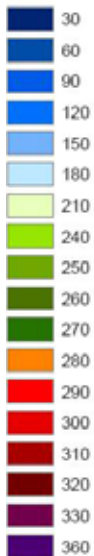
SEASON LENGTH: DATE OF AUTUMN FREEZEUP

THE MAPS BELOW show projections for the shift in the date of fall freezeup, as defined by the time at which mean temperatures cross 0°C. These data were derived by interpolating daily temperature values based on linear temperature ramps between monthly means. Mean values were assumed to occur in the middle of each month.

Areas which do not experience freezeup are shown in purple. As points of reference, September 1 corresponds to ordinal day 244, October 1 is day 274 November 1 is day 305, and December 1 is day 335.



Mean Date of Freeze-Up (Ordinal Date)

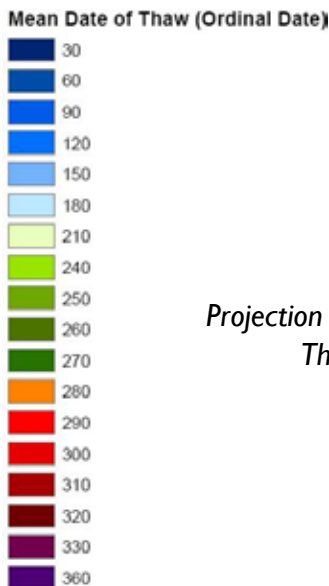
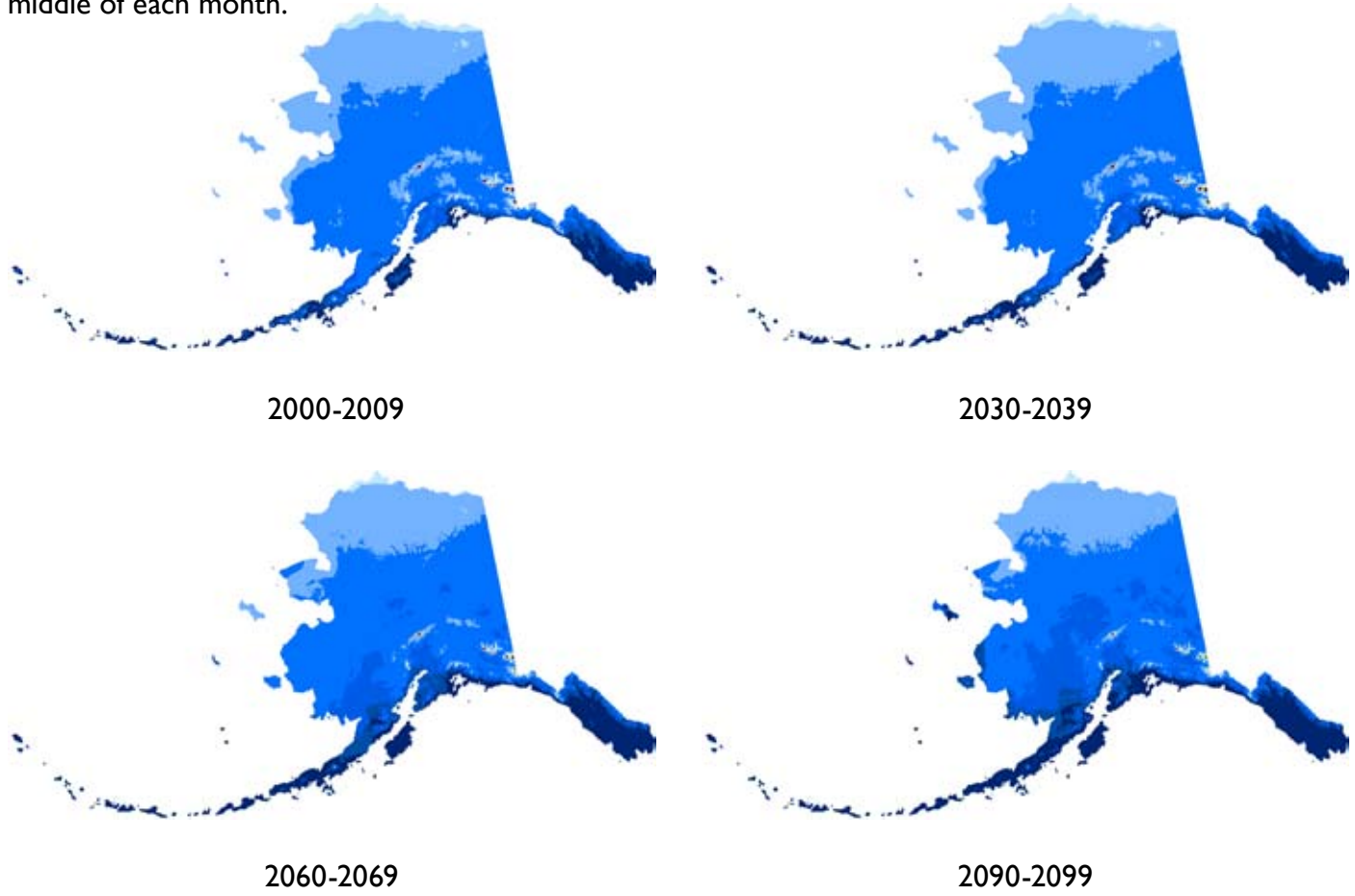


Projection of mean date at which temperatures will cross the freezing point (0°C) in fall. These values were derived via interpolation of mean monthly temperatures.

SEASON LENGTH: DATE OF SPRING THAW

THE MAPS BELOW show projections for the shift in the date of spring thaw, as defined by the time at which mean temperatures cross 0°C. These data were derived by interpolating daily temperature values based on linear temperature ramps between monthly means. Mean values were assumed to occur in the middle of each month.

Areas which do not experience freezeup or thaw are shown in dark blue. As points of reference, March 1 is ordinal day 60, April 1 is day 91, May 1 is day 121, and June 1 is day 152.



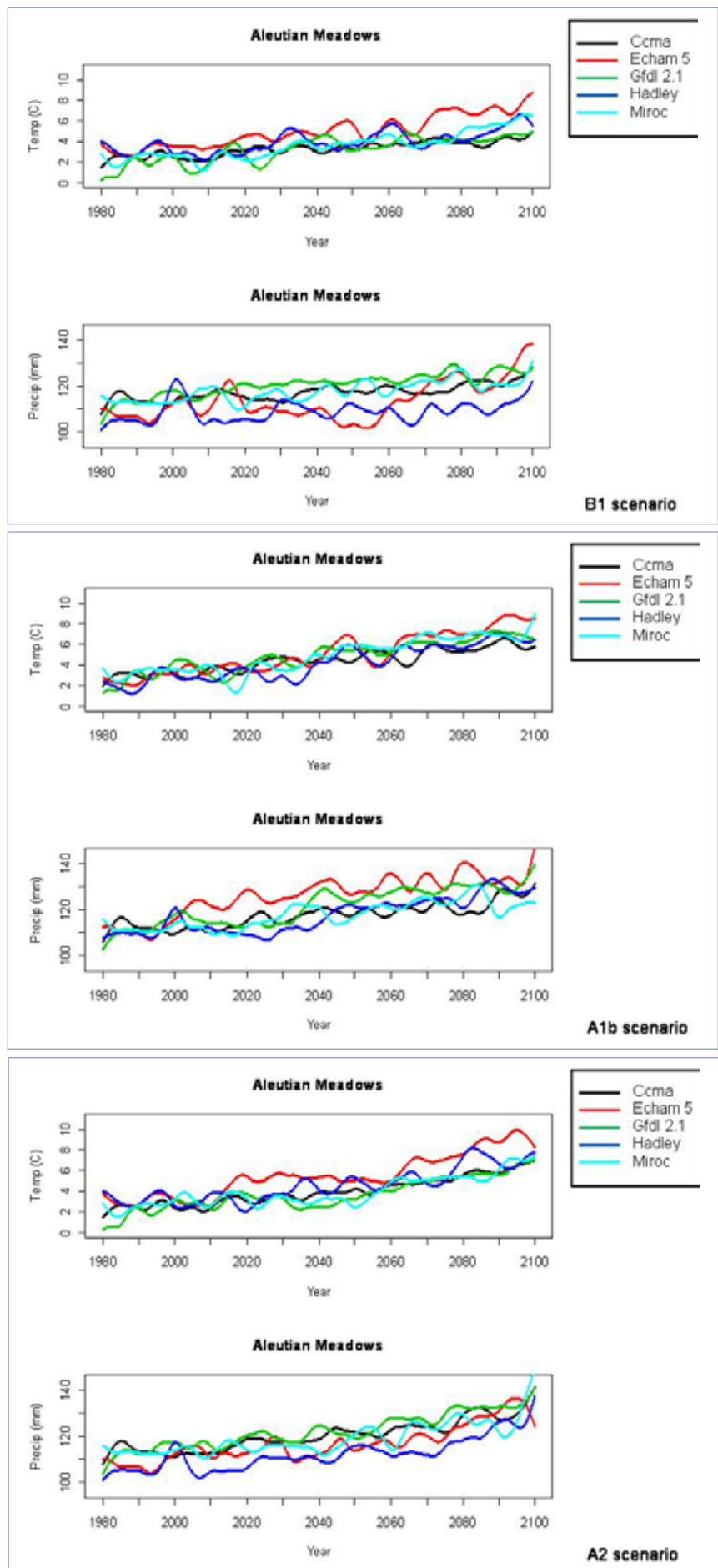
Projection of mean date at which temperatures will cross the freezing point (0°C) in spring. These values were derived via interpolation of mean monthly temperatures.

REGIONAL TIME SERIES FOR THREE EMISSION SCENARIOS

THE GRAPHS ON the following pages show temperature and precipitation projections for all five models for eight Alaskan ecoregions. Each set of maps demonstrates the contrast between model outputs for the B1 (low), A1B (midrange), and A2 (high) emission scenarios.

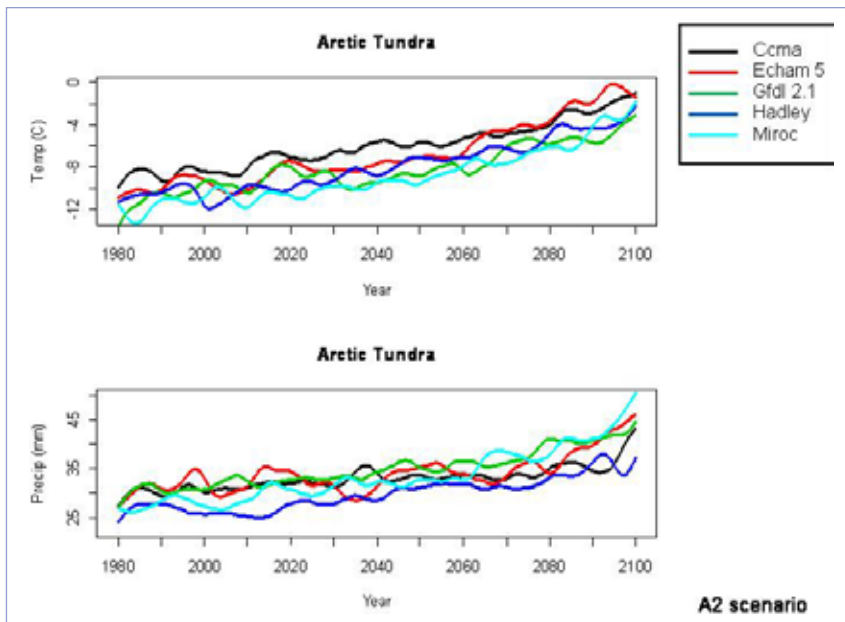
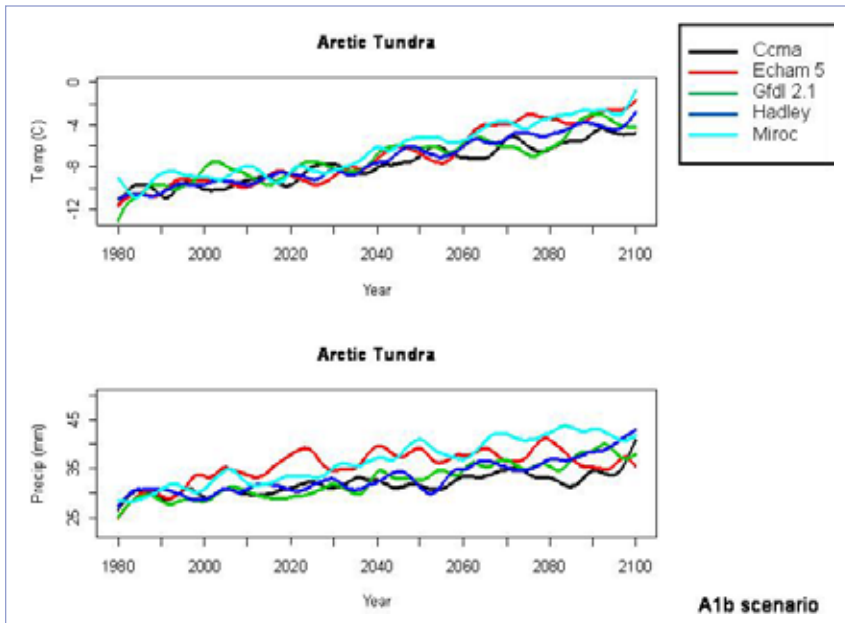
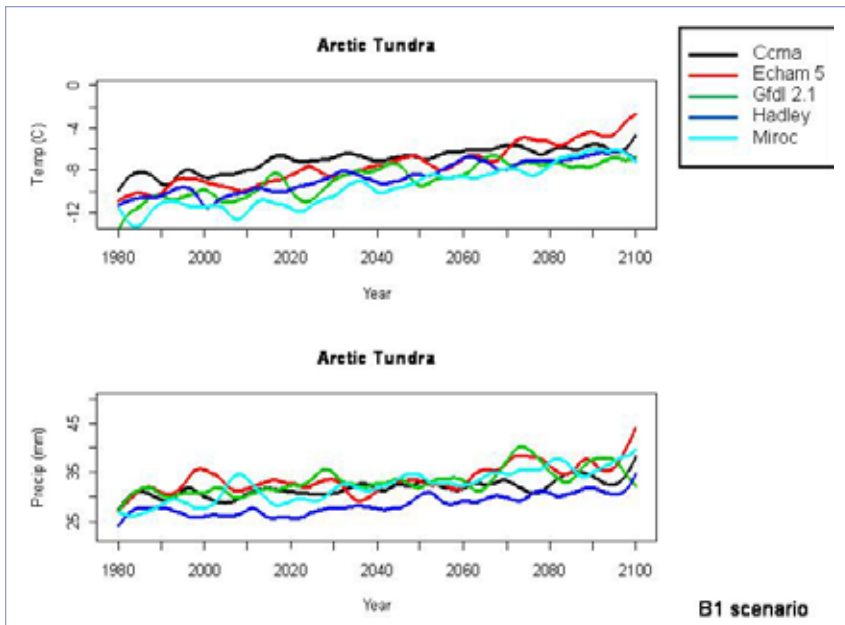
ALEUTIAN MEADOWS

As compared to inland and northern regions, more modest temperature increased are projected for this ecoregion.



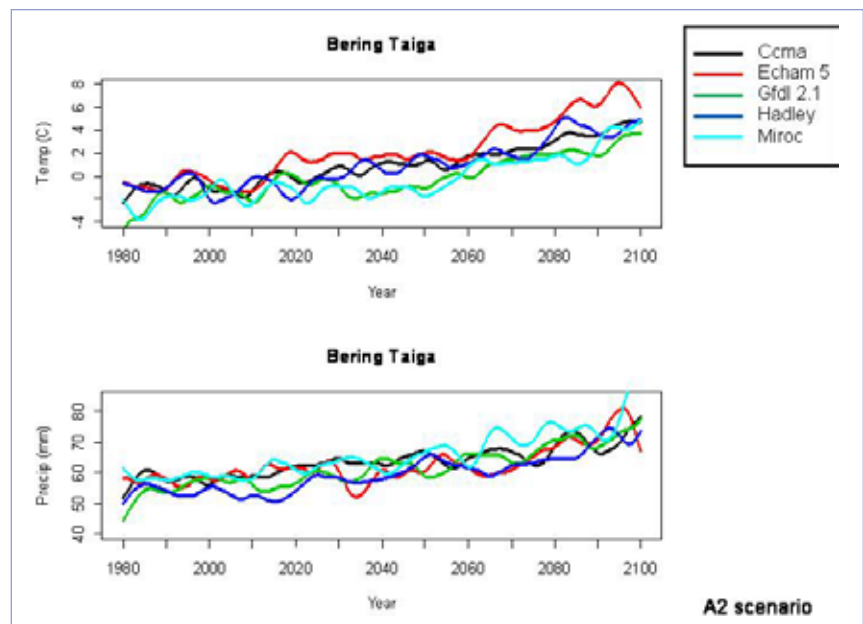
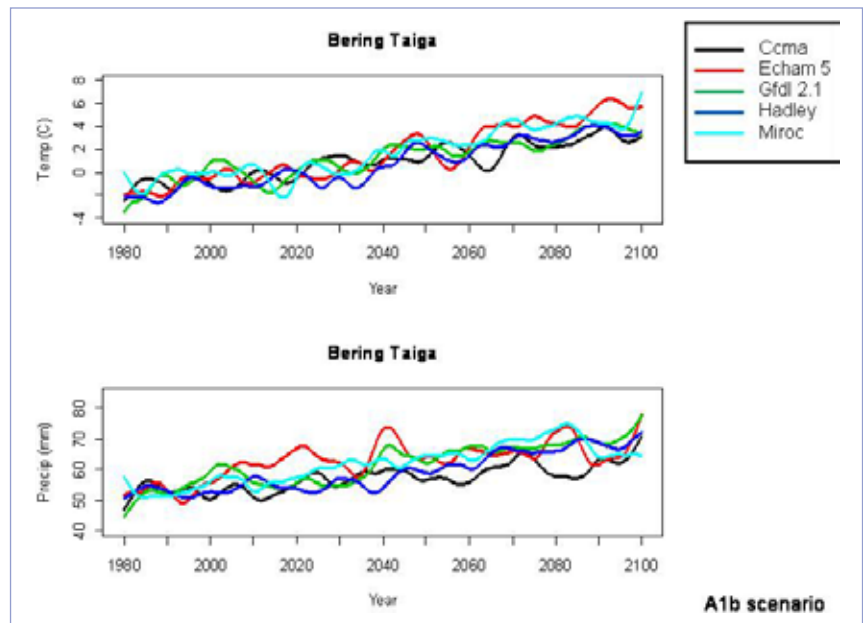
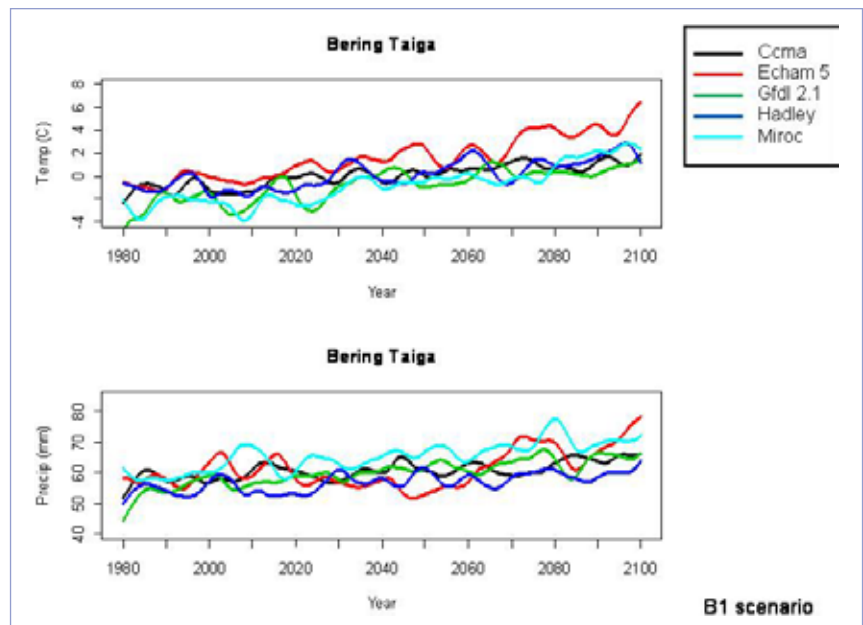
ARCTIC TUNDRA

Low precipitation in this ecoregion accentuates variability among model outputs.



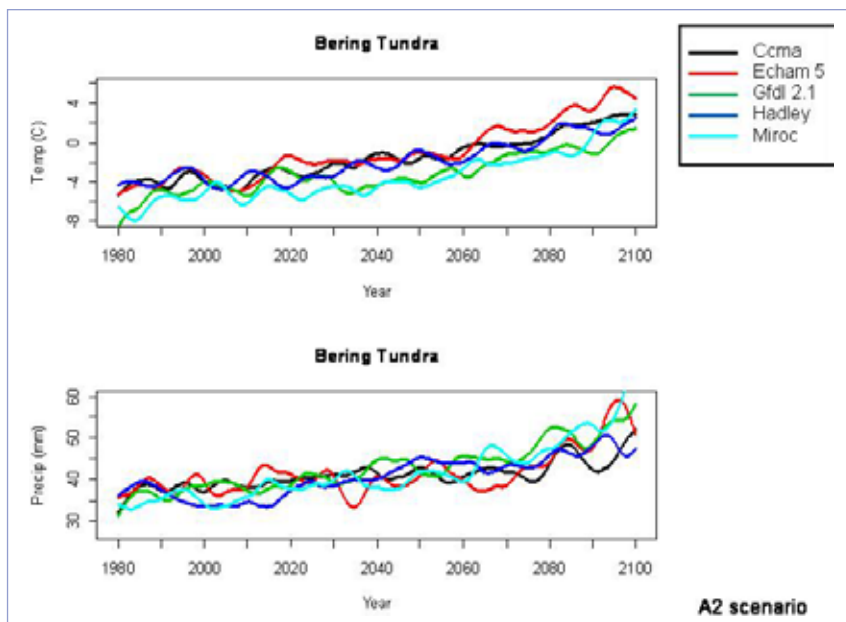
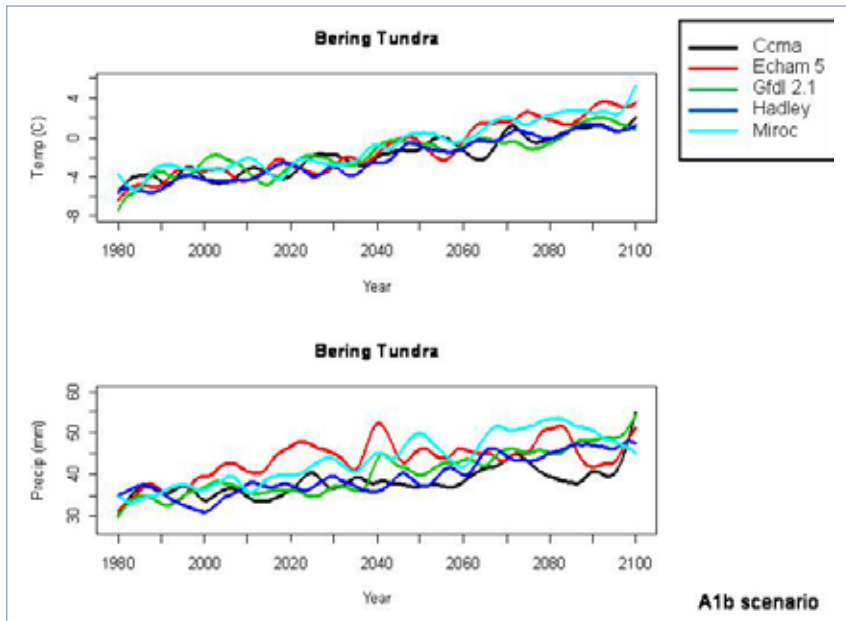
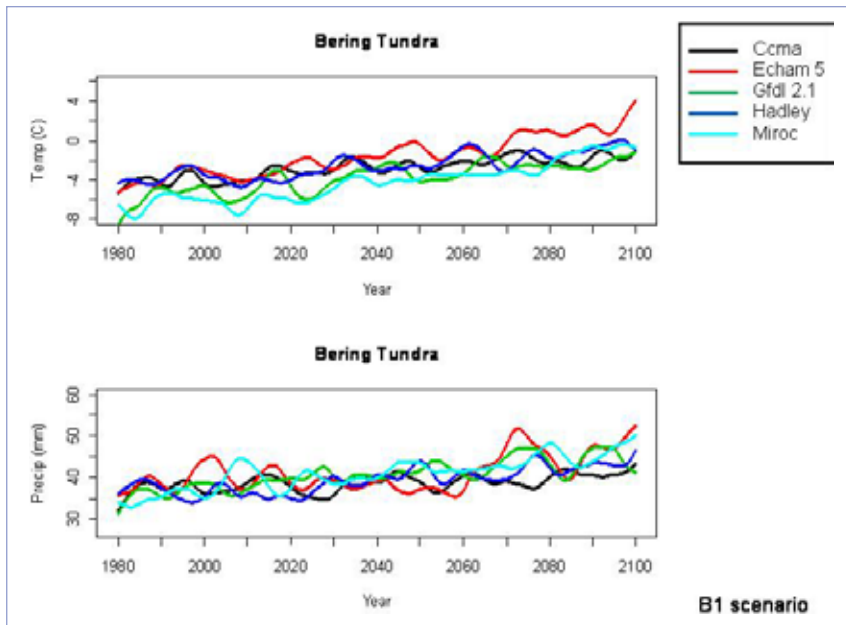
BERING TAIGA

Mean annual temperatures in this ecoregion are projected to rise from below freezing to above freezing in all scenarios.



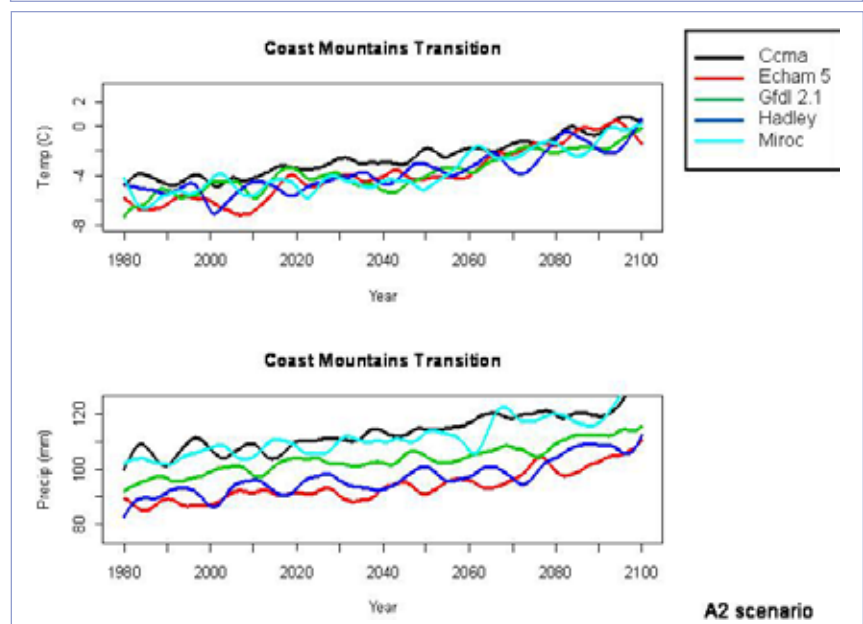
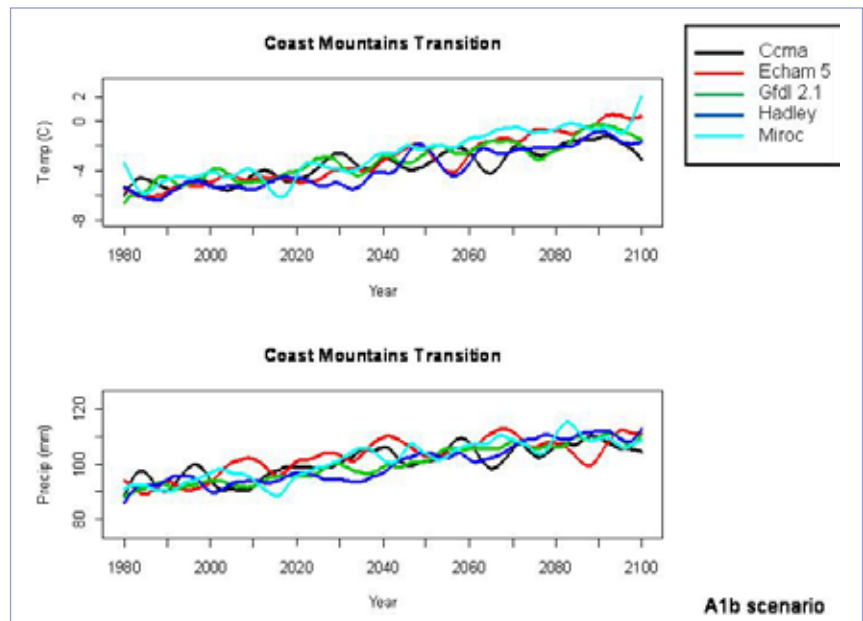
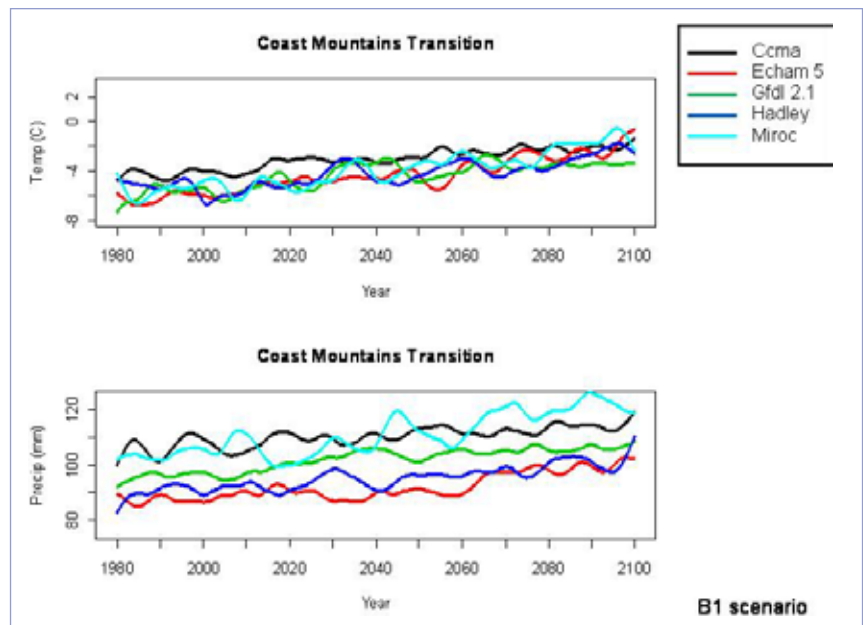
BERING TUNDRA

The northern regions of the state, including the Bering Tundra and the Arctic Tundra, are projected to experience the greatest overall temperature increases.



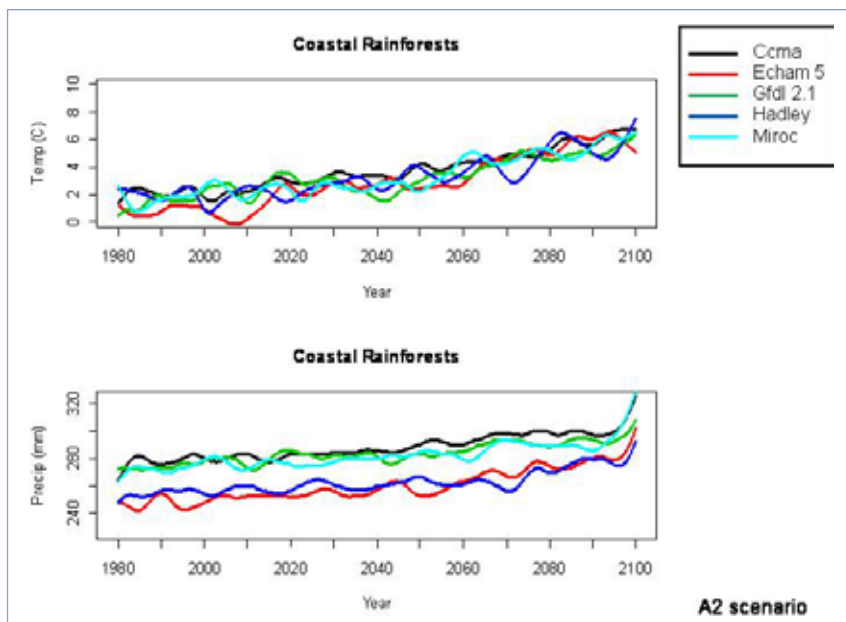
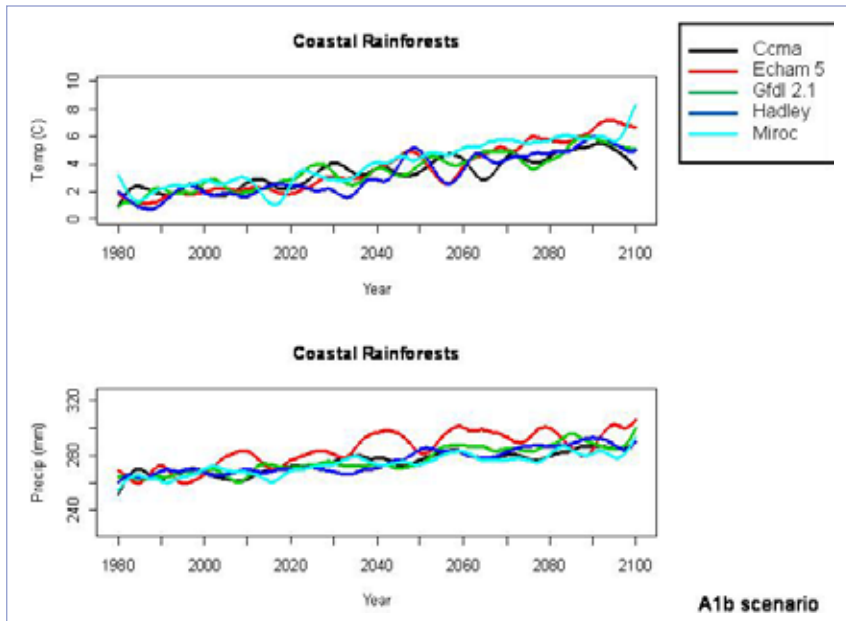
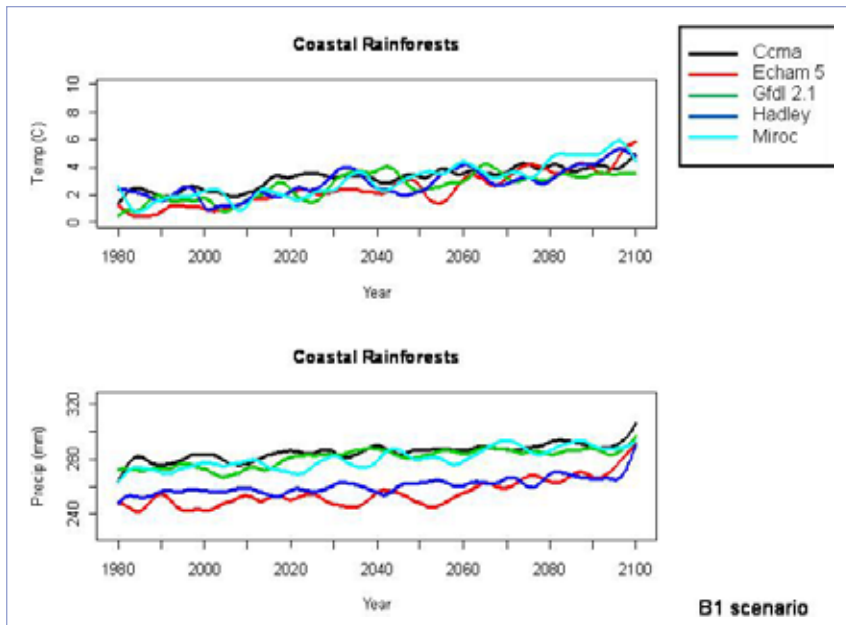
COAST MOUNTAINS TRANSITION

Note that some of the variability between models can be attributed to interannual variability within each model, but that in some cases a particular model output is consistently higher or lower than that of other models.



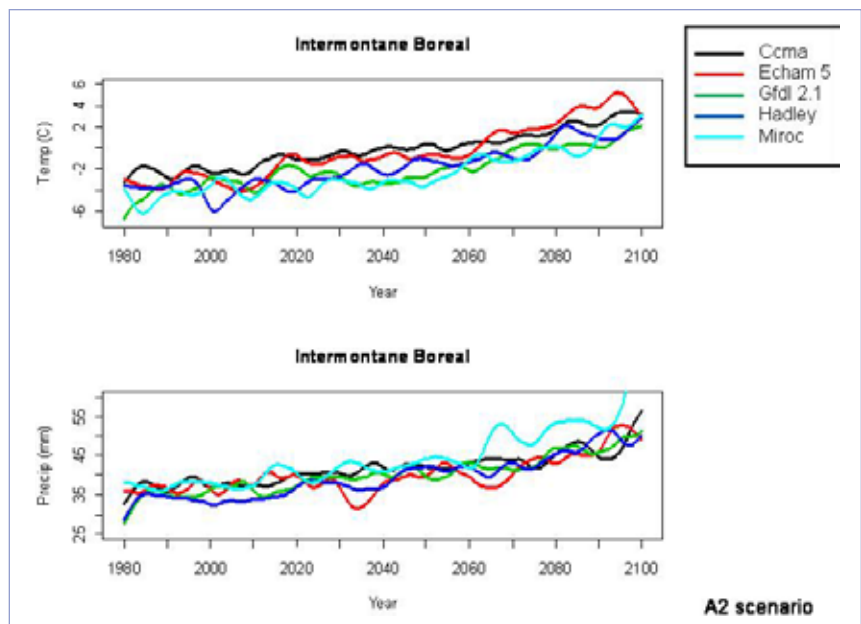
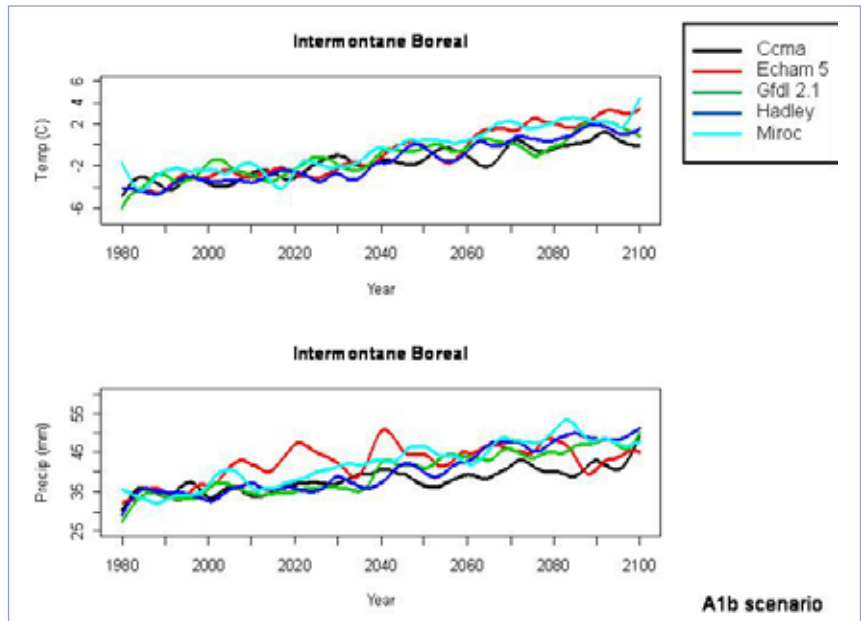
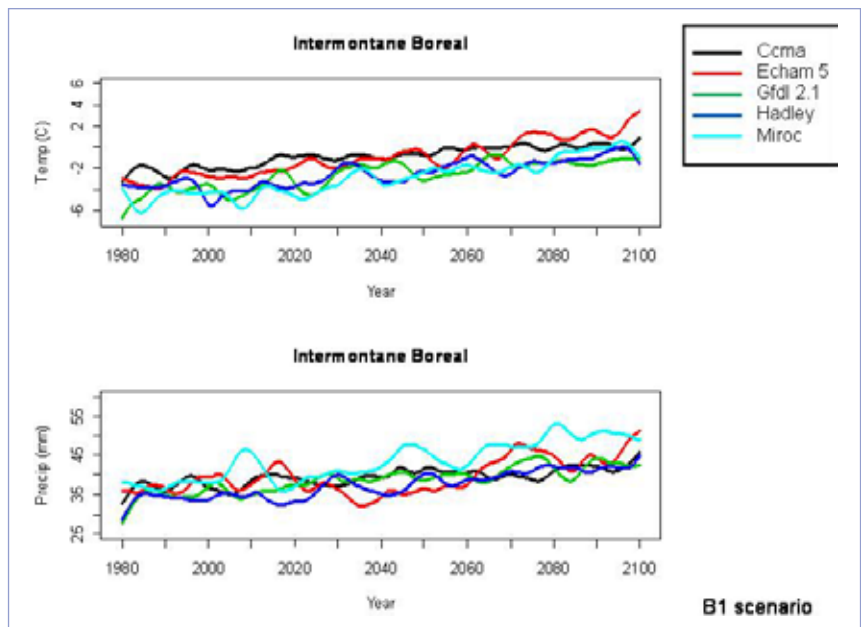
COASTAL RAINFORESTS

All models predict modest increases in the already extremely high rainfall experienced in this ecoregion.



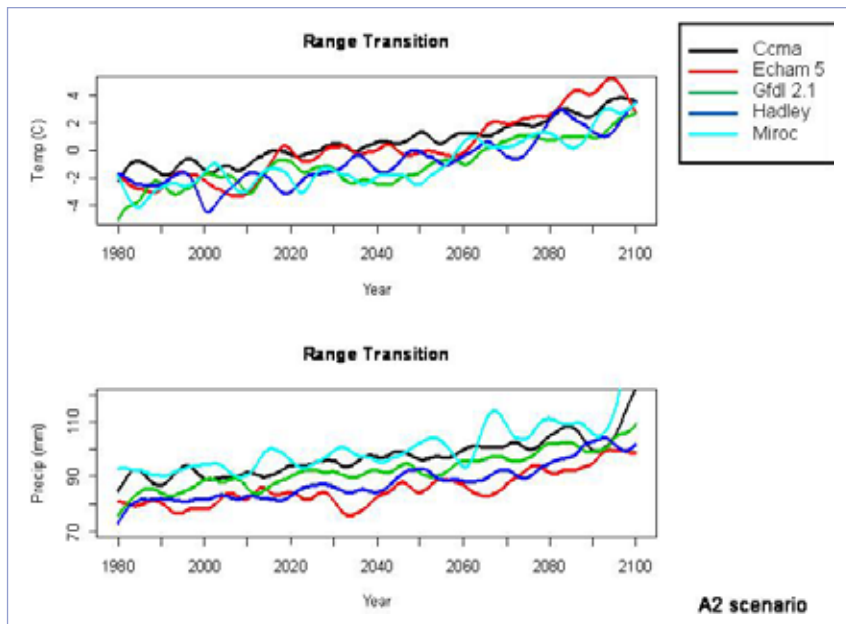
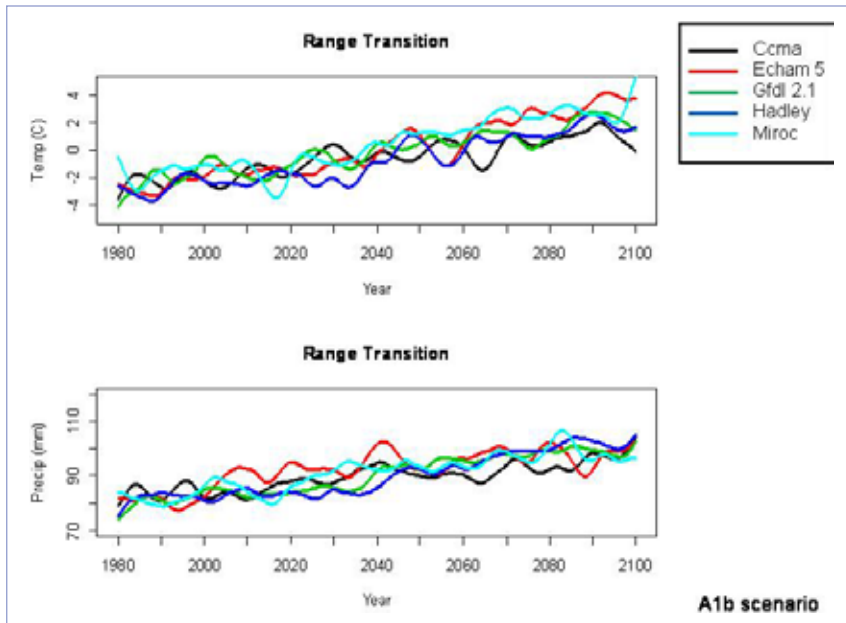
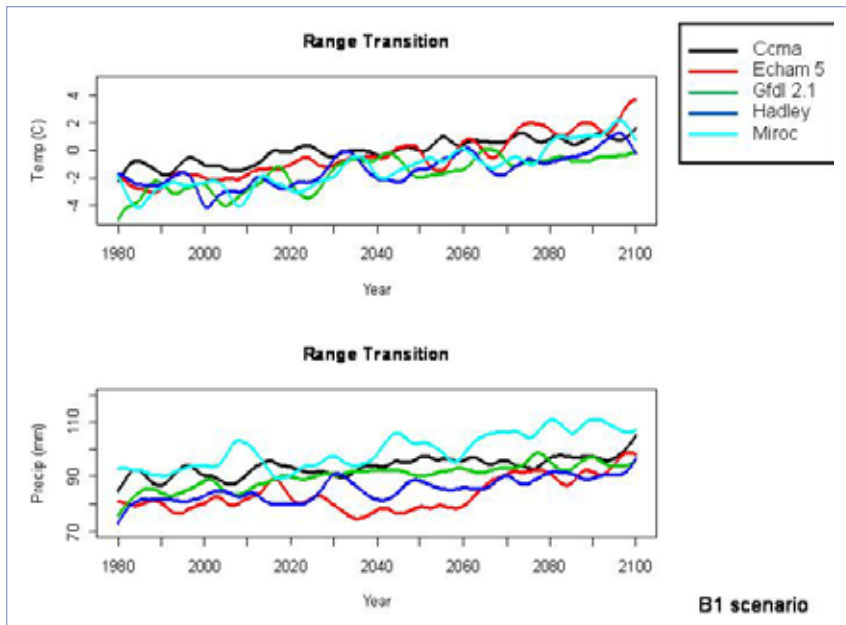
INTERMONTANE BOREAL

Mean annual temperatures in this region are projected to rise from well below freezing to above freezing in all but the BI scenario.



RANGE TRANSITION

Mean annual temperatures in this region are projected to rise from well below freezing to above freezing in all but the BI scenario.



POTENTIAL FUTURE PRODUCTS

SNAP CLIMATE PROJECTIONS can be used in conjunction with additional data and research to create scenarios that address a wide range of issues. These include but are not limited to:

SUBSISTENCE RESOURCES

- Wildlife population changes
- Fish population changes
- Availability of sea ice and river ice for safe hunting
- Freeze-up dates for ease of travel and storage of game

INVASIVE SPECIES AND DISEASE

- Pests that affect agricultural crops
- Pests that affect natural ecosystems
- Human disease
- Disease in fish/wildlife
- Forest pests and associated changes in fire risk

SHIPPING ROUTES

- Northwest Passage
- Northern Sea Route

OIL & GAS EXPLORATION AND OPERATION

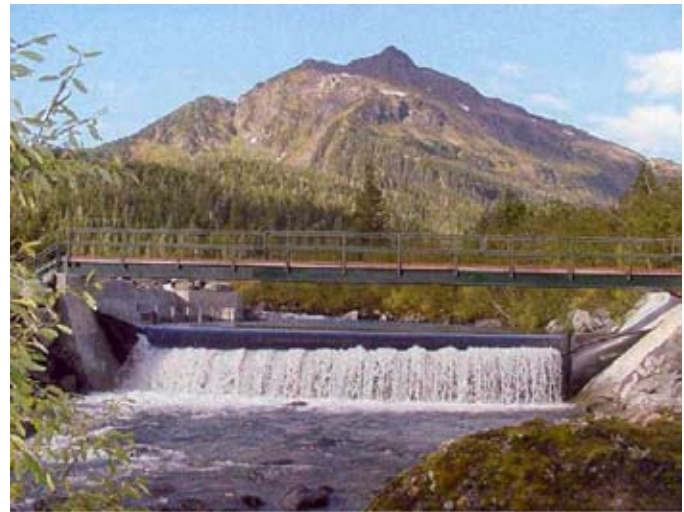
- Frozen ground, snow cover, and tundra travel
- Availability of water for ice roads

PERMAFROST THAW

- Structural integrity and engineering
- Hydrologic effects
- Ecosystem effects

EROSION AND FLOODING

- Coastal communities
- River communities
- Industry impacts



Powder Creek Hydroelectric Project, Cordova
(Alaska Energy Authority)

MARINE FISHERIES

- Ecological impacts
- Economic impacts

HYDROLOGY AND WATER RESOURCES

- Drinking water
- Industrial uses
- Wildlife habitat



Melting sea ice may open new shipping routes in the near future.

(UNEP/GRID Arendal)

ALTERNATIVE ENERGY RESOURCES

- Hydropower
- Wind power
- Solar potential
- Biomass power

In most cases, creating these secondary products requires additional time and funding, as well as input from participating partners. Collaborative agreements can be set up between SNAP and stakeholders in government, industry, private enterprise, or nonprofit organization.

To learn more about SNAP or to download Alaska climate projections, visit our website: www.snap.uaf.edu or contact: Dr. Nancy Fresco: ffnlf@uaf.edu (907) 474-2405.

Maps, graphs, data, and text in this report were produced by the SNAP integration team and SNAP collaborators, including John Walsh, Scott Rupp, Mark Olson, Anna Springsteen, Tim Glaser, Paul Duffy, Jen Schmidt, Bill Chapman, Sarah Trainor, Pete Larson, Terry Chapin, and Nancy Fresco.

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