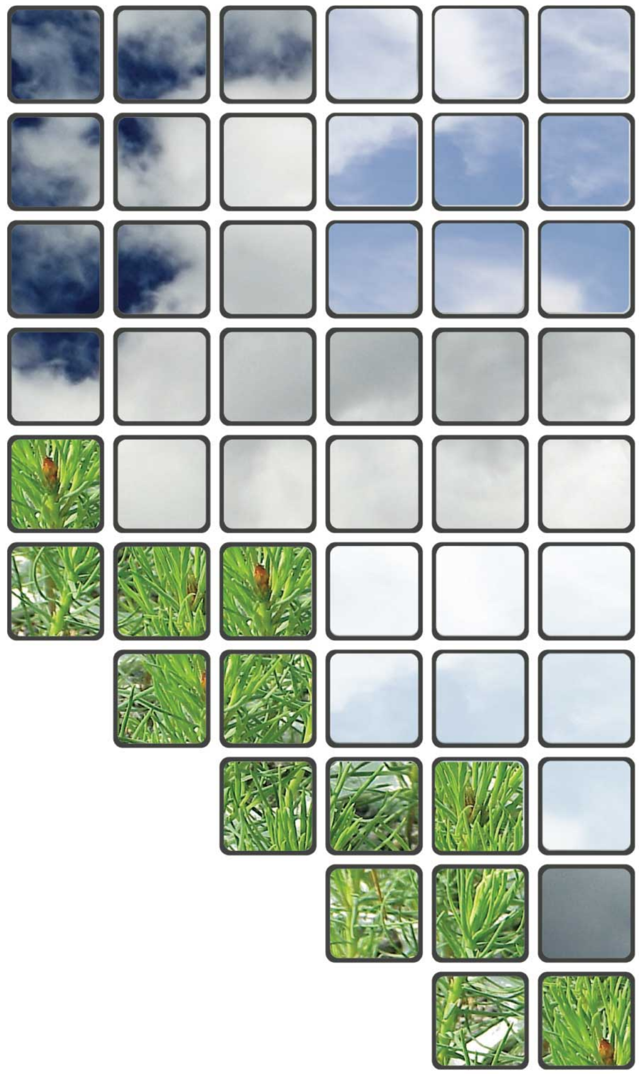

A COMPREHENSIVE SET OF INTERPOLATED

Climate Data for Alberta

Government of Alberta

A COMPREHENSIVE SET OF INTERPOLATED CLIMATE DATA FOR ALBERTA

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Publication Number: Ref. T/235

ISBN No. 978-0-7785-9184-9 (On-line Edition)

ISBN No. 978-0-7785-9183-2 (Printed Edition)

Printed November, 2010

This document can be found on the Alberta Sustainable Resource Development website:

http://www.srd.alberta.ca/MapsFormsPublications/Publications/AD.aspx

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EXECUTIVE SUMMARY

We present an easily accessible database of interpolated climate data for Alberta that includes monthly, annual, decadal, and 30-year normal climate data for the last 106 years (1901 to 2006), as well as climate change projections for the 21st century from 23 general circulation models. The database builds on the Alberta Climate Model (Alberta Environment 2005) and a set of five future projections that are recommended and widely used by Alberta government agencies (Barrow and Yu 2005). We added 15,000 historical and projected climate surfaces that include variables relevant for biological research and infrastructure planning, such as growing and chilling degree days, heating and cooling degree days, growing season length descriptors, frost free days and extreme minimum temperature. The database can be queried through a provided software package ClimateAB. A representative subset of these climate surfaces has been thoroughly checked against observed weather station data. We report error estimates for historical climate data and discuss the strengths and limitations of this database for use by natural resource managers and researchers.

Introduction

With the increasing concern over climate change, interpolated climate data have recently become essential for biological research and applications in forest management, conservation policy development, and infrastructure planning. Assessing potential impacts of observed or projected climate on natural systems is a prerequisite for developing adaption strategies. Past climate is usually available from weather station records, however very often these stations do not adequately cover all areas of interest. In order to obtain complete spatial coverages, weather station data are interpolated using a variety of techniques, including kriging and neural networks (Attorre et al. 2007), thin plate splines (Hutchinson 1995) or, for more complex landscapes, the Parameter Regression of Independent Slopes Model (PRISM), which is a combination of regression and expert knowledge of local weather patterns (Daly et al. 1994; Daly et al. 2002).

This paper presents interpolated climate data for Alberta generated with thin plate splines. The database includes monthly, annual, decadal, and normal climate data for the last 106 years (1901 to 2006) as well as climate change projections for the 21st century (23 models). Various climate datasets that include Alberta in their geographic coverage have previously been developed (Daly et al. 2000; Hijmans et al. 2005; McKenney et al. 2006; Mitchell and Jones 2005; New et al. 1999). However, these databases are not easily accessible to non-specialists because they come in various file formats, different geographic projections and resolutions, and sometimes as very large files with global coverage. Similar to previous work for British Columbia and the Yukon Territories (Hamann and Wang 2005; Wang et al. 2006; Mbogga et al. 2009), we have developed a database specifically optimized for Alberta's physical geography.

To make this database useful for resource managers in Alberta, we have built this database on monthly temperature and precipitation grids for the 1961-1990 normal period previously published by Alberta Environment (2005), which we included here without modifications. In addition, we included work by Barrow and Yu (2005), who selected five general circulation models to be used as a "standard" by Alberta government agencies and researchers for planning climate change adaptation strategies. We further added 15,000 historical and projected climate surfaces that include variables relevant for biological research and infrastructure planning, such as growing and chilling degree days, heating and cooling degree days, growing season length descriptors, frost free days and extreme minimum temperature. We report error estimates for a representative subset of climate variables and discuss the strengths and limitations of this database for use at different temporal and spatial scales in Alberta.

In order to efficiently query this database of approximately 15,000 climate surfaces, we provide an easy-to-use computer program ClimateAB, which runs on all versions of Windows (usually no installation required). The software overlays historical data and future projections as medium resolution anomalies (deviations) on the high resolution 1961-1990 normal data, a procedure that balances data quality with file size (Mbogga et al. 2009). The software can be used to interactively query locations of interest or to process spreadsheets of sample locations. Users can also process digital elevation models with a recommended resolution of up to 250m to generate climate surfaces using lapse-rate based "intelligent" down-sampling techniques described by Hamann and Wang (2005).

Methods

Climate datasets

As climate baseline dataset we used a 30 arc-second (or approximately 1km) resolution 1961-1990 climate averages from the Alberta Climate Model (Alberta Environment 2005). This model covers 36 climate variables: monthly average minimum and maximum temperature and precipitation. The Alberta

Climate Model was developed using ANUSPLIN software (Hutchinson 1995), which employs thin-spline techniques to interpolate weather station data from Alberta and surrounding jurisdictions (Alberta Environment 2005).

Monthly historical climate data for the 1901-2002 period was extracted from a global climate dataset (CRU TS 2.1) at 30 arc minute resolution (Mitchell and Jones 2005). Although this dataset is provided in absolute values for precipitation (mm) and temperature (°C), we recovered the original interpolated anomalies by subtracting a matching 1961-1990 normal dataset, which Mitchell and Jones provided. These anomalies were then overlaid on the high resolution normal dataset described above. Further, we updated Mitchell and Jones's data to 2006 using weather station data from the Adjusted Historical Canadian Climate Database (Mekis and Hogg 1999; Vincent and Gullett 1999; Vincent et al. 2002). Interpolated monthly anomaly surfaces for the 2000-2006 period were computed from weather station data (expressed as anomalies) using PROC G3GRID procedure with a spline smoothing factor of 0.01 (SAS Institute 2004). The smoothing factor was chosen for consistency with Mitchell and Jones's data (2005), so that the overlapping years (2000 to 2002) visually conformed (data not shown).

For future climate projections we used data generated by various climate modeling groups generated for four SRES emission and population growth scenarios (A1FI, A2, B1, B2), recommended by the Intergovernmental Panel for Climate Change (Nakicenovic et al. 2000): A1FI represents a trend of globalization, resource-intensive economic growth, and rapid population increase; A2 assumes slower population growth and regionally fragmented economic growth. B1 assumes the same global population growth as A1, but a shift towards a service and information economy. B2 represents the lowest population increases and local, environmentally sustainable economies.

Each SRES scenario was implemented for the 2020s, 2050s, and 2080s or in decadal time steps to 2090 by various climate modeling groups for a total of 109 projections. We included the second generation Canadian model CGCM2 (Flato et al. 2000), the Australian model CSIRO2 (Watterson et al. 1995), ECHAM4 from Europe (Roeckner 1996), the third generation model HADCM3 of the Hadley Climate Center, United Kingdom (Johns et al. 2003), and the Parallel Climate Model, PCM from the US (Washington et al. 2000). In addition to ensemble runs for the scenario families A1FI, A2, B1, B2 (Mitchell et al. 2005), we included individual model runs, selected to represent a wide range of moisture-temperature combinations for Alberta: NCARPCM–A1b, CGCM2–B23, HADCM3–A2a, CCNRIES–A1FI and HADCM3–B2b (Barrow and Yu 2005).

ClimateAB software

We provide free software to query this climate database: ClimateAB[1]. The basic function of the ClimateAB software are data queries by location, grid manipulations, and data overlays that would usually have to be carried out with geographic information systems. The program adds or subtracts coarser-scale climate change projections or historical data (interpolated to a location of interest avoid step-artifacts at grid boundaries) to high resolution baseline data. The quality of historical estimates can still be maintained because, for example, an exceptionally warm July in a particular year can be represented by the same deviation value along a small-scale mountain slope, although the absolute climate baseline value may rapidly increase or decrease along that slope (Mbogga et al 2009).

Secondly, the program carries out lapse-rate adjustments for temperature variables whenever an elevation is provided together with a sample location of interest. This adjustment depends on the difference between the grid elevation used by the Alberta Climate Model (built into the software) and the actual elevation for the location of interest. When accurate elevation estimates are available for sample locations, this procedure significantly enhances the statistical

[1] Download link: http://www.ualberta.ca/~ahamann/ClimateAB.html

accuracy and precision of temperature variable estimates (Hamann and Wang 2005). If a digital elevation model is used as input data rather than sample points, seamless high resolution climate coverages can be generated for any climate variable and for any historical period or future projection, (e.g. Fig. 1).

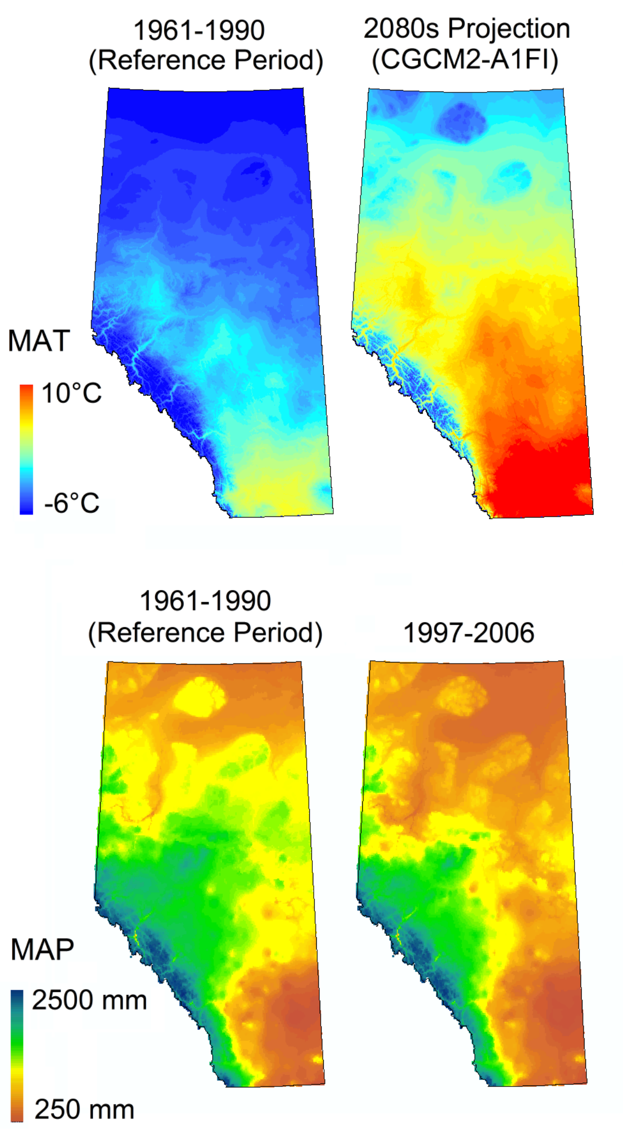

Figure 1. Examples of climate surfaces that can be generated by the ClimateAB software, using overlays of medium resolution historical and projections in combination with high resolution baseline climate data.

Finally, the program calculates seasonal, annual, decadal, or 30-year averages for any time interval from 1901 to 2006 and generates variables that are relevant for biological analysis or infrastructure planning: mean warmest month temperature (MWMT), mean coldest month temperature (MCMT), temperature difference between January and July average temperatures (TD), mean annual temperature (MAT), mean annual precipitation (MAP), mean summer precipitation (MSP), precipitation as snow (PAS) annual heat moisture index ((MAT+10)/MAP*1000), summer heat moisture index (MWMT/MSP*1000), degree days below 0°C, degree days above 5°C, heating degree days (degree days below 18°C), cooling degree days (degree days above 18°C), number of frost free days (NFFD), frost free period (FFP), beginning and end of the growing season (5°C threshold) in Julian days, and estimated extreme minimum temperature (over a 30 year period). Algorithms to calculate these variables are described in detail by Wang et al. (2006).

Results and Discussion

Data quality

To quantify the precision of the interpolated climate data, we compare estimates of climate variables from the ClimateAB software to climate data observed at weather stations in Alberta. This is not an independent test, because the test data has also been used to generate the climate surfaces. However, relative quality comparisons for different time periods are useful, and have been carried out for two annual, two monthly, and one seasonal variable for each month of the past 106 years and for the 1961-1990 baseline data (Fig. 2). We find that mean absolute errors of climate variable estimates are slightly lower for Alberta than for the more mountainous landscapes of British Columbia and the Yukon Territories (Hamann and Wang 2005). The mean absolute error of monthly and annual temperature estimates in Alberta is approximately 0.5°C, except for winter temperatures, where the errors may be as high as 8°C for approximately 1 out of 20 years over the past century.

These large errors in winter temperature are due to thermal inversions in mountain valleys of Alberta's Rocky Mountain ranges, which occur at small scales in winter with a high degree of stochasticity that cannot easily be accounted for in climate models. Users should avoid using estimates of individual monthly winter temperature estimates for Rocky Mountain valleys. In contrast, decadal or 30-year normal estimates, where stochastic variation is averaged out over a longer period, are precise with a mean absolute error of less than 0.5°C for all temperature variables.

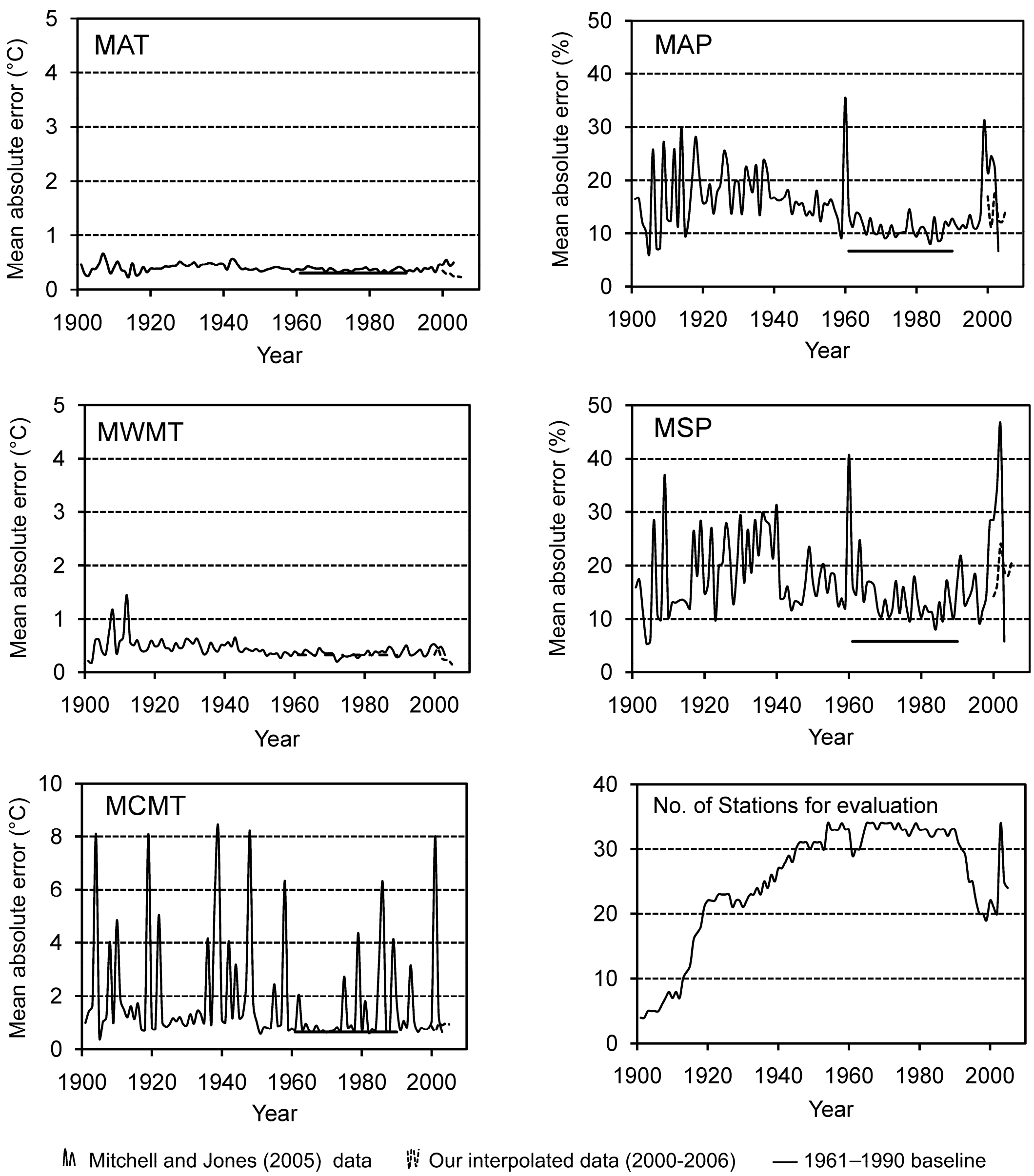

Figure 2. Mean absolute error between observed and interpolated mean annual temperature (MAT), Mean warmest month temperature (MWMT), mean coldest month temperature (MCMT) data, mean annual precipitation (MAP) and mean summer precipitation (MSP). Errors are reported for individual years between 1901-2006 and for the 1961-1990 normal period (flat line). The number of available weather stations for the comparison in each year is also shown.

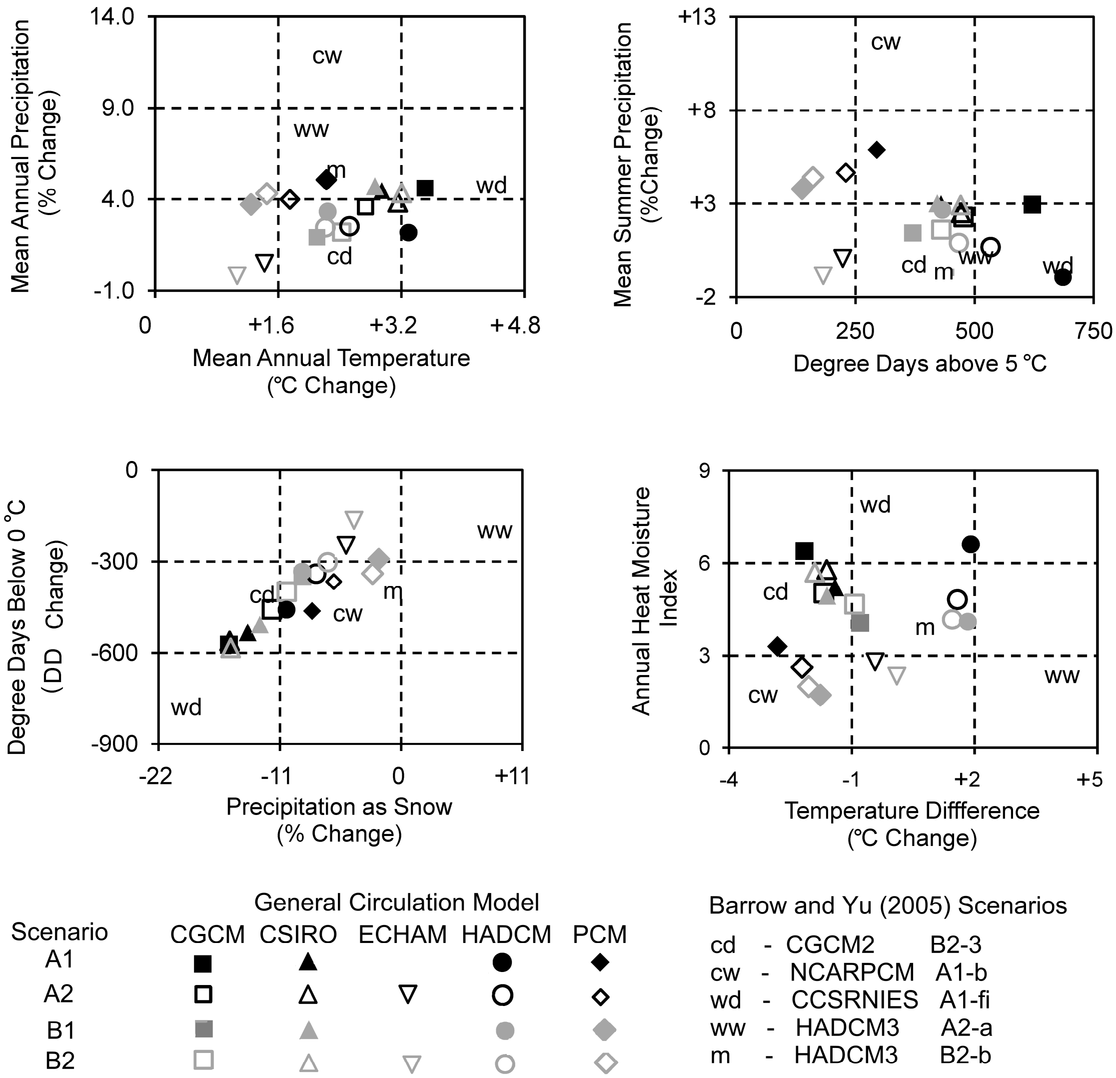

Figure 3. Change in eight climate variables projected for the 2050s based on ensemble runs of 4 SRES scenario families and 5 general circulation models, as well as 5 individual model runs selected to represent a wide range of projections for Alberta: warm/wet (ww), warm/dry (wd), cool/wet (cw), cool/dry (cd), and median (m).

Typical deviations in precipitation variables are mean absolute errors of 15% from the observed values with a fair amount of stochasticity in monthly and annual data. In the first half of the century, where weather station coverage is relatively poor, errors of 25% are common (in 1 out of 5 years). In the second half of the century, errors of this magnitude are rare (approximately 1 out of 20 years). Decadal averages and 30-year normals are precise for all precipitation variables (5 to 10% mean absolute errors).

Applications

Interpolated climate data have recently become essential for the development of climate change adaptation strategies. This usually involves the determination of “worst case”, “best case”, and “median” climate change projections. Scatter plots of projections from general circulation models for multiple variables show that it is a relatively complex task to generally determine “worst case” or “best case” scenarios (Fig. 3). For example, if loss of snow-cover in winter is a major concern for a wildlife management application, "worst case" scenarios may be quite different than those based on the greatest mean annual temperature increase, or the greatest mean annual precipitation reduction. Furthermore, Barrow and Yu (2006) pointed out that there can be pronounced differences for individual scenario projections for different regions of Alberta. The ClimateAB software can be used interactively to quickly determine the full range of future projections for a particular time period, location, and climate variable of interest.

The most pertinent application of this database may be the analysis of historical biological records to establish correlative relationships with climate. If a correlative relationship is supported by a plausible causal link between climate and a biological response, this may be the most effective approach to predict impacts of projected climate change, and to better understand plant-climate relationships. An example for this type of study are growth projections of lodgepole pine for various ecological regions in Alberta based on historical growth response to climate anomalies by Chhin et al. (2008), who used this database. Many other biological response variables for which we have historical records could be investigated in a similar way, such as databases for success of plantation establishment, historical surveys of forest pests and diseases (e.g. Woods et al 2006), or records of wildlife population dynamics and migratory behavior. Finally, the software can be used to develop ecological niche models of species habitat or ecosystem distributions under climate change scenarios (e.g. Schneider et al. 2009).

Limitations

This database and software provides easy access to climate data at any scale but also has important limitations that we would like to point out. The quality of monthly climate variable estimates for the far north of Alberta and the Rocky Mountains deteriorates because of sparse weather station coverage, although decadal or 30-year normal averages remain precise. Due to the lapse-rate based elevation adjustments implemented through ClimateAB, small-scale temperature gradients along mountain slopes are well characterized, but microclimatic conditions of any other kind (frost pockets, vegetation influence, slope and aspect) will not be correctly represented. All climate grids are generated from standard weather stations in flat open areas and consequently represent those conditions.

Acknowledgements

We would like to thank Alberta Environment for access to the Alberta Climate Model data. Elaine Barrow, Alberta Environment, provided scenario data. Lucie Vincent and Eva Mekis from the Climate Research Branch of the Meteorological Service of Canada allowed us access to the complete Adjusted Historical Canadian Climate Database. Funding for this work was provided by an NSERC Collaborative Research and Development Grant CRDPJ 349100-06.

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