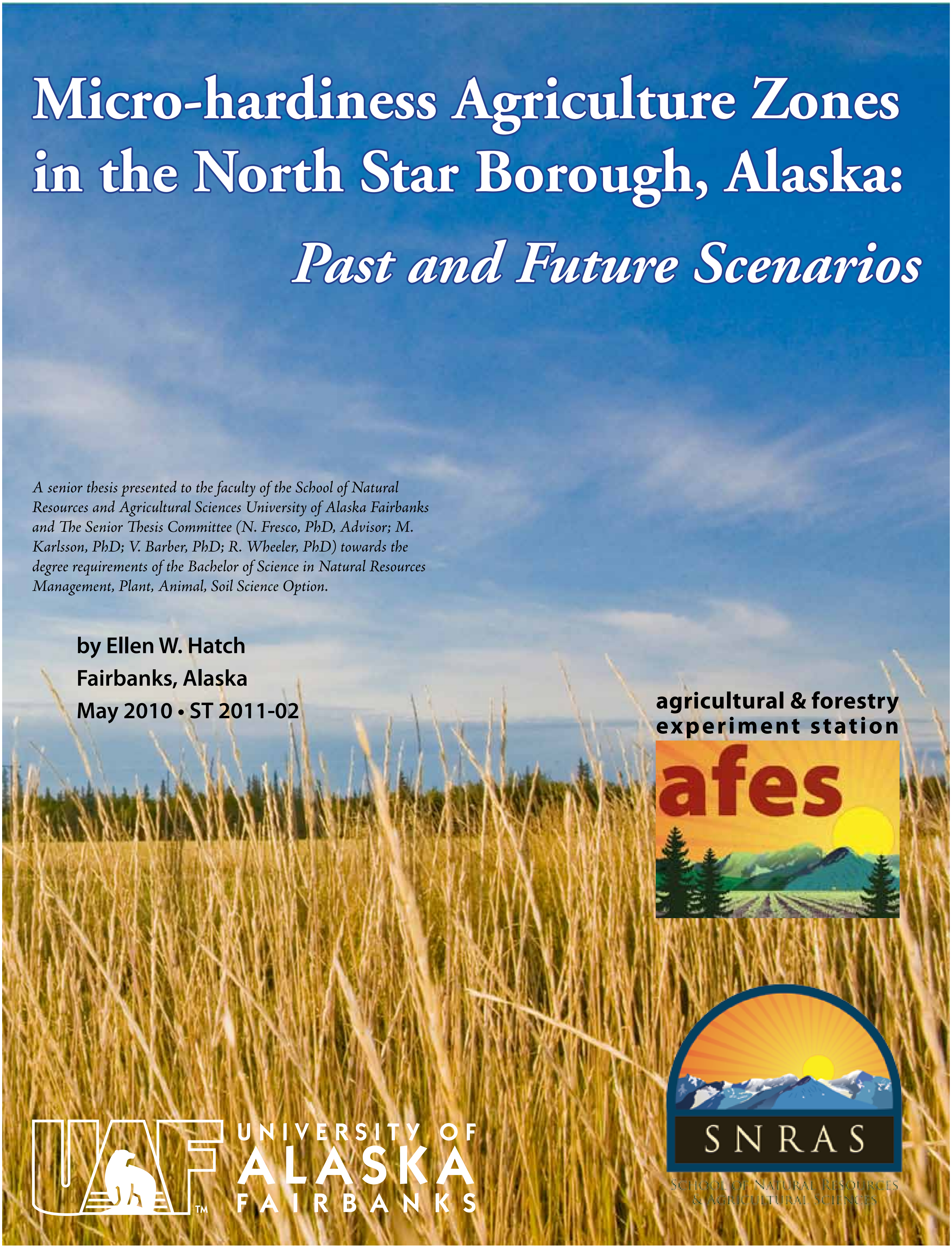

Micro-hardiness Agriculture Zones in the North Star Borough, Alaska:

Past and Future Scenarios

A senior thesis presented to the faculty of the School of Natural Resources and Agricultural Sciences University of Alaska Fairbanks and The Senior Thesis Committee (N. Fresco, PhD, Advisor; M. Karlsson, PhD; V. Barber, PhD; R. Wheeler, PhD) towards the degree requirements of the Bachelor of Science in Natural Resources Management, Plant, Animal, Soil Science Option.

by Ellen W. Hatch
Fairbanks, Alaska
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agricultural & forestry
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Cover: Fairbanks Experiment Farm fields.
UAF photo by Todd Paris

I. Abstract

Agriculture in the Arctic is often limited by the low receipt of heat energy, which is often measured in growing degree days (GDD). With the advent of increasingly powerful climate modeling, projection and downscaling techniques, it is becoming possible to examine future climates in high resolution. Recent availability in Alaska has prompted interest in examining the distribution of current and the potential future of local agriculture. The goal of this study was to utilize Scenarios Network for Alaska Planning (SNAP) downscaled, ensemble projections to examine this in terms of GDDs in the Fairbanks North Star Borough of Alaska. Historic and projected monthly mean temperatures were utilized to calculate GDDs and then map the borough at a 4 km^2 scale. Additionally, local agriculturalists were interviewed in order to put these theoretical calculations into context. Ultimately, projections of the examined agricultural locations showed an average of a 2% increase in GDD per decade and a 26% increase in GDDs from 1949 to 2099. This project indicated that the North Star Borough will receive increased heat energy due to climate change over the next century that may further enable increased yields and varieties of crops.

II. Introduction

Historically, extreme minimum temperature has been used to provide counsel on perennial plant selection which is typically represented in the form of plant hardiness zone maps (McKenney et al., 2006). As noted by McKenney in 2007, and visible in Figure 1, the coarseness of the maps and nonsystematic approach to plant hardiness assignment within these zones has limited their functionality in the past, especially to Alaska growers. Also, these hardiness zones have been shifting northward over the past few decades due to climate change (McKenney et al., 2006). This has subsequently necessitated the recalibration of many models (Harp et al., 2002). As these maps have the potential to be useful to prospective agricultural

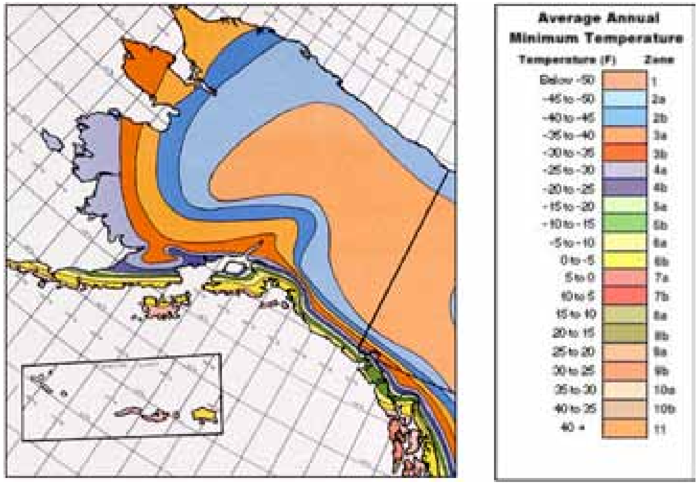

Figure 1. USDA Hardiness Zones for Alaska (Cathey 1990).

expansion planning in regions such as Alaska, it is of interest to the agricultural community to try a new approach to correlating the growth potential of crops with regional climatic conditions. The heat energy-based, cumulative unit of growing degree days (GDD) is an attractive candidate for this new approach due to heat's key role in plant growth and development cues (Juday et al., 1997). This is especially true in the arctic region, where short seasons are often responsible for the failure of crop maturation (Juday et al., 1997).

New micro-zone maps could be beneficial to local farmers by providing information on potential crop production zones, estimating the potential future of crops and growth zones based on predicted climate change, and by further gauging possible diversification of the local produce market in the North Star Borough. Additionally, the use of PRISM-downscaled global climate models provides the opportunity to capture important microclimatic differences throughout the borough due to differences in elevation, slope, and aspect. Thus, it was proposed to create a detailed micro-zone map for the Fairbanks North Star Borough and an accompanying table of feasible crops for current and future local microclimates based on growing degree days in order to capture the temporal and spatial variation of GDD receipt in the North Star Borough. This study could provide a unique, highly resolved, future projection of climatic-based agricultural opportunities in the Fairbanks North Star Borough.

III. Literature Review

Part 1: Climate Modeling and Predictions

Atmospheric Ocean General Circulation Models

Set up in 1989, the Intergovernmental Panel on Climate Change (IPCC) was charged by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to examine climate change from scientific, socioeconomic, and technologic perspectives through the review and assessment of scientific works (IPCC, 2010; Nakicenovic et al., 2000). In more recent years this has manifested as reviews of climate modeling, such as of Atmospheric Ocean General Circulation Models (AOGCMs), Earth System Models of Intermediate Complexity (EMICs), and Simple Climate Models (SCMs; Meehl et al., 2007). While each of these is a tool to predict overall trends in climate, AOGCMs are of the highest resolution and most commonly discussed, though are somewhat limited in potential by current computer capability (Rupp et al., 2009; SNAP, 2009b). AOGCMs illustrate climate change through modeling the climate and then the subsequent modeling of climatic responses, such as to greenhouse gas (GHG) radiative forcing via methodology focusing on either equilibrium climate sensitivity modeling or transient climate response modeling (Rupp et al., 2009; Meehl et al., 2007). The first of these involves modeling the surface air temperature under twice the carbon dioxide concentrations as compared to present concentrations; the latter depends on more realistic fluctuations of emissions over a modeled time period. AOGCMs are also model summaries of the scientific knowledge to date on the processes and stochastic nature of climate, including the interannual and intrannual variability of weather systems (SNAP, 2009b). The IPCC-reviewed, coupled AOGCMs generally rely on climatic processes including surface pressure, horizontal-layered components of temperature and fluid velocity, shortwave (solar) and longwave (infrared) radiation, convection, land surface processes, albedo, hydrology, cloud cover, and sea ice dynamics (Rupp et al., 2009).

Many global climate models (GCMs) have been developed and evaluated around the world. These models have come to many fairly consistent conclusions. In general, GCMs agree especially on the increase in high-latitude temperature as well as an increase in high-latitude precipitation due to climate change (Meehl et al., 2007). The greatest foreseen increases in global mean surface air temperatures (SAT) are expected to be over land, which will likely increase the intensity and frequency of heat waves and cause the opposite for cold episodes (defined as >2 days at 2 SDs below average winter mean; Meehl et al., 2007; Walsh et al., 2008). These trends are expected to be amplified by feedbacks and vary seasonally, with greater increases to be observed in autumn and early winter (Meehl et al., 2007; Walsh et al., 2008). In conjunction with overall increasing global mean temperatures, daily minimum temperatures are expected to rise more quickly than daily maximum, decreasing diurnal range and total number of frost days, ultimately resulting in a longer growing season (Meehl et al., 2007).

Increase in global mean precipitation, especially at high latitudes (approximately 20%) is predicted and thought to be due to the projected overall intensification of the global hydrologic cycle and changes in circulation and increase in intensity of storm events at high latitude (Meehl et al., 2007). The effect of this is increased runoff and increases in high latitude river discharge, coupled with summer drying and drought and possible vegetation die offs at mid-latitudes (Meehl et al., 2007). Decrease in snow cover (9–17%), thus shortening of snow season overall, as well as decreases in sea ice, glacier and ice cap mass, especially in the northern hemisphere, is projected to result in sea level rise (Meehl et al., 2007). On a global scale, sea ice in the Arctic is decaying faster than in the Antarctic, causing northward heat transport via ocean circulation (Meehl et al., 2007).

Additionally, after permafrost melt initially causes increases in soil moisture, subsequent decreases are expected as snow cover declines (Meehl et al., 2007). Globally, soil active layers are likely to become 30–40% thicker and drier soils around world will act as a feedback to extreme heat events (Meehl et al., 2007).

There is expected to be an increase in sea level pressure (SLP) at sub-tropics and mid-latitudes, but a decrease at high latitudes causing a weakening of Hadley circulation and movement toward the high latitude of storm tracks and Westerlies

(Meehl et al., 2007). This suggests a future of fewer storms at mid-latitude while increasing cyclonic activity observed in the poles (Meehl et al., 2007).

GCMs are run under a number of different estimates about global population, the future dependency on different fuel sources, technology, and the cumulative impacts of these on the climate. Choice of emissions scenario becomes key mid-century (2046-2065) and increases in importance as the century progresses (Meehl et al., 2007). The models show increases in CO2 in the atmosphere, reduction in land and ocean efficiency in absorbing CO2 (due to reduced net primary productivity and increased soil respiration), and subsequent acidification of the ocean (by 0.14-0.35 pH units; Meehl et al., 2007). Ozone increases are projected to be largest in the tropics and subtropics (Meehl et al., 2007). Finally, cloud radiative feedback is dependent on temperature and thus linked to elevation and latitude (Meehl et al., 2007). This is especially important in circumpolar regions as cloud cover is expected to increase at high latitudes (Meehl et al., 2007). Other emissions and aspects of different scenarios are discussed below.

Finally, when considering model data trend, commitment is an important topic. Commitment of climate projections refers to the fact that climate impacts will continue after emissions are ceased as that forcing does not instantly stabilize, due primarily to oceanic thermal inertia (Meehl et al., 2007). Additionally, it should be noted that succession of emissions does not necessarily mean reduced concentrations in the atmosphere; this is dependent on the processes of transfer as well as chemical and biological systems that act on emissions (Meehl et al., 2007). A gas's lifetime is defined as the time it takes to be in a form or state that causes the equivalent of only 37% of the initial disruption observed to the atmospheric system. Therefore, CH4 has a lifetime of 12 years, N2O about 110 years, and the lifetime of CO2 cannot be defined (Meehl et al., 2007). For example, in the modeling of a complete elimination of CO2 by 2100, the BERN-CC model experiments still suggest that 100 to 400 years would elapse before CO2 concentrations dropped from maximum to below double the pre-industrial values (i.e. a drop from 650–700ppm to around 560ppm; Meehl et al., 2007).

Finally, since all independently created models are assumed to have independent errors and biases, the best projection is thought to be obtained by using the mean of several models (Meehl et al., 2007). The IPCC's Fourth Assessment Report (AR4) AOGCM ensemble is currently thought to provide the most comprehensive range of processes and thus most accurately depicted projections when compared to climate observations and has been highly scrutinized (Meehl et al., 2007). For discussion on the uncertainties associated with AOGCMs see Appendix D.

Special Report on Emission Scenarios A1B

As previously discussed, projections created by AOGCMs are based on long-lived greenhouse gases (LLGHGs) defined by the observed historic record; futuristic models depend on the effects of foreseen emission concentrations based on estimates in changes in population as well as energy use and source, which differ by model and scenario (Meehl et al., 2007). For the purposes of examining climate change, the IPCC uses non-mitigated scenarios at scales that range from multiple-hundred kilometer projections to global-scale projections (Meehl et al., 2007). Consistent projections of the Earth's processes have been made by these models. These include trends such as the rising of the global mean surface air temperature (SAT) as driven mainly by anthropogenic greenhouse emissions and associated radiative forcing as previously discussed (Meehl et al., 2007).

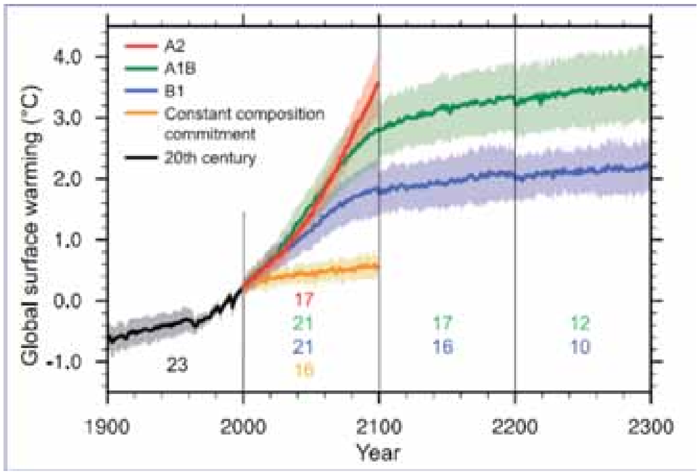

Figure 2. Surface warming per SRES emission scenario (average in bold, shading +/- 1 SD). Colored numbers indicate numbers of models factoring into the mean (Meehl et al., 2007).

Historically, the IPCC provided the first characterization of the suite of potential GHG concentrations with the original 1992-released, IS92 emission scenarios (Nakicenovic et al., 2000). These were updated in 1996 to better reflect new understanding of socioeconomic controls on emissions, and were reviewed in 1997 and then made available to climate modelers in 1998 (Nakicenovic et al., 2000). This was all subsequently summarized in the Special Report on Emission Scenarios (SRES; Nakicenovic et al., 2000).

The SRES scenarios encompass different potential emission scenarios, assuming no climate policy is implemented, to reflect the potential paths of emissions and subsequent climate impact as determined by the socioeconomic, technological, and political roots of emissions (Meehl et al., 2007). They represent a range of scenarios and are not meant to suggest probability of occurrence (Nakicenovic et al., 2000). As seen in Figure 2, the projected impacts vary widely with scenario.

As a part of the SRES scenario creation, there were four storylines produced to reflect a range of socioeconomic and technological forces on emissions. Different modeling approaches to these four story lines gave rise to forty scenarios created by six modeling teams (Nakicenovic et al., 2000). Figure 3 and Table 1 reflect the hierarchy of scenario plots and the characteristics of these respectively.

Table 1. Summary developed based on storyline comparison from Nakicenovic et al. (2000).

Storyline	Economic Growth	Population Growth	Technologic Growth	Groups
A1	Very rapid	Peak mid-century, decline after	Rapid, new and efficient	Fossil intensive (A1FI), non-fossil energy sources (A1T), balance across sources (A1B)*
A2 – heterogeneous	Emphasis on local identities, regional, and per capita	Continuously increasing	Fragmented, relatively slower	
B1 – convergent	Rapid change towards service /info technologies	Peak mid-century, decline after	Reduction in material emphasis technology; clean, resource efficient	
B2 – local	Intermediate development, local focus	Continuously increasing (<A2)	Less rapid, more diverse	

*N.B. for the purposes of this report, A1B is followed.

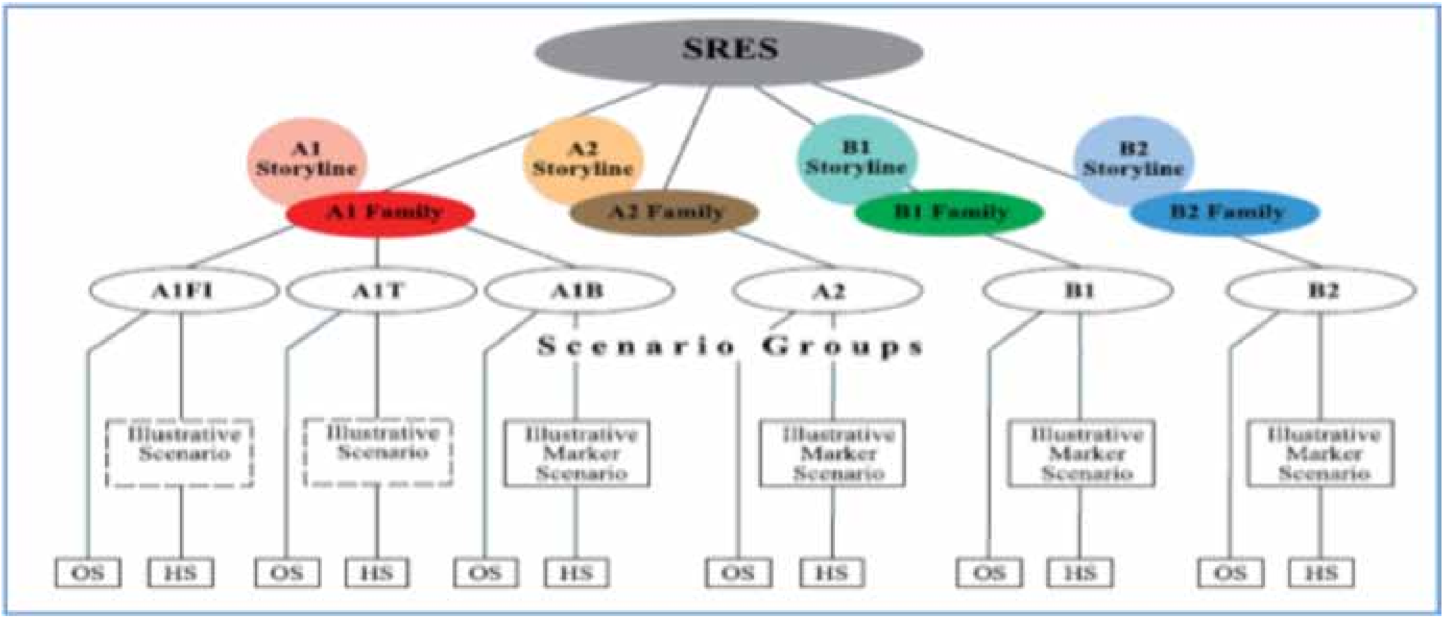

Figure 3. Depiction of the hierarchy of model storylines, families and scenarios. For the purpose of this report, scenario A1B, HS was followed. "HS" and "OS" refer to the harmonized or more exploratory nature of the models in respect to treatment of uncertainties, respectively (Nakicenovic et al., 2000).

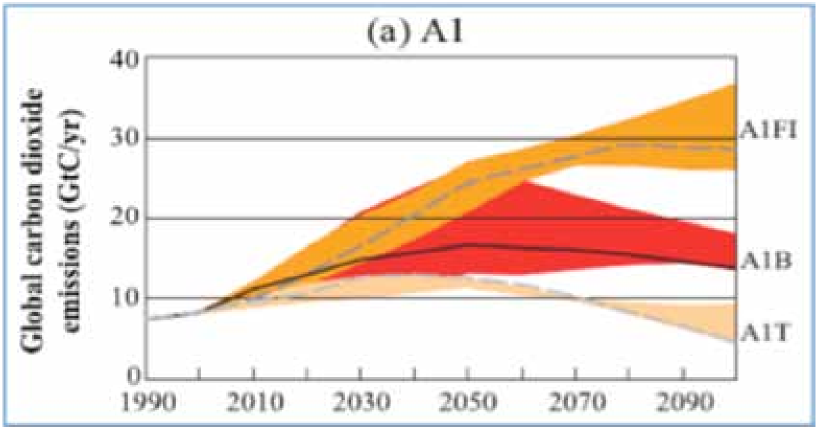

Figure 4. Global annual carbon dioxide emissions predicted under a A1 storyline from all anthropogenic sources for all 40 SRES scenarios (Nakicenovic et al., 2000).

In general, all projections predict a more affluent state of the world including between a 10- to 26-fold global gross product increase (Nakicenovic et al., 2000). Projections do show reversals in trends, as seen in the carbon dioxide emission projection in Figure 4, which are mostly due to improvements in productivity or declining population (Nakicenovic et al., 2000). The scenario predictions are most similar early in the century and then exhibit irreconcilable and widely divergent climatic trends later, as seen in Figure 4 (Nakicenovic et al., 2000; Christensen et al., 2007). For example, as seen in Figure 4, carbon emissions up to 2100 are estimated to be from 770 GtC to 2540 GtC depending on scenario (Nakicenovic et al., 2000).

The SRES include consideration for radiatively active species carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), chloroflourocarbons (CFCs), and sulfur dioxide (SO2), as well as for ozone, other aerosols and their indirect effects (e.g. cloud albedo), land use and solar variability (Meehl et al., 2007). By reflecting the effects of these different emission concentrations, the scenarios can be used to monitor progress in mitigation and policy, as well as predict future trajectories. For example, hydrofluorocarbons (HFCs) and sulfur emissions are presently lower than scenario predictions due to alternatives and legislation, respectively, and predicted versus observed climatic effects have been documented (Nakicenovic et al., 2000).

A1B scenarios, utilized by this report, predict a global mean surface air temperature increase of +2.8°C (1.7°C to 4.4°C), attributing uncertainty to anthropogenic forced changes, and, according to Wigley and Raper (2001), some uncertainties in carbon cycle, ocean mixing, emissions, climate model sensitivity and aerosol forcing (Meehl et al., 2007). Overall, the global mean warming when looked at in 20 year segments (to decrease internal variability in models) for the A1B scenario with a base period of 13.6°C is projected to be: 2011-2030 (+0.69°C), 2046-2065 (+1.75°C), 2080-2099 (+2.65°C), 2180-2199 (+3.36°C; Meehl et al., 2007).

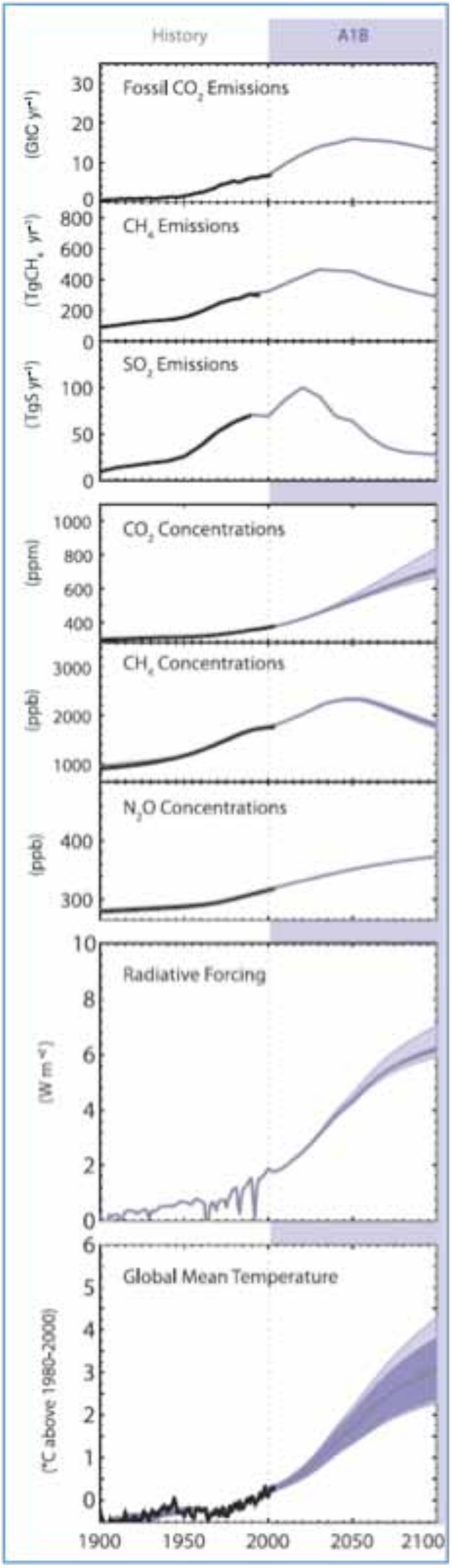

Figure 5 (at right). SCM, calibrated to 19 AOGCMs models, projected emissions for the A1B scenario (mean +/- 1 SD dark shading, carbon cycle feedback uncertainly in lighter shading). Radiative forcing includes anthropogenic and natural forcing. A1B results in 2.3 to 4.3°C warming (Meehl et al., 2007).

Regional Climate Models

Advances in climate modeling have indicated that there are important sub-global processes that affect the climate of regions—“nearly every region is idiosyncratic in some way” (Christensen et al., 2007). For example, climate change is projected to be highly varied per latitude, due to differential solar heating and other processes and physical characteristics (Christensen et al., 2007). Additionally, geography, such as proximity to oceans and mountains is crucial to regional climate impacts and hydrologic processes, for example snow and ice retreats are thought to be more important on a local scale (Christensen et al., 2007). Thus, Regional Climate Models (RCMs) allow the capturing of trends, such as warming beyond the global mean over some land areas, and the illumination of nuances in precipitation that AOGCMs cannot provide in terms of resolution (Christensen et al., 2007). Finally, the effects of some important feedbacks, such as aerosols that reflect solar radiation and can cause loading effects (especially those with high absorptive capacity, like black carbon) are seen primarily at the regional scale in the form of lower surface temperatures (Meehl et al., 2007).

Regional climate projections can be produced in a number of ways. This includes sourcing or downscaling AOGCMs, modeling the scientific understanding of regional processes, and modeling recent historical climate change for the region (Christensen et al., 2007). Additionally, RCMs are subjected to probabilistic and verity testing just as AOGCMs. For example, one such method, proposed by Tebaldi et al. (2005) involves the Bayesian statistical approach which ultimately weighs models based on their ability to simulate present day climate or how predictions relate to that of the overall ensemble mean (Meehl et al., 2007).

Alaska has been modeled as a component of both the North American Regional Climate (NARC) models (Fig. 6) and the Polar Region climate models. When comparing the separate results of each, discrepancies between the projections appear due to the inclusion of different areas of consideration. Thus the inclusion of circumpolar regions in the modeling of lower latitudes tends to bias the results for the arctic region toward the predictions for these lower latitude areas as opposed to modeling them separately. For instance, positive feedbacks from reduced time of snow coverage suggests that Northern Canada and Alaska will experience the greatest warming, projected as up to 10°C in the winter, which is slightly different than the larger estimates made by Polar Region RCMs (Christensen et al., 2007).

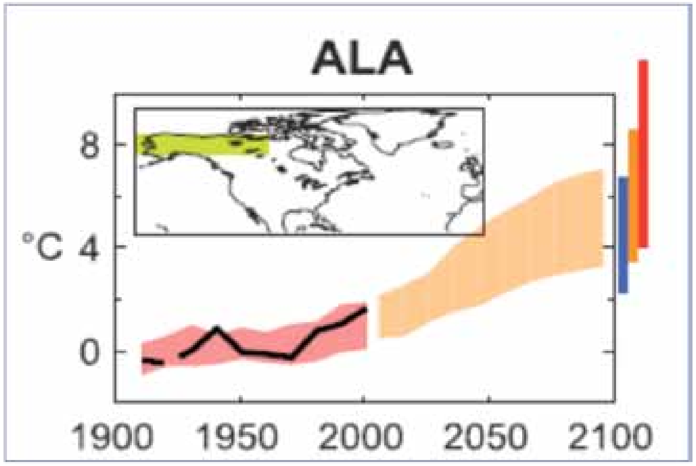

Figure 6. Historic (black line) and projected (red) temperature anomalies modeled for which bars at ends of graphs indicated B1 (blue), A1B (orange), and A2 (red) scenarios (Christensen et al., 2007).

Polar Region

For the purpose of regional climate modeling, the IPCC defines the Polar Regions as the Arctic at 60°N, 180°E to 90°N, 180°W and Antarctic defined as 90°S, 180°E to 60°S, 180°W, putting Fairbanks (64.82°N, 147.87°W) in this group (Christensen et al., 2007). RCMs are particularly important to Arctic modeling as lower latitude biases in GCMs cause lower temperature and precipitation predictions (Christensen et al., 2007).

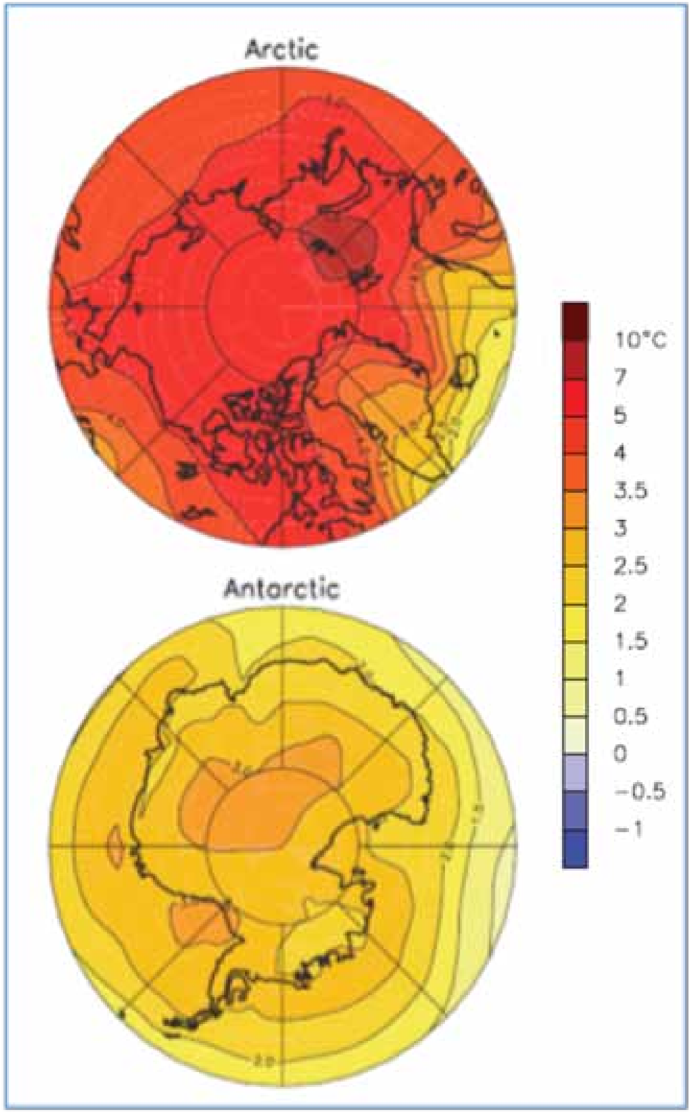

Figure 7. Projected annual surface temperature change between 1980-1999 and the 2080-2099 time periods for MMD modeling of the A1B scenario (Christensen et al., 2007).

Overview:

The polar regions of the world are increasingly recognized for their geopolitical and economic importance as well as their extreme vulnerability to climate change and potential to contribute significant feedbacks (Anisimov et al., 2007). As identified by RCMs, the average for the region occupying north of 60 degrees latitude has already increased 1-2°C since the temperature low in the 1960s and 70s (Anisimov et al., 2007). In the future, the polar regions are *very likely*[1] to experience warming greater than the global mean increase indicates, most acutely in the winter and likely up to two times the global mean increase due to polar amplification (Christensen et al., 2007; SNAP, 2009b). Overall, the projected arctic annual warming is expected to be approximately 5°C (Christensen et al., 2007). Additionally, it is *very likely* precipitation will increase, most noticeably in the winter, though this may not indicate an overall increase in soil moisture (Christensen et al., 2007; SNAP, 2009a). It is projected to be *very likely* Arctic sea ice will decrease in thickness and extent (Christensen et al., 2007). Climate scientists are *uncertain* as to how Arctic Ocean circulation will change as a result of this and other processes (Christensen et al., 2007).

Temperature:

RCMs that specifically examine the A1B winter mean warming project 4.3°C to 11.4°C increases in temperature and summer warming around 1.2°C to 5.3°C (Christensen et al., 2007). Arctic summers are already observed to be the warmest in 400 years (SNAP, 2009b).

Precipitation:

Climate change effects on precipitation are of great concern, especially in regard to agriculture. Projections suggest that precipitation varies widely by geography due to synoptic (large-scale tropospheric system) circulation patterns (Christensen et al., 2007). In the Arctic, seasonal runoff and routings are projected to be affected; additionally, later freeze up and earlier thaw of rivers and lakes will occur (Anisimov et al., 2007). Predictions of the future moisture regime, however, are complicated by projected evapotranspiration increases as vegetation shifts from lichen-dominated tundra to woody shrubs (Anisimov et al., 2007; SNAP, 2009a). This could possibly result in lower river discharge in the summer and drier soils, despite increases in precipitation (Anisimov et al., 2007; SNAP, 2009a). Additionally, vegetation is likely to also play a role in countering increases in sediment loading (Anisimov et al., 2007). All in all, there is strong correlation across models between increases in temperature and precipitation in the Arctic (R2=0.907) suggesting that there may be a 5% precipitation increase per degree Celsius increase (Christensen et al., 2007).

Soil:

Besides impacts on temperature and precipitation, climate change impacts on soil are likely to have pronounced effects on the future of agriculture in the polar regions. Decreases in the extent of permafrost (20-35% in the northern hemisphere mostly in discontinuous zones, but some due to increased patchiness of continuous permafrost) means an overall increase in bog habitat and a shift in some Arctic zones from dry-habitat vegetation to wet-habitat vegetation initially (Anisimov et al., 2007). With this there is a projected increase in thickness of the active soil layer (10-15% in thawing permafrost areas in the next thirty years alone) and exposure of more bare ground (Anisimov et al., 2007). Ultimately, there is some uncertainty regarding the polar soils as a future source or sink of carbon dioxide; however, more certain is that warming Arctic soils will be a source of methane (Anisimov et al., 2007).

Fairbanks North Star Borough, Alaska

A few additional notes are pertinent to climate change projected in interior Alaska. Interior regions of most continents are expected to warm more than coastal regions (Christensen et al., 2007). Alaska, according to Chapman and Walsh (2007), is the land region with the smallest signal to noise ratio (noise being internal variability in the 20 year averages used for the RCMs). This ratio is converted to a time increment to indicate when the signal, or trend, is "clearly discernable" from pure variability (i.e. 95% confidence; Christensen et al., 2007). However, according to Cassano et al. (2006) there are expected to be cold anomalies over Alaska due to winter circulation changes (Christensen et al., 2007).

Scenarios Network for Alaska Planning

The University of Alaska Fairbanks Scenarios Network for Alaska Planning (SNAP) is a Fairbanks-based network that utilizes five of the IPCC-reviewed global models for the A1, A1B, and B1 scenarios, downscaled with PRISM, in order to help Alaska communities and land managers plan for adaptive measures in the face of climate change.

(SNAP, 2009a; Rupp et al., 2009). At present, SNAP is working to make data more accessible by converting ASCII formatting into KML (Google Earth) formats, to be used by a variety of land managers and municipal planning agencies. SNAP is also able to perform modeling in ASCII and single or ensemble models for specific purposes for clients (SNAP, 2009b; Rupp et al., 2009). Finally, SNAP also utilizes historic Climate Research Unit (CRU) data for mapping, which is obtained from online datasets and also PRISM downscaled to provide avenues for validation of futuristic climate projections (SNAP, 2009b).

Dr. John Walsh, a SNAP collaborator, participated in the review of fifteen IPCC GCMs that had been previously reviewed in the Coupled Model Intercomparison Project (SNAP, 2009b; Walsh et al., 2008). Based on root-mean-square error (RMSE) analysis of model data compared against 40-year European Center for Medium-Range Weather Forecast (ECMWF) Re-Analysis (ERA-40) data, models were selected that performed

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[1] IPCC Uncertainty terminology of Working Group I: Virtually certain: >99% probability (1:100), Extremely likely: >95% (1:20), Very likely: >90% (1:10), Likely: > 66% (1:3), More likely than not: >50%, Unlikely: <33%, Very unlikely: <10%.

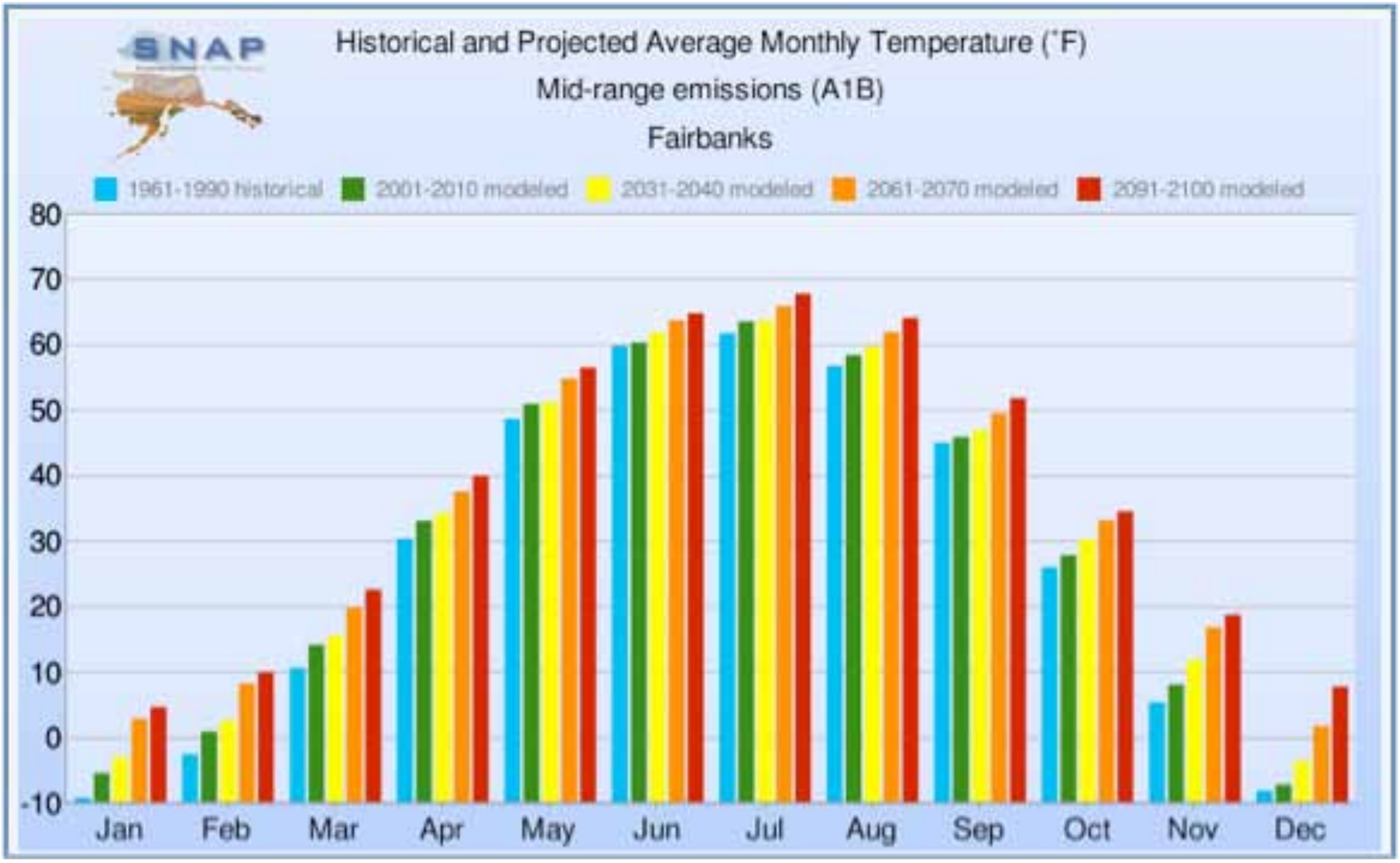

Figure 8. Monthly average temperatures from five IPCC GCMs (SNAP 2009).

best for Alaska (SNAP, 2009b; Walsh et al., 2008). The study identified five models that occupied the top three rankings for temperature, sea level pressure, and precipitation in variable ranking for RMSE with annual mean biases included (Walsh et al., 2009). These selected models were:

- MPI ECHAM5 (Germany)
- GFDL CM2.1 (United States)
- MIROC3.2 MEDRES (Japan)
- UKMO HADCM3 (United Kingdom)
- CCCMA CGCM3.1 (Canada)

The resulting ensemble of five models was further scrutinized for Arctic purposes through modeling historic climates and then comparing the results to the 1980-2007 data from 32 of Western Region Climate Center's (WRCC) weather station in Alaska (Rupp et al., 2009). The

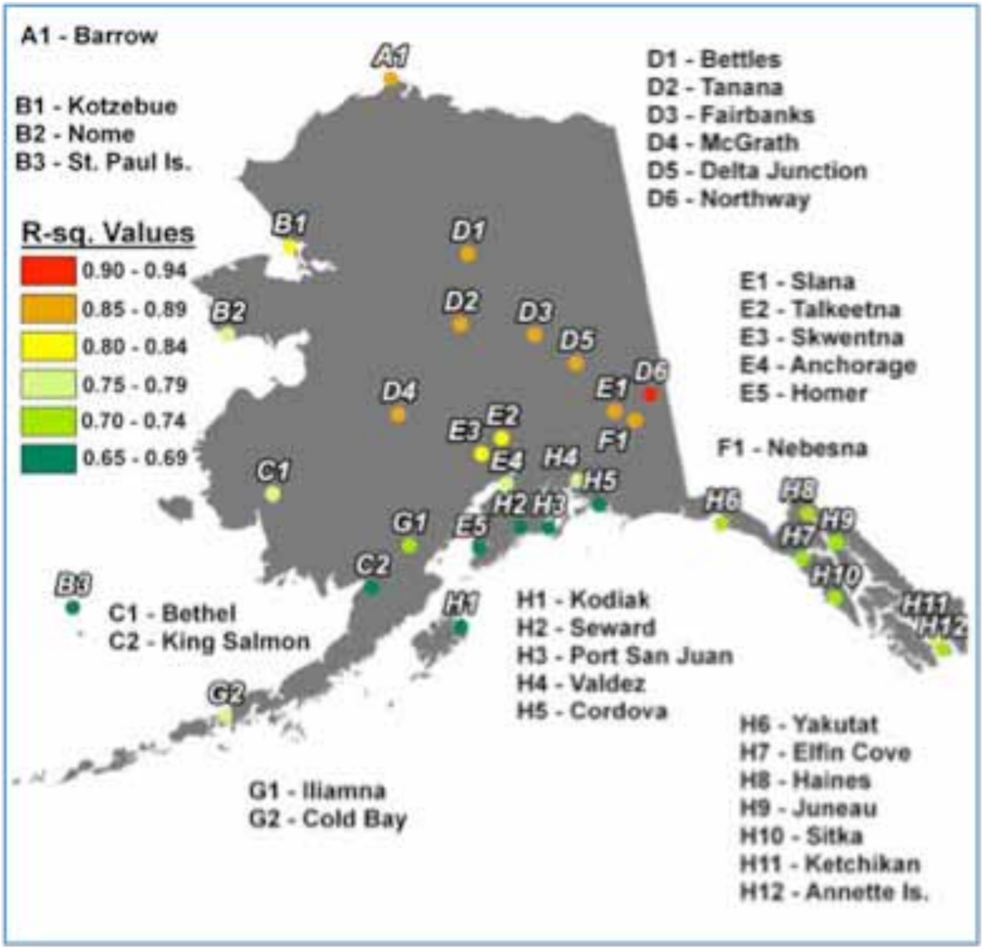

Figure 9. SNAP validation of five model ensemble for Alaska compared to 32 WRCC weather stations' historic data (Rupp et al., 2009).

Model ID, Vintage	Sponsor(s), Country	Atmosphere Top Resolution[a] References	Ocean Resolution[b] Z Coord., Top BC References	Sea Ice Dynamics, Leads References	Coupling Flux Adjustments References	Land Soil, Plants, Routing References
4: CGCM3.1(T47), 2005	Canadian Centre for Climate Modelling and Analysis, Canada	top = 1 hPa T47 (~2.8° x 2.8°) L31 McFarlane et al., 1992; Flato, 2005	1.9° x 1.9° L29 depth, rigid lid Pacanowski et al., 1993	rheology, leads Hibler, 1979; Flato and Hibler, 1992	heat, freshwater Flato, 2005	layers, canopy, routing Verseghy et al., 1993
8: ECHAM5/MPI-OM, 2005	Max Planck Institute for Meteorology, Germany	top = 10 hPa T63 (~1.9° x 1.9°) L31 Roeckner et al., 2003	1.5° x 1.5° L40 depth, free surface Marsland et al., 2003	rheology, leads Hibler, 1979; Semtner, 1976	no adjustments Jungclaus et al., 2005	bucket, canopy, routing Hagemann, 2002; Hagemann and Dümenil-Gates, 2001
12: GFDL-CM2.1, 2005	U.S. Department of Commerce/ National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	top = 3 hPa 2.0° x 2.5° L24 GFDL GAMDT, 2004 with semi-Lagrangian transports	0.3°–1.0° x 1.0° depth, free surface Gnanadesikan et al., 2004	rheology, leads Winton, 2000; Delworth et al., 2006	no adjustments Delworth et al., 2006	bucket, canopy, routing Milly and Shmakin, 2002; GFDL GAMDT, 2004
19: MIROC3.2(medres), 2004	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	top = 30 km T42 (~2.8° x 2.8°) L20 K-1 Developers, 2004	0.5°–1.4° x 1.4° L43 sigma/depth, free surface K-1 Developers, 2004	rheology, leads K-1 Developers, 2004	no adjustments K-1 Developers, 2004	layers, canopy, routing K-1 Developers, 2004; Oki and Sud, 1998
22: UKMO-HadCM3, 1997	Hadley Centre for Climate Prediction and Research/Met Office, UK	top = 5 hPa 2.5° x 3.75° L19 Pope et al., 2000	1.25° x 1.25° L20 depth, rigid lid Gordon et al., 2000	free drift, leads Cattle and Crossley, 1995	no adjustments Gordon et al., 2000	layers, canopy, routing Cox et al., 1999

Figure 10. Model features from the five models selected by Walsh et al. (2008) for SNAP modeling (Randall et al., 2007).

Model	Forcing Agents																	
	Greenhouse Gases						Aerosols										Other	
	CO_2	CH_4	N_2O	Stratospheric Ozone	Tropospheric Ozone	CFCs	SO_4	Urban	Black carbon	Organic carbon	Nitrate	1st Indirect	2nd Indirect	Dust	Volcanic	Sea Salt	Land Use	Solar
CGCM3.1(T47)	Y	Y	Y	C	C	Y	2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	C	C	C	C	C
ECHAM5/MPI-OM	1	1	1	Y	C	1	2	n.a.	n.a.	n.a.	n.a.	Y	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GFDL-CM2.1	Y	Y	Y	Y	Y	Y	Y	n.a.	Y	Y	n.a.	n.a.	n.a.	C	C	C	C	C
MIROC3.2(M)	Y	Y	Y	Y	Y	Y	Y	n.a.	Y	Y	n.a.	Y	Y	Y	C	Y	C	C
UKMO-HadCM3	Y	Y	Y	Y	Y	Y	Y	n.a.	n.a.	n.a.	n.a.	Y	n.a.	n.a.	C	n.a.	n.a.	C

Figure 11. Radiative forcing agents included in the models utilized by SNAP. Y indicates model includes agent, C denotes variation included, E indicates carbon dioxide equivalent is utilized in place of agent, and N.A. denotes agent is not specified (adapted from Meehl et al., 2007).

individual models, when tested against historic WRCC data for Alaska, proved accurate (average R2 for temperature was 0.89 and for precipitation was 0.60 for the Fairbanks area) for boreal and tundra regions (Rupp et al., 2009). These results, consistent with larger climate modeling, were less accurate for precipitation than temperature due to high variability over time and space (Rupp et al., 2009).

PRISM Downscaling

Additionally, local topography can be key to local climate processes, and land management decisions are usually based on a regional to local scale (SNAP, 2009b). In order to receive accurate information from AOGCMs at or near grid scale, downscaling is necessary (Meehl et al., 2007).

There are two common types of downscaling: dynamical and statistical downscaling (SD). Dynamical relies on high resolution AOGCMs and then observed data or lower resolution AOGCMs at boundaries whereas SD utilizes observational data from the desired resolution and derives values in between observations from relationships between parameters. Additionally, SD uses predictors (large scale climate variables) and predictands (small scale climate variables) relationships along with historic, similar weather locales to assign predictands to resolved predictors and locations (Christensen et al., 2007). SD is capable of finer scales and is comparably less expensive (Christensen et al., 2007).

Parameter-elevation Regressions on Independent Slopes Model (PRISM), developed by Dr. Christopher Daly at Oregon State University, is the statistical-geographical downscaling hybrid method employed by SNAP (Curtis and Taylor, 2009; SNAP, 2009b) in which a 2km resolution is achieved via multiple regressions from weighted weather station data (SNAP,

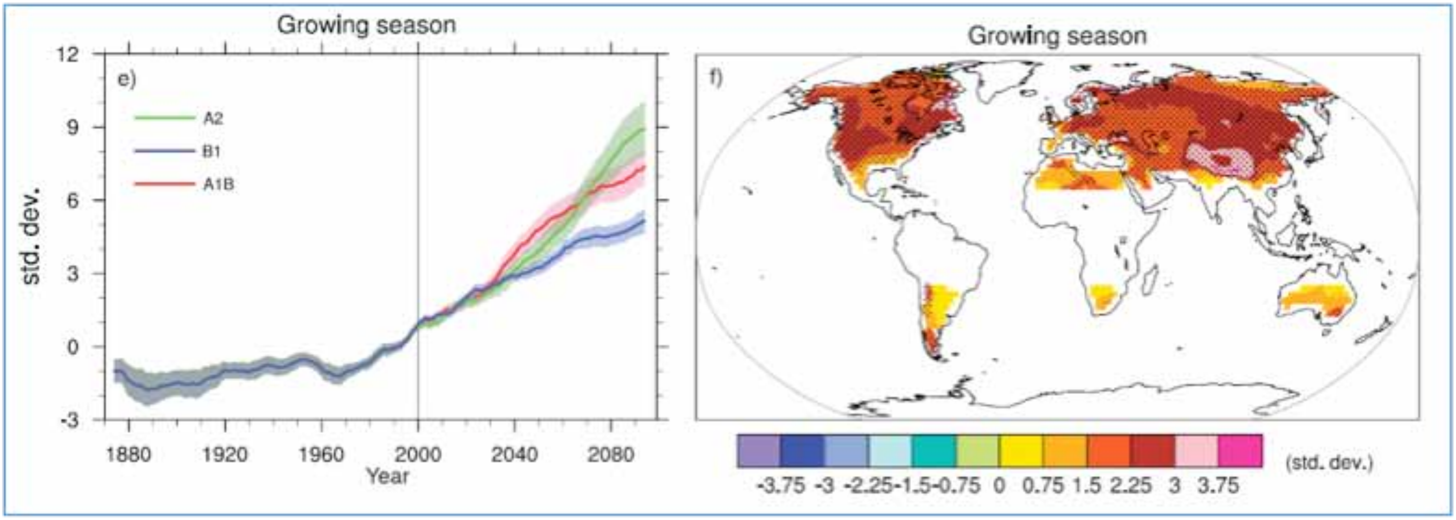

Figure 12. Model averages for change in growing season length (defined as time between 5 consecutive days of temperatures above 5°C at the start and finish of the season). On the right, the mapping of scenario A1B (Meehl et al., 2007).

2009b). The crux of these calculations is based on the fact that climate parameters are strongly influenced by elevation and thus relationships can be linearly defined (Daly et al., 1997). This weighting system results in defining faceted polygons on a given hillside, where each facet is given a value based on five factors: distance to weather station, elevation, vertical layer, topographic effects, and coastal proximity (Curtis and Taylor, 2009; Rupp et al., 2009). Weather station data comes from a variety of local, state and federal sources (Curtis and Taylor, 2009). PRISM was evaluated by the National Resources Conservation Service (NRCS) for performance in all 50 U.S. states as well as by a panel of state climatologists (Daly, 1996).

In interior Alaska, PRISM is an especially good choice for downscaling data in that its methods can accurately simulate inversions via performing individual regressions on two vertical layers (boundary and atmosphere) and then reflect the strength of an inversion by allowing varied amounts of data sharing between the layer regressions (Daly et al., 1997). Additionally, PRISM is able to preserve highly varying local climate regimes as that the regression of each pixel, in facet-mosaic form, is separately calculated to retain the unique climate parameter and elevation relationship (Daly et al., 1997). Additionally, this downscaling methodology is especially important to the analysis of agriculture via growing degree day, as that local differences observed in GDD receipt have been attributed to differences in microclimate such as elevation, slope, aspect and wind which are accounted for by PRISM (Barton and Ball, 2007).

Implications for Agriculture

As noted by Polar Region RCMs, increases in temperature, changes in moisture regime and increases in soil thaw are projected to occur. Additionally, decreases in the period of snow cover, mostly attributable to decrease in spring snow residence time, may change the time planting can feasibly occur (Anisimov et al., 2007). In Alaska, summers are projected to lengthen as freezeup and thaw dates shift (SNAP 2009b) and the growing season is projected to increase by approximately three days every decade as depicted in Figure 12 (Anisimov et al., 2007; SNAP, 2009a).

Agricultural land use changes projected in the SRES scenarios are primarily caused by changes in demographics and diets, but are also impacted by socioeconomic, technologic and institutional factors which may have impacts on the relative feedbacks as demands on agriculture throughout the world shift (Nakicenovic et al., 2000). This includes considerations such as methane and nitrous oxide emissions that are frequently associated with agricultural land use changes (Nakicenovic et al., 2000). Historically, and likely pertinent to the future as well, conversion between forested and agricultural land (and back) has had significant impact on greenhouse gases. However, conversion of some lands to agricultural production, especially at middle latitudes, is likely to have a cooling effect and continued agricultural expansion is likely to be seen in western North America as well (Christensen et al., 2007). Other similar studies, such as the *Arctic Climate Impact Assessment* (ACIA), have projected findings similar to these (Hassol, 2004; Sparrow, 2007).

Finally, consideration should be given to the local and global economic pressures of food distribution and its impacts on high latitude agriculture. For example, changes in temperature and sea ice could alter existing transportation routes and markets, especially of Native Alaskan groups (Norton, 2002), and could also open new markets and routes to potential agricultural trade (Anisimov et al., 2007).

IV. Literature Review – Part 2: Climate and Agriculture

General Ecology

Many lab and field studies have been conducted in the Arctic in efforts to estimate the impacts of global climate change in this region. Findings have indicated that Arctic species are expected to show changes in range and abundance with projected climate change (Anisimov et al., 2007). Productivity is expected to increase as seen by increased greenness, and there is expected to be decreases in surface albedo and changes in the exchange of GHGs between landscape and atmosphere in the Arctic (Anisimov et al., 2007). Thawing permafrost and increases in wetlands are expected to add to radiative forcing (Anisimov et al., 2007). Shifts in ecosystems have been viewed by satellite, indicating a transition from grasses to shrubs and overall increased Normalized Difference Vegetation Index (NDVI), a measure of photosynthetic activity of a region consistent with increased growing season (Anisimov et al., 2007; SNAP, 2009a). This northward shift in ecosystems and increased productivity has included observed treeline shift approximately 10km northward in the Arctic, and a gain in tree line altitude in some places as well (Anisimov et al., 2007). Two percent of the Seward Peninsula's tundra has converted to forest and 10-50% of the global tundra may be forest by 2100 according to projection estimates (Anisimov et al., 2007). Farther north, polar desert is expected to be replaced to the extent of 10-25% by tundra with a potential 70% increase in net primary productivity (NPP; Anisimov et al., 2007). Geographical constraints to this ecosystem shift will result in upwards of 145% net primary productivity increase in some areas of the Arctic (Anisimov et al., 2007).

Additionally, the establishment and colonization of southern weedy plants are projected to expand (Anisimov et al., 2007). Artificial warming experiments, such as by Walker et al. (2006) have shown that within two seasons plant communities respond to 1-3°C warming with relative increases in shrubs and vascular plants and decreases in overall diversity at least initially (Anisimov et al., 2007; SNAP, 2009a).

Agriculture

Temperature:

Photoperiod and temperature define the growth and development of plants (Challinor et al., 2009). Plant development is reliant on temperature and specific heat unit input for phenological development and varies by stage (Miller et al., 2001; Miller, 1975), although other factors, such as climate, soil fertility and moisture, genetics and cultural practices impact maturation stages (Miller et al., 2001). Temperature can also be relative to moisture in that increased temperatures are found in crop canopies suffering from drought because of reduced transpiration (Miller et al., 2001). Though likely to allow increases in yield and variety in circumpolar regions, it should be noted that in some areas the rising average temperature will mean a decrease in growing season as temperatures become so high as to no longer support growth and development (Sling et al., 2005). Extremes in temperature can be very detrimental, especially if they coincide with crucial developmental stages (Slingo et al., 2005).

Historically, the northern limit to agriculture was estimated, as in the study by Sirotenko (1997) to be based on cumulative degree-days with a threshold of +10°C (Anisimov et al., 2007).

Increased CO2:

Experimentally-increased carbon dioxide concentrations have been seen to cause transient plant responses, the restructuring of microbial communities, and the reduction of frost hardiness of some plants (Anisimov et al., 2007). Water usage is thought to be more efficient in higher carbon dioxide concentration scenarios, due to decreases in overall transpiration (Slingo et al., 2005; Challinor et al., 2009). Net photosynthesis is increased when carbon dioxide levels are increased to saturation to allow for the most efficient carboxylation by the enzyme Rubisco and an increase in inhibition of photorespiration results (Long et al., 2005). For example, C3 plants are well characterized and an increase in atmospheric CO2 from approximately 372 to 550 µmol mol-1 CO2 is estimated to allow for an increase in net leaf photosynthesis by 12–36% (Long et al., 2005). Thus, growth and yield are likely to increase under increased carbon dioxide concentration conditions (Challinor et al., 2009). However, there do exist disagreements about the means by which these studies have been conducted historically (i.e. chamber versus Free-Air Concentration Enrichment (FACE) versus field experimental method) to arrive at these conclusions and there may be need to further investigate these effects (Long et al., 2005; Challinor et al., 2009).

Increased ozone:

Ozone is a strong oxidant which can result in lesions in plants at high enough concentrations, damaging structure, function, and economic value (Challinor et al., 2009). Tropospheric ozone is recognized as a culprit for decreases in crop yield, causing decreases of the photosynthetic rate, acceleration of leaf senescence and impacts on fertilization (Long et al., 2005; Challinor et al., 2009). Reduction in carbon assimilation and yield as well as nutritional value have also been observed, such as in European wheat experiments (Challinor et al., 2009).

Increased UV-B:

Experimentally-increased UV-B radiation has been observed to reduce some nutrient cycling (Anisimov et al., 2007).

Pests and disease:

Warming is likely to increase the incidence of pests, such as the spruce bark beetle of the Kenai Peninsula, disease, parasites, and fires (Anisimov et al., 2007). Polar species tend to be highly specialized for survival in the harsh conditions of the Arctic and are thus poor competitors with pests, parasites, and immigrants from warmer regions (Anisimov et al., 2007). Additionally, emigrants into Alaska will likely bring an additional suite of competitors in the form of parasites and disease, further increasing native mortality (Anisimov et al., 2007). Projected warmer winters are likely to affect the survival and distribution of overwintering insects, and provide another vector for disease movement into and through the Arctic (Anisimov et al., 2007).

Quality:

Gluten levels in grains as well as mycotoxins in groundnuts are thought to be dependent on climatic conditions during production (Slingo et al., 2005).

Socioeconomic: Predicted climate changes are forecasted with high confidence to have a cascading effect on bio-physical systems that will not only cause global feedback, but will stress northern high latitude social and economic schemes (Anisimov et al., 2007). Food growth and distribution is a complex system of farms, markets, industry and distribution, and ending ultimately with the consumer. Changes along any or all of these paths in policy and decisions will impact the direction of agriculture under new climatic regimes (Slingo et al., 2005). There is high confidence in negative impacts on food access and availability due to changes in risk which are likely to change management schemes and lifestyle (Anisimov et al., 2007). Additionally, there are thought to be many barriers to Arctic community adaptation ranging from management regimes to politics and legalities (Anisimov et al., 2007), though perhaps a shift in the focus of crop subsidies would make agriculture more possible, and aid with adaptation in general.

Soils:

As mentioned during the discussion of projected polar region RCM climate change predictions, the melting of permafrost and exposure of additional bare ground, coupled with an increasing active soil layer (Anisimov et al., 2007) provides more opportunity for agriculture. This melting of permafrost also has implications for the nutrient, sediment, and carbon-loading of the soil as well as a resulting enhancement of microbial and higher tropic productivities (Anisimov et al., 2007).

In conclusion, many factors of climate change have individually been reviewed in controlled studies and are expected to affect the future of agriculture depending on their actual realized amounts. However, there are likely to be interactions among these factors that will appear as crops undergo multiple stressors that increase the uncertainty of these findings in the future environment (Challinor et al., 2009).

Food Security and Potential

Climate change is likely to have effects on global food security, especially since a large portion of the world's annual crops come from the climatically sensitive tropics (Slingo et al., 2005). Climate change benefits, such as agricultural opportunity, are likely to be region specific, with some regions of the globe suffering drought and agricultural difficulty, and others discovering new potential (Anisimov et al., 2007; Lobell et al., 2008). Likely to be among those with increased potential, circumpolar increases in near-surface ground temperatures, earlier spring melt, and improved transportation likely indicate potential for increased agricultural opportunity at high latitudes (Anisimov et al., 2007). Arctic agriculture is currently thought to be limited by short, cool growing seasons, limited infrastructure and market (Anisimov et al., 2007). However, two-thirds of Arctic occupants live in urban areas with over 5,000 residents (Anisimov et al., 2007) indicating a degree of infrastructure capable or potentially capable of agricultural economy. The Arctic is a growing, and relatively youthful sector of the global population, and increasingly important on the global scale in regard to politics and economy (Anisimov et al., 2007; SNAP, 2009b). As a final note, there is currently a high level of dependence on natural food sources, mostly by Native Alaskans who consume 465g/day, but urban Alaskans average 60g/day as well according to the Arctic Monitoring and Assessment Program of 2003 and Chapin et al. (2005; Anisimov et al., 2007). This food source is estimated to be worth around 200 million USD/year (Anisimov et al., 2007). This indicates an interest in local food sources as well as the potential for vulnerability in the face of climate change. These factors seem to indicate a potential for infrastructure development and suggest that cool, short seasons are the sole reason for limited circumpolar agriculture to date. In the end, resilience and flexibility of resource bases will be key to mitigation and benefit, which may include taking advantage of expanded agricultural opportunities (Anisimov et al., 2007).

Though growing seasons are lengthening for Alaska and productivity is increasing as depicted in this study, these "benefits" of climate change are highly spatially variable (Anisimov et al., 2007; SNAP, 2009). Thus, as has been important historically in the determination of appropriate agricultural cultivars to an area, review of climatic suitability will be necessary in analyzing future scenarios. Many means of examination and amelioration of climatic circumstances exist. More expensive time and research intensive mitigation and analysis techniques include expanded irrigation and new crop variety development (Lobell et al., 2008). However, relatively inexpensive mitigation and examination techniques exist which have been in use for centuries. These include planting at different dates and utilizing different crop varieties or cultivars already in existence (Lobell et al., 2008).

Plant Selection and Success Prediction Techniques

There are many different historical methods of zoning, such as the USDA's hardiness zone scheme which has been utilized in both the United States and Canada as well. Other schemes are based on other aspects of temperature, such as heat receipt.

Growing Degree Days

The use of the heat unit increment, the growing degree day (GDD) has been utilized for over two centuries and was first identified by Réamur in 1735 in fruit ripening (Allen, 1975; Andrewartha and Birch, 1973). This led to the study and development of mathematical descriptions of heat receipt in relation to stages of development of plants and poikilothermic organisms (Andrewartha and Birch, 1973). Most heat unit computing methods utilize a linear rate-temperature assumption, such that degree days were sometimes called "linear heat units" (Allen, 1975). Many scientists have endeavored to develop equations, classified by Davidson in 1944 as either theoretical or empirical, that more thoroughly mimic actual temperature curves (Andrewartha and Birch, 1973). Simpson (1903) was the first to use the term "degree days" in conjunction with the mathematical description (Equation 1) in which y represented the duration of development (days), x, the temperature (daily minimum and maximum), a, the developmental zero, and k, the thermal constant (Andrewartha and Birch, 1973).

$$k = y(x - a)$$

Equation 1

Key to this are the lower and upper developmental thresholds below and above which, respectively, development is thought to cease or becomes less linear (Miller et al., 2001; Allen, 1975). At the time of Andrewartha and Birch's book The History of Insect Ecology (1973), the main use of degree days was for interpretation of past events and "rough predictions" about the future state of the weather were not considered useful in degree day estimates. However, degree days were acknowledged to remove variations otherwise seen in development when growth comparisons are based on calendar days (Miller et al., 2001).

Degree day information is currently useful for planning cereal crops, predicting times for the use of pesticides and herbicides, predicting the development of diseases, comparing crops at different times or locations, scheduling nutrients and irrigation, and assessing potential damage from seasonal, climatic episodes (e.g. weather; Miller et al., 2001). Pests and disease are currently being modeled by similar processes as discussed with AOGCMs and downscaling. One study, done by Seem (2004) involved downscaling global-change models, analogous to GCMs, to predict changes in plant pathologies. Today, degree days are becoming increasingly mapped. One of the front runners of mapping, Oregon State University, where PRISM downscaling techniques were developed, has conducted a project in which current degree days were calculated from more than 900 sites from five northwestern states, interpolated with actual degree day data and displayed on a GIS interface (Coop and Jepson, 2003). This project looked at the phenology of insects, diseases, crops, weeds, and mating (Coop and Jepson, 2003).

As Alaska can be defined as a locale in which climate is the dominant determinant of agricultural success, it makes sense to utilize models of climatic restrictions to estimate the future of local agriculture.

V. Methods

In the spring of 2009, it was proposed that this project be undertaken to 1) utilize the Scenarios Network for Alaska Planning (SNAP) downscaled IPCC ensemble data to calculate GDDs and then to 2) examine the available growing degree days throughout the North Star Borough spatially and temporally, and then 3) interview local agriculturalists to put this information into context. The methodology of this project can be broken into two phases: modeling the projection of future growing degree days and the interview process. Through these two means both reliable and relevant information on the future of agriculture of the North Star Borough was explored.

Projection

Growing Degree Day Calculation

Data was received from SNAP for the average monthly temperatures of May, June, July, August, and September for six time points: historically, 1950 and 2007 (CRU historic data, resolution 1 km2), and future projections for 2007[2], 2020, 2050, 2098 (resolution 2 km2) from the Scenarios Network for Alaska Planning (SNAP) A1B projection model in the form of text datasets (previously ASCII files). Three consecutive years from each of these time points were utilized in order to minimize interannual variability noise. Monthly averages were rationalized to be an acceptable substitute for daily values as that, assuming linear progression of temperature, falsely high values for the beginning of colder, spring months would nominally balance overly low values at the end of the month, and the opposite for the months at the end of the season, when cooling occurs. Each month was then formatted into an Excel spreadsheet forming books based on the three consecutive year sets (e.g. 2006, 2007, and 2008). Cells, each representative of the monthly average temperature for a 4km2 area in the North Star Borough, were summed throughout each year as in Equation 2 (opposite page), resulting in a spreadsheet of the annual, three-year averages of GDDs per 4km2 area.

As seen in Equation 2, the threshold selected was freezing. This threshold was selected due to the fact that one limitation of growing degree days is that GDD values vary per cultivar, location, and even growth stage of plants (Juday et al., 2005). However, due to the nature of this project's aim—the spatial and temporal comparison of heat energy receipt—this simplicity was appropriate. Due to chosen methods, future revisitation of these equations to create models specific to other thresholds would be straightforward.

The final sets of Excel data were returned to SNAP to be converted back to ASCII files and into maps. This was accompanied by a list of GDD increments that would become the

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[2] At the time of the original projections in 2002, 2007 was a future estimate. However, expanded funding allowed SNAP the retrieval of more current historic CRU data in 2009 such that both historic and projection data exist for this time period.

$$\begin{aligned}&\mathit{Annual\ GDD\ per\ cell}\\&\quad = \mathit{SUM}((31 * 5.2006!\,H28) + (30 * 6.2006!\,H28) + (31 * 7.2006!\,H28)\\&\quad + (31 * 8.2006!\,H28) + (30 * 9.2006!\,H28))\end{aligned}$$

Equation 2. The Excel calculation used to sum five monthly mean temperatures. Numbers represent the number of days in the respective month and are multiplied by the cell, e.g. H28, per monthly Excel sheet of that year.

nine zones that were reflective of the range of annual GDDs expressed over the time period from 1949 to 2099 in the North Star Borough. Finally, statistical analysis was performed on the Excel spreadsheets to determine the percent increase of GDDs throughout the borough and per local agriculturalists' locations.

Crop Feasibility Table

After obtaining the GDD ranges of the zones from the mapping procedure and the North Star Borough GDD verified values (see Local Agriculture section of Methods), a table was created to reflect the range of crops that are currently, and then those that could be potentially, grown. Current literature was originally intended to be utilized to supply estimated GDDs for crops not yet grown in the North Star Borough. However, as that relatively less literature exists on growing degree days for horticultural crops, especially in the circumpolar regions, a comparison to current contiguous United States growing regions was utilized instead. An online thirty-year average GDD map for the contiguous United States that compiled temperature data from numerous organizations, such as the National Weather Service, and was downscaled with PRISM, as SNAP's models, was used as this point for comparison to put future potential heat receipt into context (Coop, 2010b).

Local Agriculture

Local Agriculture Interviews

> *Scientific knowledge about climate change needs to be more specific in order to interact with local expertise shared within the northern communities.*
>
> — Igor Krupnik, 2002

As pointed out in this quote by Igor Krupnik, global climate change can be difficult to scale down into meaningful, local predictions. One means of translating climate change predictions into terms of northern community effects is through the establishment of climatic dependence of different user groups, as has been done with climate change and impacts on indigenous northern communities (Krupnik, 2002). Thus, local agriculturalists were interviewed to establish relative interaction with growing degree days in North Star Borough agriculture.

After receiving IRB exemption, semi-directed interviews of eight local agricultural establishments, ranging from private gardens (three) to community-supported agriculturalists (four), were conducted during the 2009 growing season to ascertain the extent of current, directly-seeded, annual vegetable agriculture in the North Star Borough (consent forms and interview outline, Appendix E and F). The locations of these establishments were plotted on the SNAP maps to give local focus to future projections. The data obtained from these interviews was analyzed to estimate what percent of available GDDs are currently utilized.

Growing Degree Day Verification

Since growing degree days are highly specific per cultivar and location (Juday et al., 2005; Miller et al., 2001), local growing degree day values for different cultivars were calculated. This was done by utilizing weather station data collected from the National Oceanic and Atmospheric Administration (NOAA) station at the Agriculture and Forestry Experiment Station (AFES), which was converted to GDD values (base 32°F) through the use of data obtained from Research Technician Robert Van Veldhuizen and the Annual Vegetable Trials published by Georgeson Botanical Garden (GBG; Van Veldhuizen, personal communication, April 22, 2009; Van Veldhuizen and Knight, 2004; Matheke et al. 2007, Matheke et al. 2008, Holloway et al. 2009). By calculating the GDDs received by plants between sowing and harvest, a Fairbanks North Star Borough value was assigned to directly-seeded, annual vegetable cultivars.

VII. Results

Before examining the maps generated of the borough, it is helpful to become oriented. Figure 13 (see page 16) shows the Fairbanks North Star Borough on which Fairbanks and the Tanana River, Chena Hot Springs, and the eastern stretch of the Salcha River are located.

Projection

Growing Degree Day Calculation

In Figure 14 (see page 17) are the results of the growing degree day map models for the North Star Borough Alaska from five selected time periods across three years for each period. They are presented in larger format in Appendix A. These maps were compared against Figure 15 (see page 18) and the findings were compiled in table form, which can be seen in the Discussion section.

Crop Feasibility Table

This again proved to be the most difficult portion of the projection and prediction scheme. Aside from comparison with continental United States agricultural regions, the GDD verification was completed and graphed as seen in Figure 16 (see page 18).

Local Agriculture

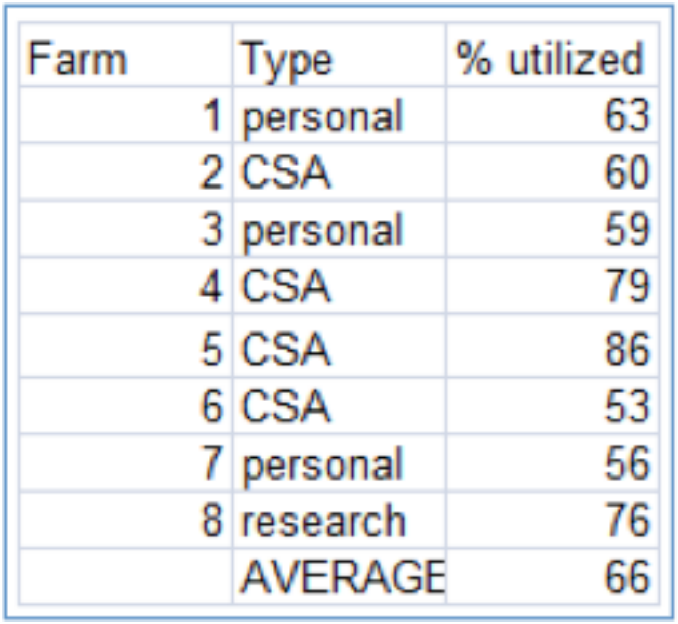
Local Agriculture Interviews

A total of eight agricultural interviews were conducted with a variety of members of the local agricultural community as reflected in Table 2. Also reflected in this table is that the average grower utilized approximately 70% of the growing degree days estimated to be available in their area.

Additionally, since the Georgeson Botanical Garden had three sources of data, a comparison was done between the NOAA weather station data, the historic Climate Research Unit (CRU) data, and the projected values (see Figures 17 and 18, page 19).

Table 2. Estimated percent GDD utilized by eight interviewed agriculturalists.

N.B. "Personal" gardeners all were qualified with Master Gardener training or subsisted largely off their produce. CSA = Community Supported Agriculture. program.



Farm	Type	% utilized
1	personal	63
2	CSA	60
3	personal	59
4	CSA	79
5	CSA	86
6	CSA	53
7	personal	56
8	research	76
	AVERAGE	66

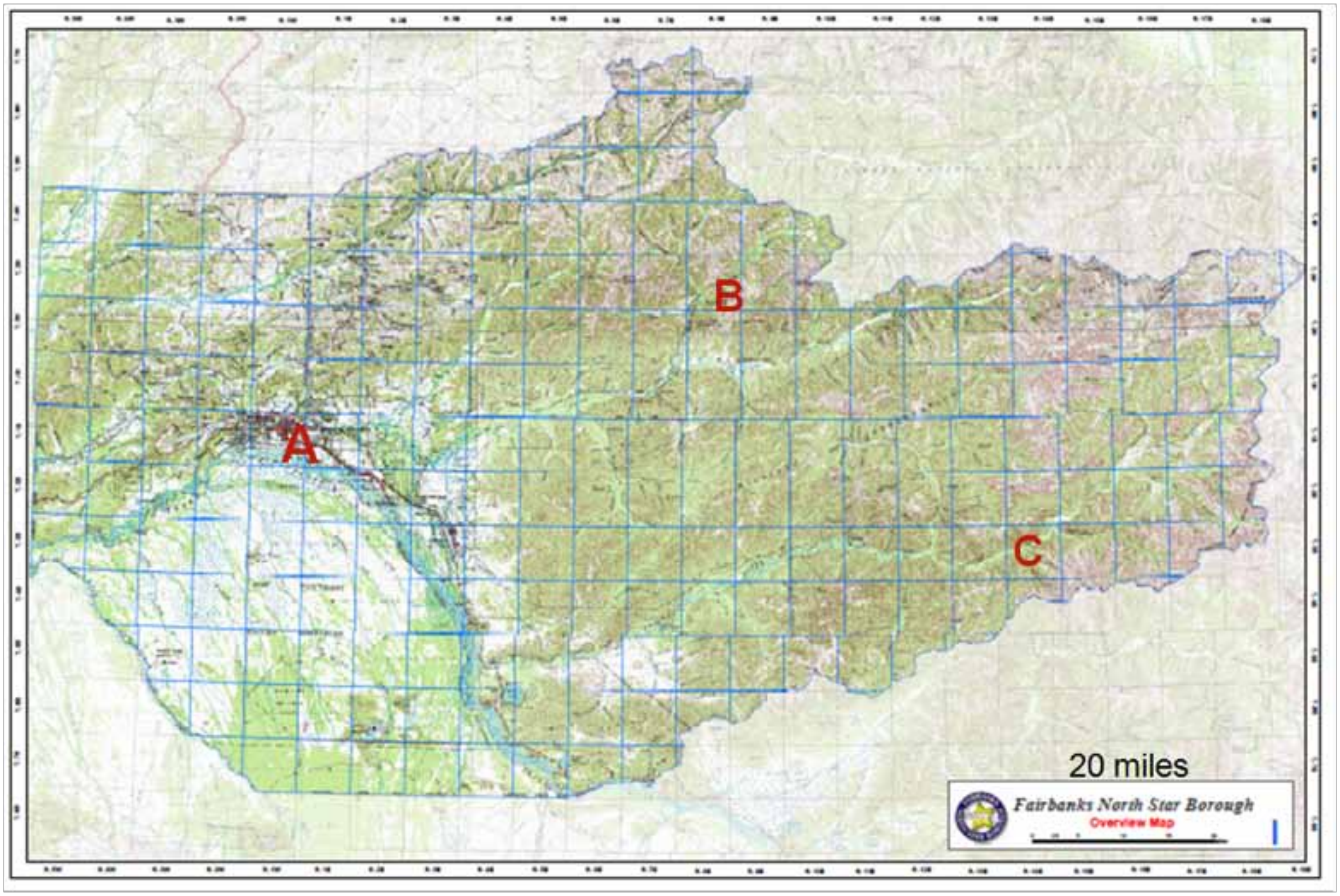


Figure 13. Adapted USGS map: A) Fairbanks, below which is the Tanana River, B) Chena Hot Springs, C) eastern portion of the Salcha River (Hernandez, 2008).

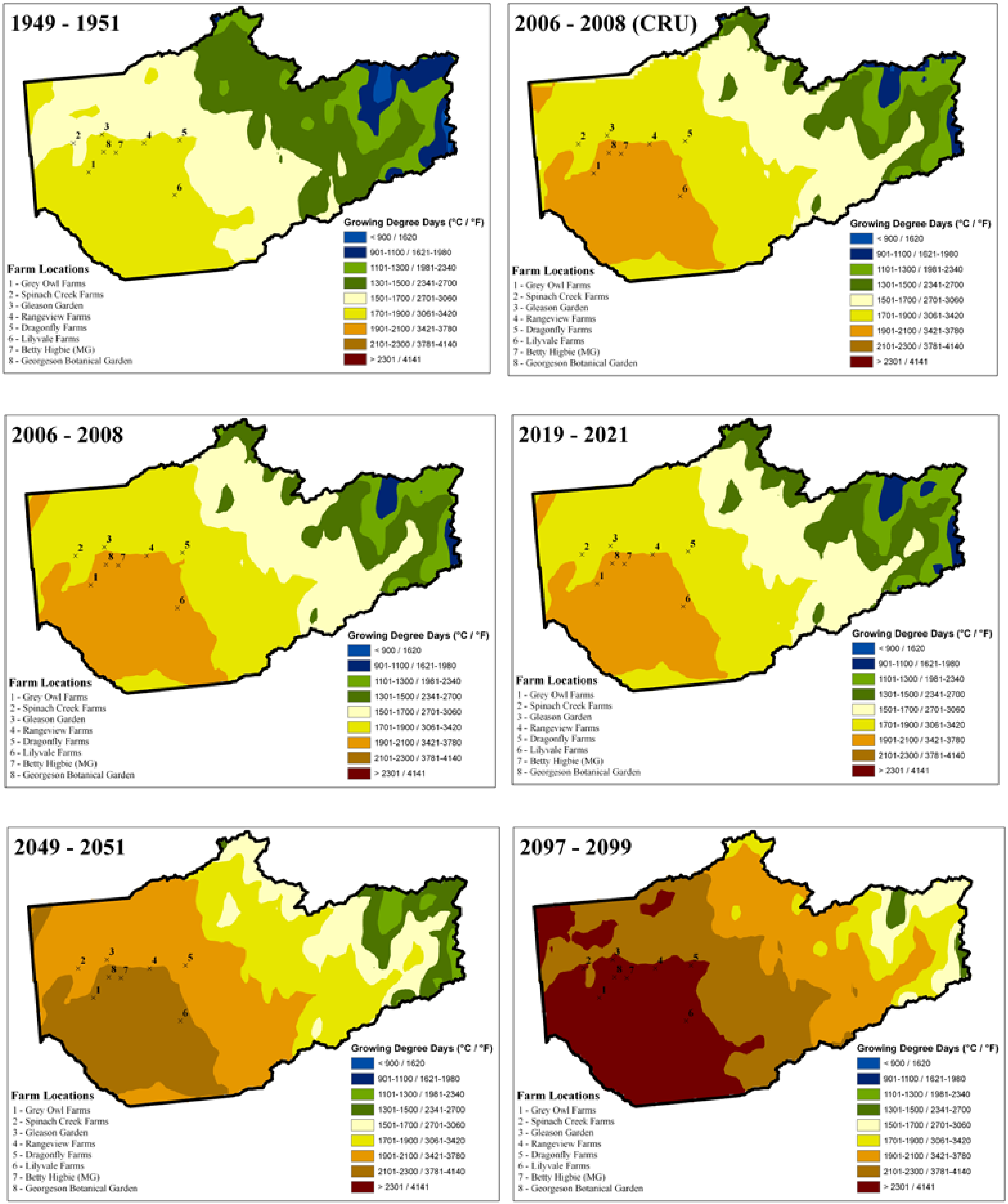
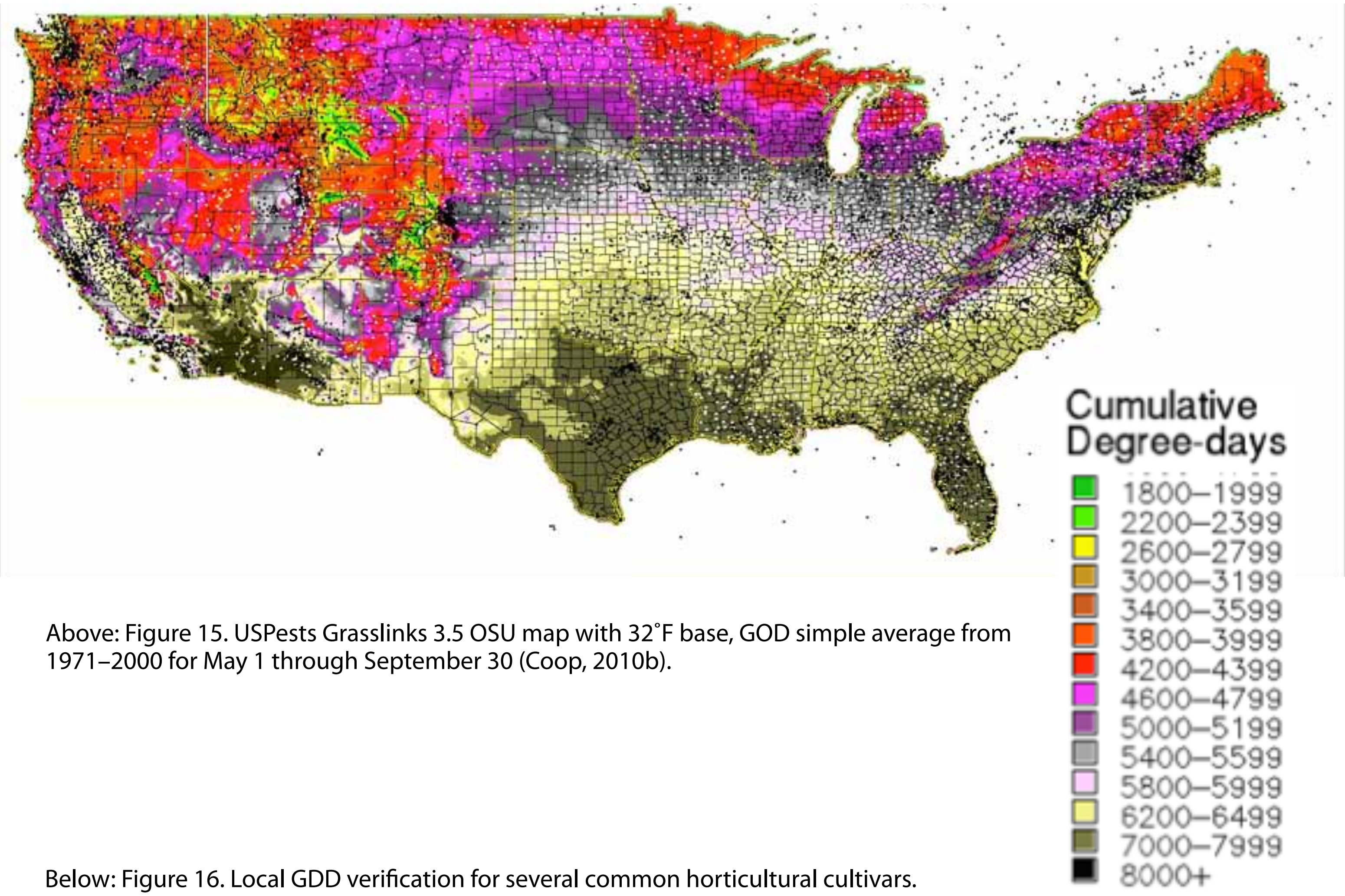
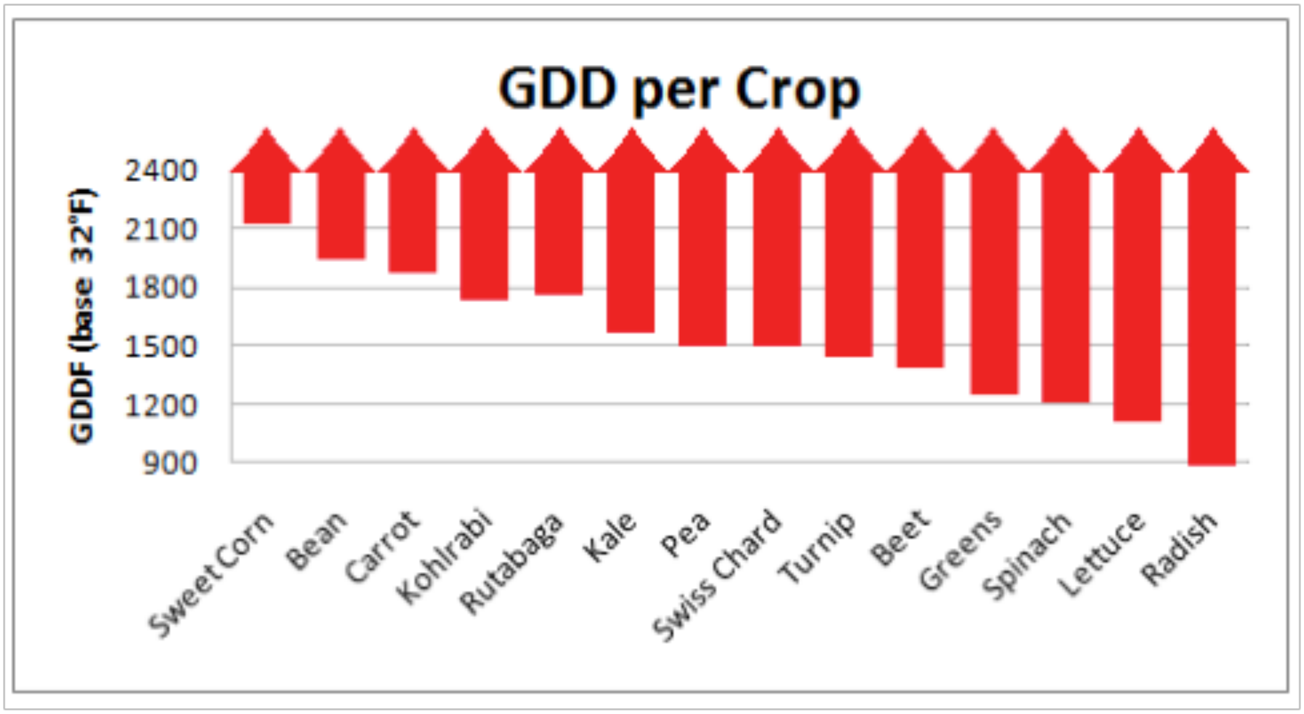


Figure 14. Projections of historic (CRU) and future of growing degree days in the North Star Borough over the six time points averaged across three consecutive years. See Appendix A - Maps, page 23, for larger views.



Above: Figure 15. USPests Grasslinks 3.5 OSU map with 32˚F base, GOD simple average from 1971–2000 for May 1 through September 30 (Coop, 2010b).

Below: Figure 16. Local GDD verification for several common horticultural cultivars.



Opposite, Figure 18. Various data sources are depicted here to demonstrate unity of trend across weather station, CRU and AFES, and SNAP model projection data.

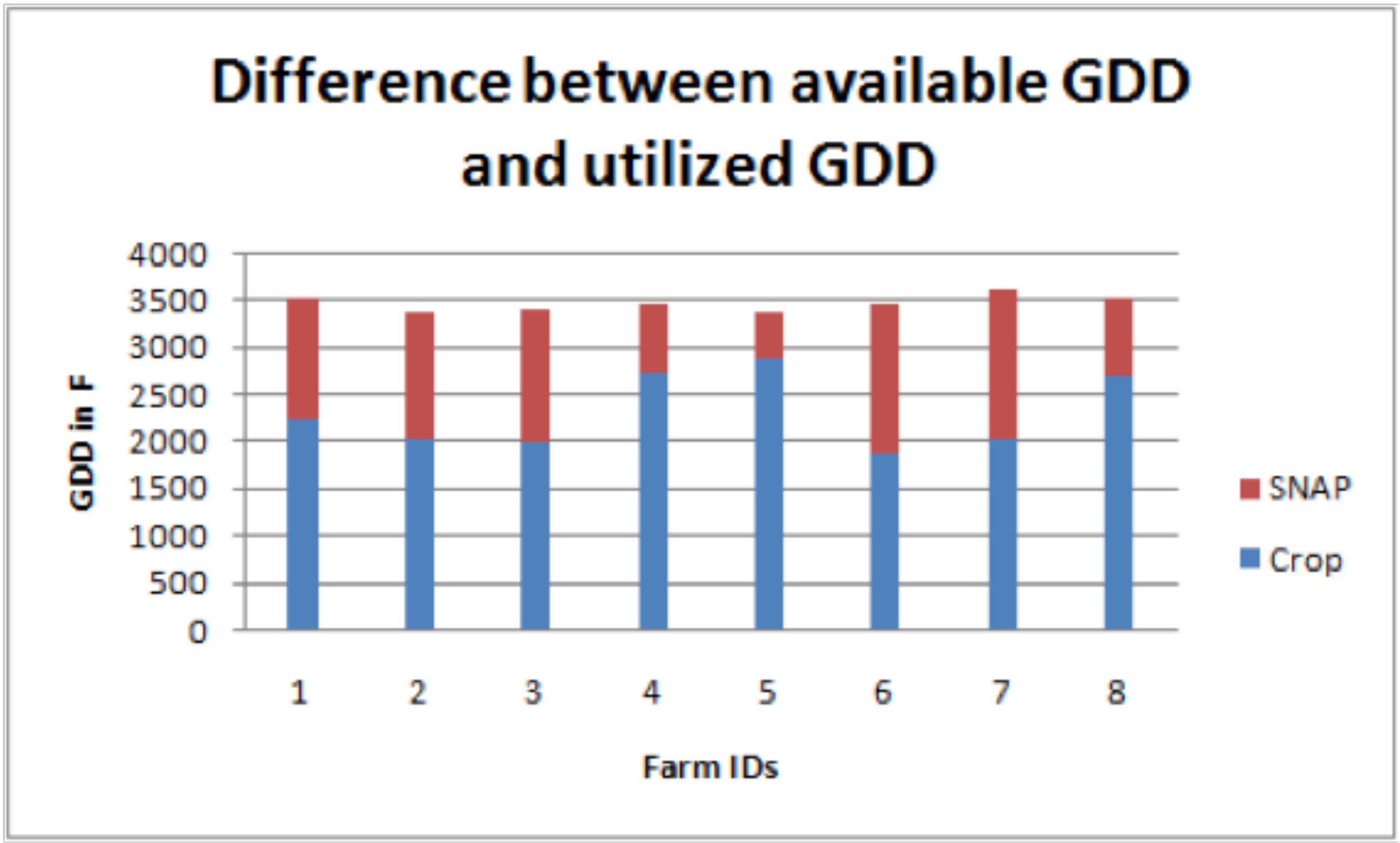
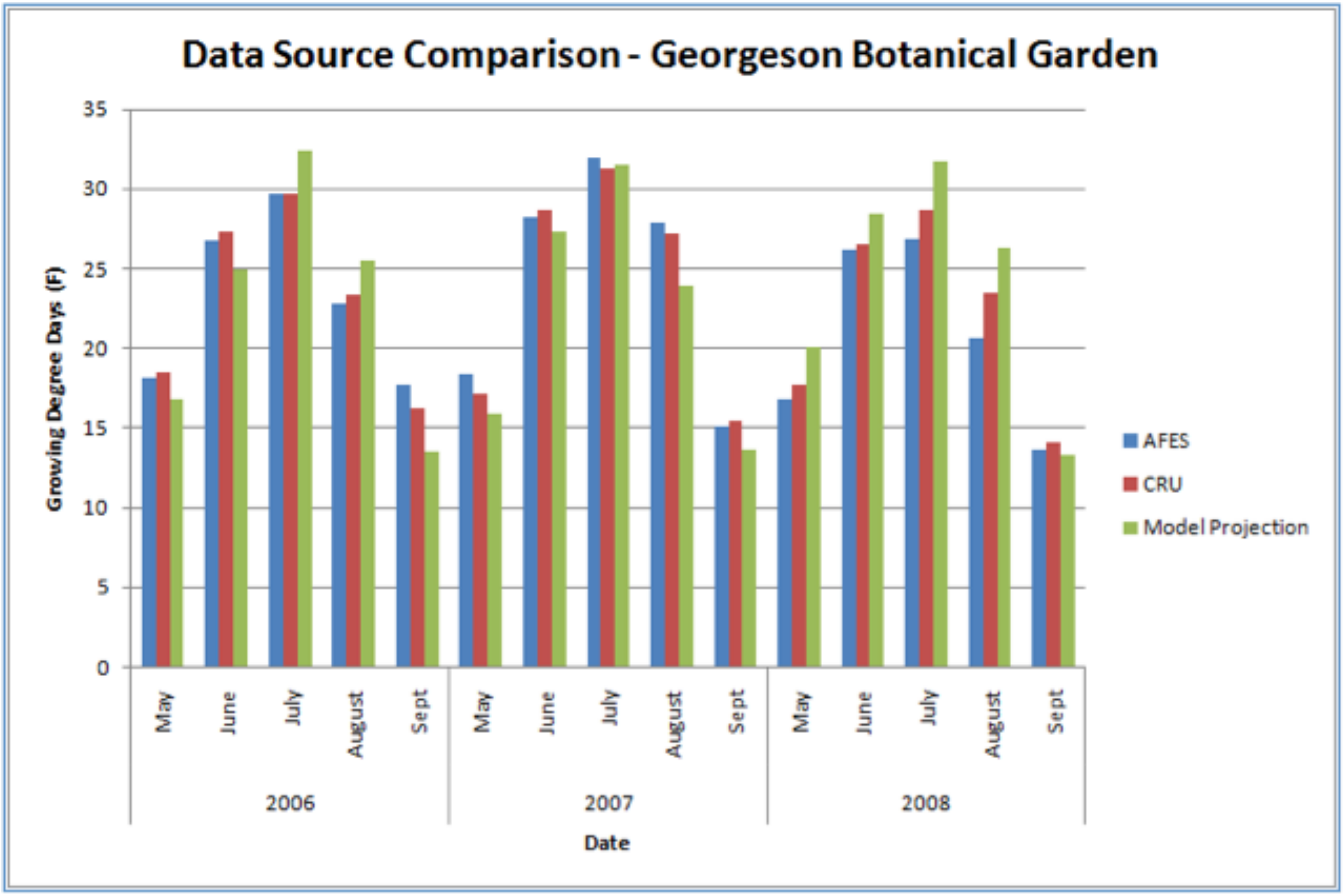


Figure 17. Comparison of utilized GDD per agricultural location in comparison with SNAP's 2006-2008 predicted available GDD.



VIII. Discussion

Future of Agriculture in the North Star Borough

When projected map data was compared to continental United States growing regions, clear trends in the potential for increased agricultural crops appeared (Table 3).

Most notably, in the absence of the 70% actual usage consideration, the Fairbanks North Star Borough is considerably similar to the Corn Belt in heat receipt by the end of the current century. This may have significant implications for the potential yield and variety of local crop production. Supplemental to this, it is important to note that the eastern portion of the borough becomes increasingly favorable to agricultural pursuits as depicted by the Yukon Energy, Mines and Resource division's table of agricultural limitations per GDD receipt (Table 4).

Further analysis of this trend, as seen in Figure 19 below, led to the finding that an average of a 2% increase in GDD per decade has and will be seen over the time period of 1949 to 2099, resulting in an overall 26% increase in GDD for the western portion of the borough by the end of the century.

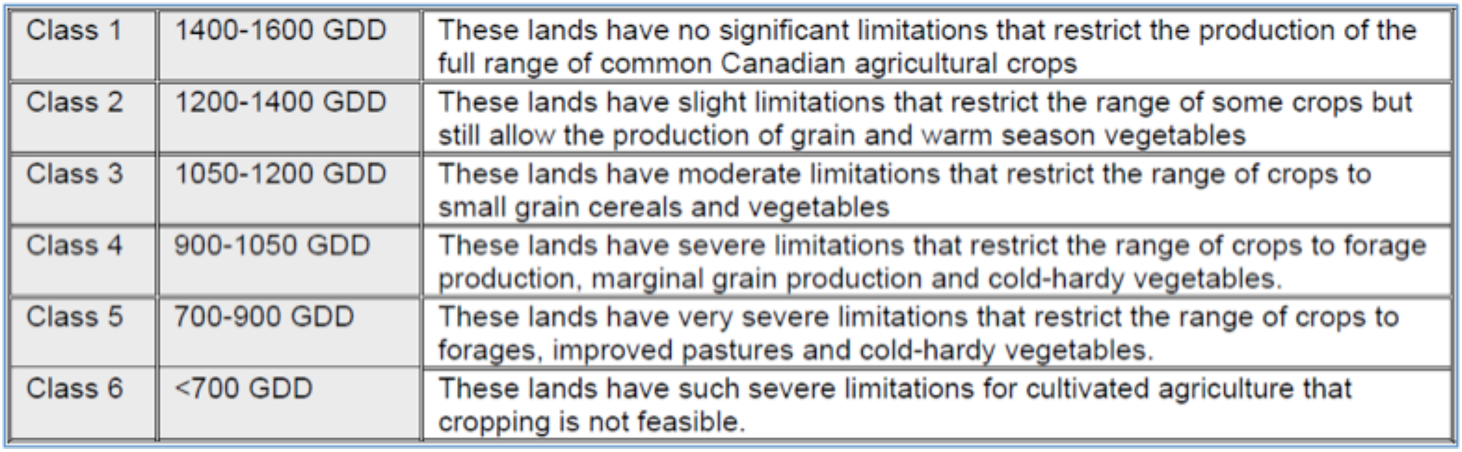
Caveats

Studies of the future are not without caveats. Most notably encountered during this project were discrepancies pertaining

Table 3. Estimated GDDs for five major time points, with and without 70% GDD-usage consideration, paired with contiguous United States equivalents.

Time Period	**Highest GDD** 70% total projected GDD (total projected GDD)	**Contiguous U.S. Equivalent** 70% GDD (total GDD)
1949-1951	2143 – 2394 (3061 - 3420)	Northwest Wyoming (Pacific Northwest: e.g. western MT)
2006-2008	2395 - 2646 (3421 - 3780)	Pacific Northwest: e.g. western MT (Pacific Northwest, very northern Corn Belt)
2019-2021	2395 - 2646 (3421 - 3780)	Pacific Northwest: e.g. western MT (Pacific Northwest, very northern Corn Belt)
2049-2051	2647 – 2898 (3781 - 4140)	Pacific Northwest (Upper Corn Belt - northern MT)
2097-2099	> 2898 (>4140) (Largest GDD value = 4476)	Pacific Northwest (Upper Corn Belt - northern MT) (Corn Belt: e.g. western NE)

Table 4. Agronomic capability classes of the Yukon territory as identified by the Agriculture Branch of Yukon Energy, Mines and Resources and calculated as GDDs base 5°C, accumulating after the first five consecutive days above this temperature and stopping after the first killing frost post July 15th (Barton and Ball 2007).



Class 1	1400-1600 GDD	These lands have no significant limitations that restrict the production of the full range of common Canadian agricultural crops
Class 2	1200-1400 GDD	These lands have slight limitations that restrict the range of some crops but still allow the production of grain and warm season vegetables
Class 3	1050-1200 GDD	These lands have moderate limitations that restrict the range of crops to small grain cereals and vegetables
Class 4	900-1050 GDD	These lands have severe limitations that restrict the range of crops to forage production, marginal grain production and cold-hardy vegetables.
Class 5	700-900 GDD	These lands have very severe limitations that restrict the range of crops to forages, improved pastures and cold-hardy vegetables.
Class 6	<700 GDD	These lands have such severe limitations for cultivated agriculture that cropping is not feasible.

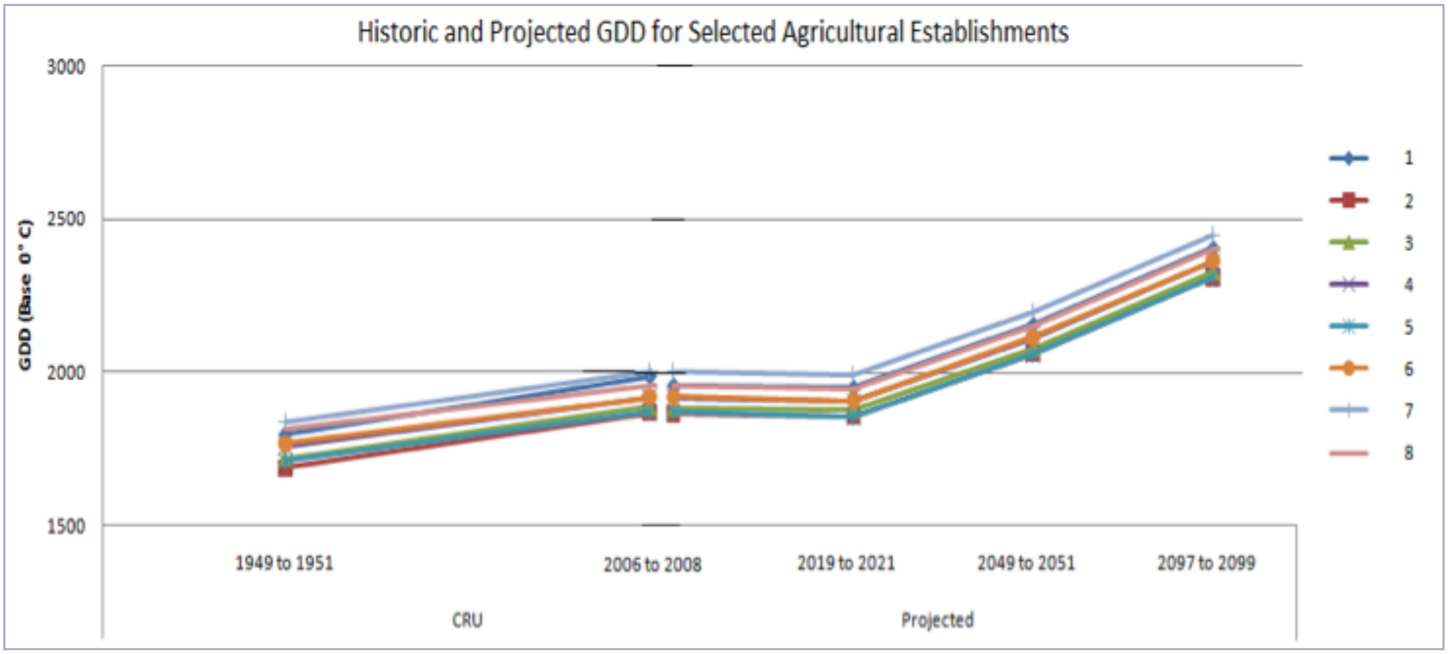


Figure 19. Historic (CRU) and projected data for the eight interviewed agricultural locations.

to frozen soils, limited sampling and prior literature, and photoperiod interactions. Ultimately, as the goal of this study was to compare spatial and temporal heat receipt in the Fairbanks North Star Borough, these caveats did not impede the attainment of relevant and useful data. However, should a goal be to determine specific potential cultivars plausible for future decades, these factors would need to be taken into account.

In regards to soil temperatures, it was noted during interviews that potential GDD heat units that are calculated based on air temperature do not always take into account the actual feasibility of planting when soils are still frozen as was noted at agricultural establishment #6 of this study. Cooler soils delay germination, reduce seed emergence, decrease root function and microbial activity, thus nutrient cycling (Barton and Ball, 2007). Currently, many agriculturalists are using HOBO soil devices to aid in the collection of soil degree data, including establishment #6, so in the future it is possible soil GDDs may be mapped in a way similar to this study and may provide better hypothesizing power as to the future of crops, especially in regards to planting, germination and other soil thaw issues.

Next, few local agriculturalist samples were obtained and of these only a narrow range of the borough was represented. This was partially due to the prohibitive climate of the eastern portion of the borough. Additionally, since a small sample size was used, it is expected that there was some variance in farm characteristics, such as size and intensity, which may impact the spatial and temporal yield reports (Challinor et al., 2009).

The first thing to note regarding caveats dealing with photoperiod is that adequate receipt of GDDs does not guarantee crop yield. Many crops have photoperiod requirements for phenological development, maturation, and reproduction. For instance, the soybean requires ten hours of darkness to flower which is not consistent to when the requisite number of GDDs for this particular phenological stage have been received by North Star Borough fields (Van Veldhuizen and Knight, 2004). Thus, soybeans, and many more dark-dependent-stage crops, are likely exempt for circumpolar regions due to long day length. Additionally, since growing degree days are highly specific to cultivar and location, and agriculture and agricultural research at high latitudes is often limited, very few sources discussed Arctic growing degree days in general (Sparrow et al., 2007). This is important in that it is thought that photoperiod also has some interactive effect with growing degree day accumulation (Goudriaan and van Laar, 1994). In Canada, "effective growing degree days" are utilized to accommodate this additional energy from long photoperiods through a multiplying factor based on latitude that otherwise would not be captured in solely temperature-based calculations. On a smaller scale, some businesses have begun to amend this by requesting feedback from local growers and assigning region relevant maturity dates to seeds, such as "early" or "late" as has Denali Seed Company (Yaple, personal communication, April 2, 2010). Also, efforts are being made to collect and distribute this information, such as through the construction of a Davis Instruments weather station by the Department of Natural Resources (DNR) Plant Materials Center (PMC) in Palmer which will be coupled with Agricultural/Turf management software to monitor growing degree days (DNR, 2009).

Finally, there was some initial criticism received based on the level of resolution to be achieved by this study (2 by 2 km); however, it has been noted in the literature that at increasingly small spatial scales non-climatic factors become increasingly important. Thus this scale seems most appropriate for a climatic review of potential agriculture in the North Star Borough (Challinor et al., 2009).

> *Technologic sophistication determines a farm's productivity far more than its climatic and agricultural endowments.*
>
> —Brown and Funk 2008

Along this vein it is also important to note that, as observed during the interviewing process, agriculturalists are extremely innovative. Thus there exist many avenues to most fully utilize the heat receipt of an area. The most common of these, as printed in *Johnny's Seed Catalog* (2010) include the use of high or low tunnels, greenhouse/cold frame sprout starts, row covers (gain 1-3°C for soil (YAA, 2010) , plastic/paper mulch or landscape fabric such as infrared radiation transmitting (IRT) plastic, and raised beds.

Climate Impacts of Increased High Latitude Agriculture

In addition to the considerations for the potential of increased agriculture in the circumpolar regions, there may also be reason to consider once again the amplification effect of climate change in the high latitudes. As discussed in the literature review, the polar region is identified as a key region to affect global climate change, thus the global human population (Anisimov et al., 2007). Climate change and agriculture form a feedback loop and major land use changes especially impact climate feedbacks (Sling et al., 2005). While the impacts of land use change are less significant than GHG impacts, it is thought that drastic land use changes could have significant impact on a regional level (Meehl et al., 2007). Some types of ecosystem conversion are more influential, such as the modification of floodplains and wetlands, on overall ecosystem services (Sathaye et al., 2007). Feedbacks of concern include albedo and carbon flux. Albedo in the northern high latitudes is a key driving force of climate change. As sea ice and snow cover decline, reducing the reflectance of solar energy, positive feedbacks to the global climate system occur (Anisimov et al., 2007). There is also uncertainty associated with the arctic carbon flux. The thickening active soil layer may prove to be a temporary sink, but it is thought that emissions from melting permafrost will outweigh these benefits (Anisimov et al., 2007). Other, less obvious effects of increased agriculture have also been seen, such as with the increase of grain production in Alaska, geese that eat this grain as winter forage have been seen to increase geometrically, putting strains on the other ecosystems, such as their coastal breeding habitats (Anisimov et al., 2007). Additionally, agriculture is a water intensive sector of the economy (Sathaye et al., 2007) and with concerns about shifts in moisture regime, drought or effects of intensive irrigation may be of concern.

Climate change is thought to progress along forced pathways, but in some cases a threshold can be crossed at which time internal dynamics control the rate of change, which may cause change to occur faster (e.g. rapid warming as in Dansgaard-Oeschger events) or more slowly (some historic cooling events). Often this involves changes in the strength of the MOC, causing widespread changes in global circulation (Meehl et al., 2007).

Also, since current conservation management depends on designating areas against direct human action (such as entry and forms of use) and not indirect actions, such as emissions remotely forcing climate change and vegetation shifts, methods of conservation need to be carefully considered (Anisimov et al., 2007). Ultimately, decisions must be made along the lines of ecosystem services and agricultural tradeoffs (Defries et al., 2004).

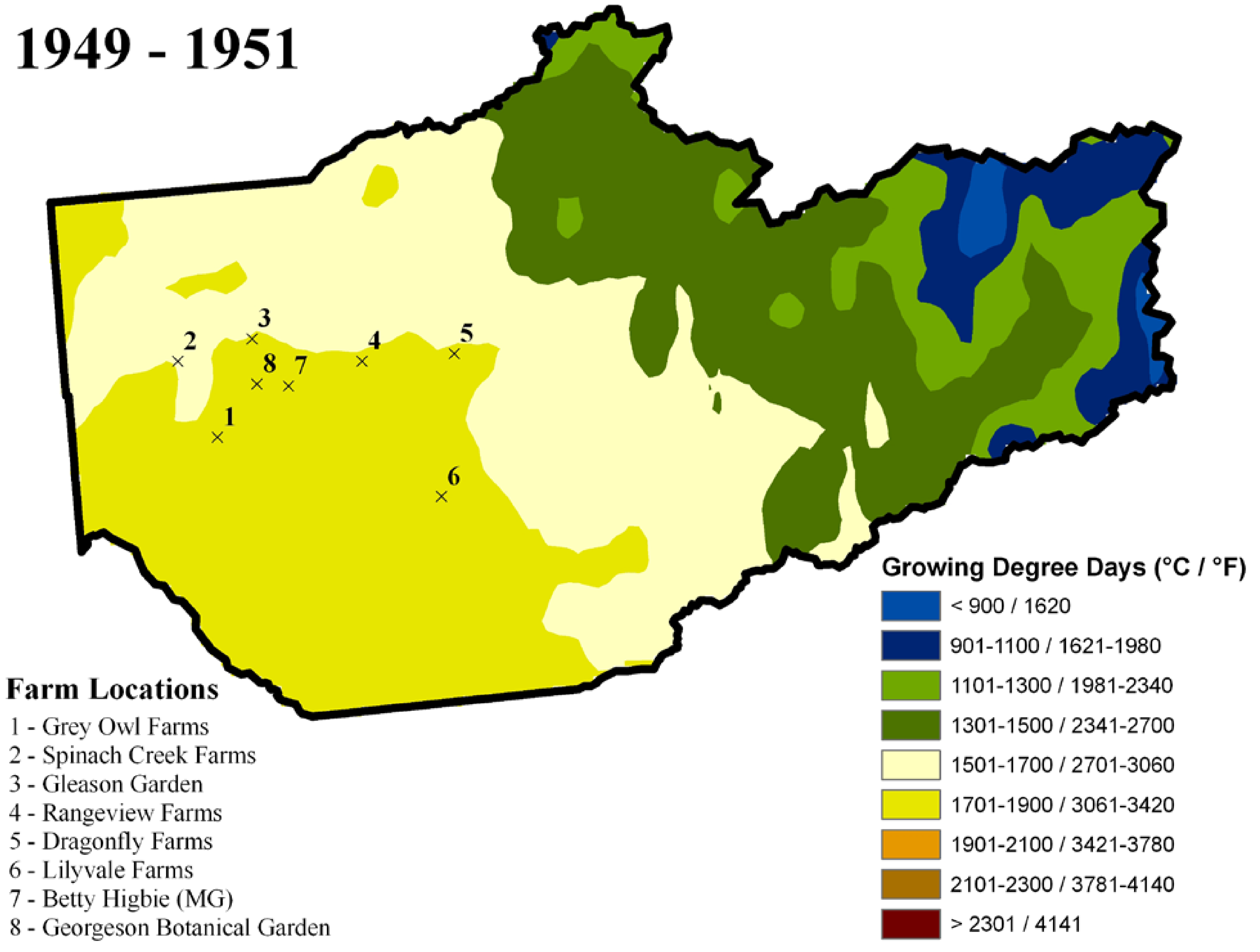
Future Projects

SNAP is still a young organization, currently in its second year. Already new models exist, such as the HadGEM1 2004 update to the HadCM3 from 1997 (Randall et al., 2007) and PRISM has announced the release of software with finer scale tunings. In the future, SNAP hopes to include more climate parameters including snow depth and daily values (Fresco, personal communication, April 1, 2010).

The next step for these sorts of models may include integration of climate and crop modeling systems which are becoming increasingly common (Slingo et al., 2005; Challinor et al., 2009) and may bridge the scientific literature gap encountered in this study pertaining to growing degree day knowledge of crops at high latitude. Other methods of crop prediction include statistical and dynamic modeling, which relate crop production and phenological stages to climate, as well as seasonal crop forecasting which is becoming well developed in some areas (Slingo et al., 2005). For example, Fischer et al (2005) used a Food and Agricultural Organization and International Institute for Applied Systems Analysis (FAO/IIASA) agro-ecological zone model with IIASA's global food system model, with climate variables from five GCMs, under four different IPCC scenarios.

IX. Conclusion

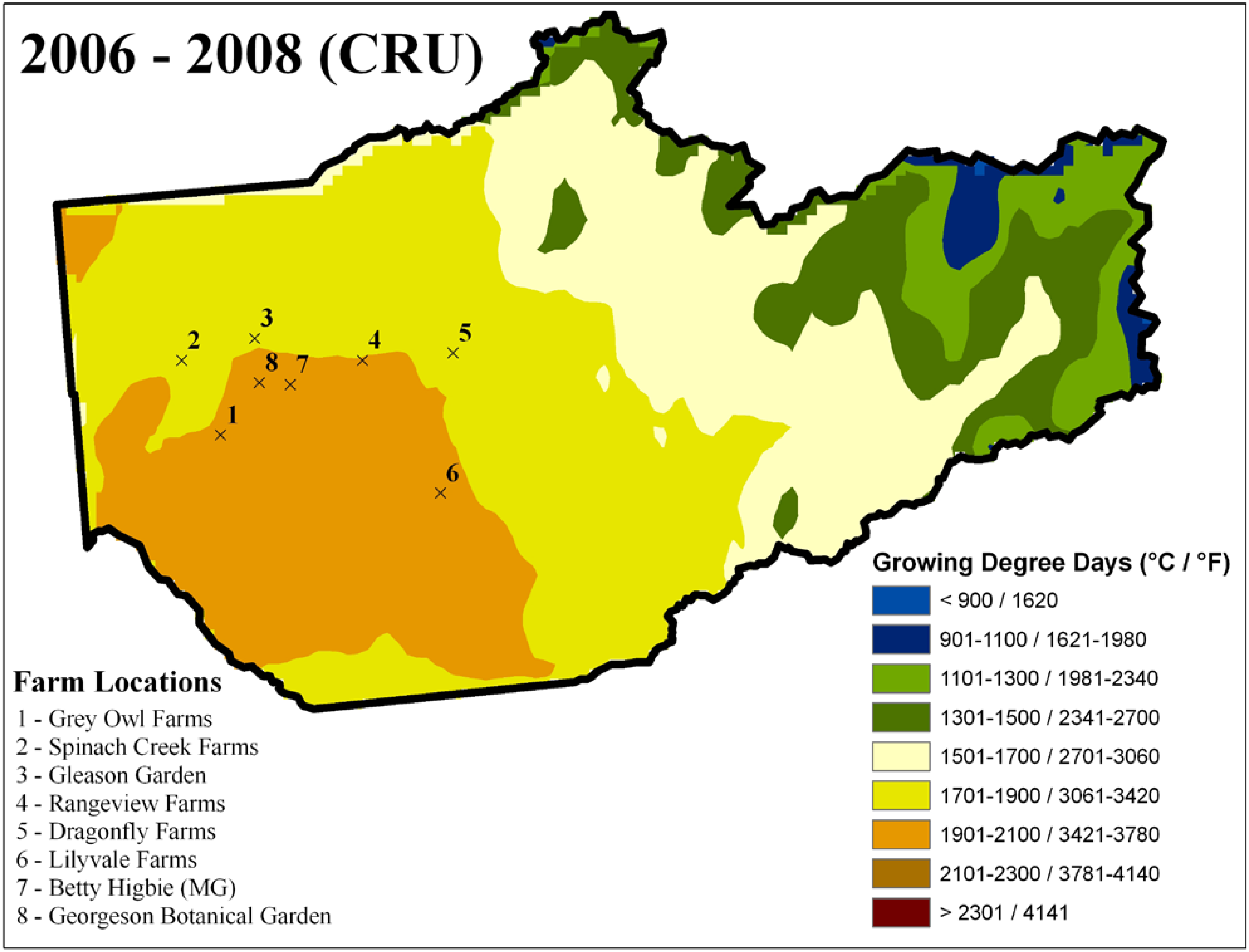
Ultimately, a discussion about climate change is a discussion about variability and unpredictability. Flexibility and variety are often the best means of mitigation when conditions of the future are unknown. Utilizing the most advanced and highly verified climate models available, such as the IPCC ensemble employed by the Scenarios Network for Alaska Planning, land managers may be afforded a more comprehensive picture of future climate scenarios with which preparation and mitigation may be more efficiently executed. Thus, as seen by the mapping and verification process presented in this report, the current climate models project a nearly 26% increase in growing degree days in the North Star Borough over the next century. This increased energy budget could enable the borough to achieve greater, more consistent yields of an increasingly wide variety of crops. This has potential implications for our local, regional, and national economy as well as for Alaska's food security and potential, self-reliance, and overall food quality.



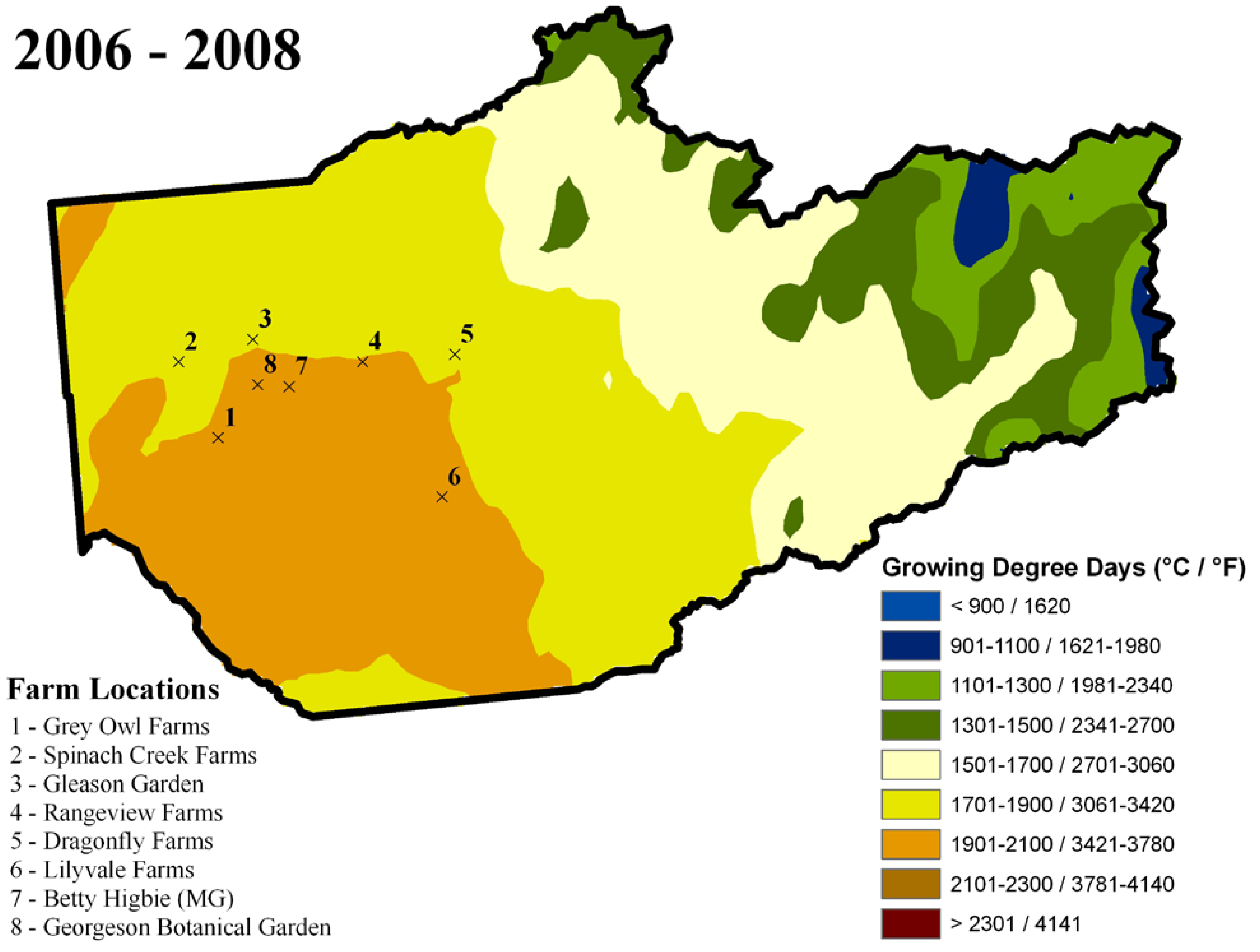
1949 - 1951

Farm Locations

1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden


2006 - 2008 (CRU)
2
3
8
7
1
4
5
6
Farm Locations
1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden
Growing Degree Days (°C / °F)
< 900 / 1620
901-1100 / 1621-1980
1101-1300 / 1981-2340
1301-1500 / 2341-2700
1501-1700 / 2701-3060
1701-1900 / 3061-3420
1901-2100 / 3421-3780
2101-2300 / 3781-4140
> 2301 / 4141

2006 - 2008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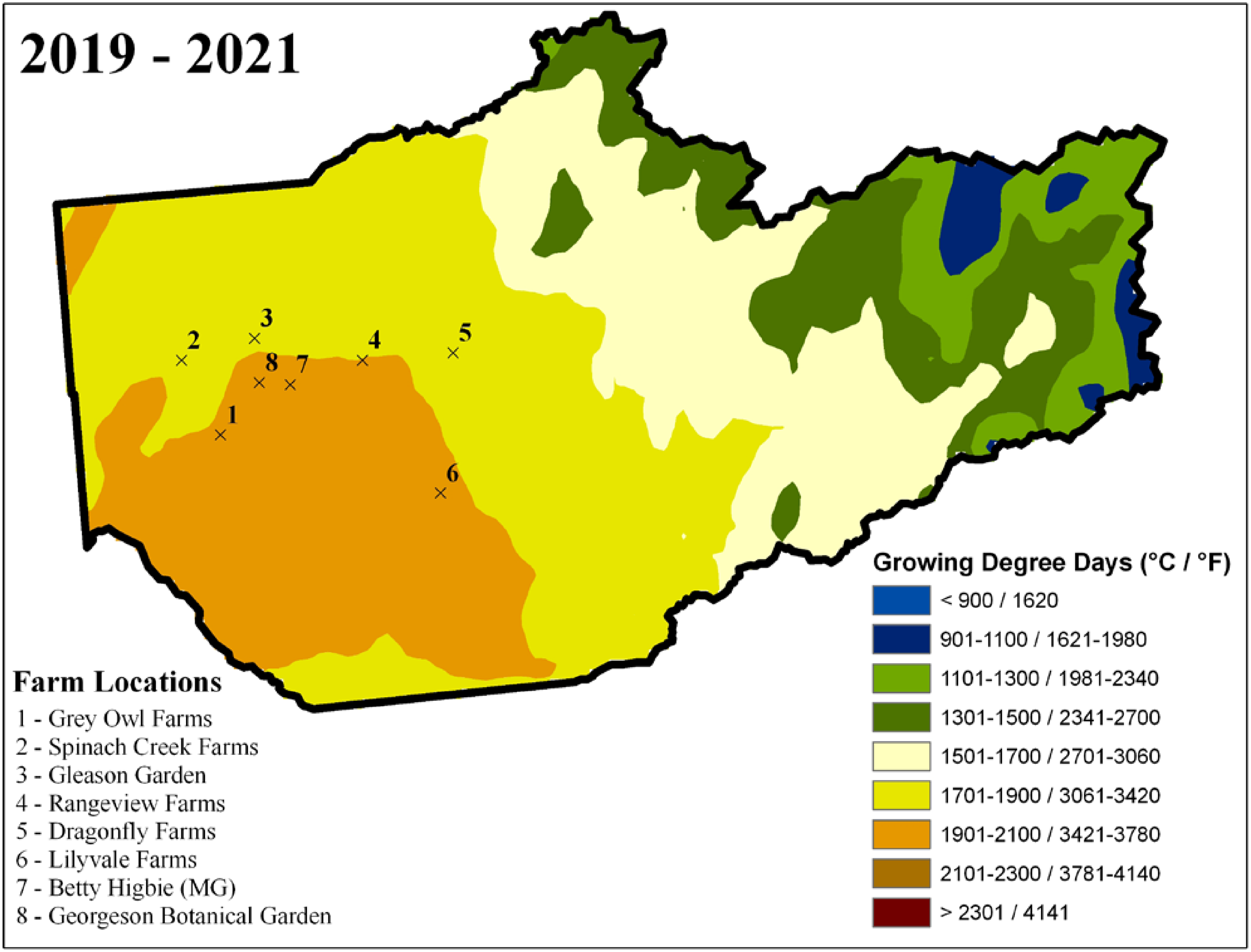
Farm Locations
1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden
Growing Degree Days (°C / °F)
< 900 / 1620
901-1100 / 1621-1980
1101-1300 / 1981-2340
1301-1500 / 2341-2700
1501-1700 / 2701-3060
1701-1900 / 3061-3420
1901-2100 / 3421-3780
2101-2300 / 3781-4140
> 2301 / 4141


2019 - 2021
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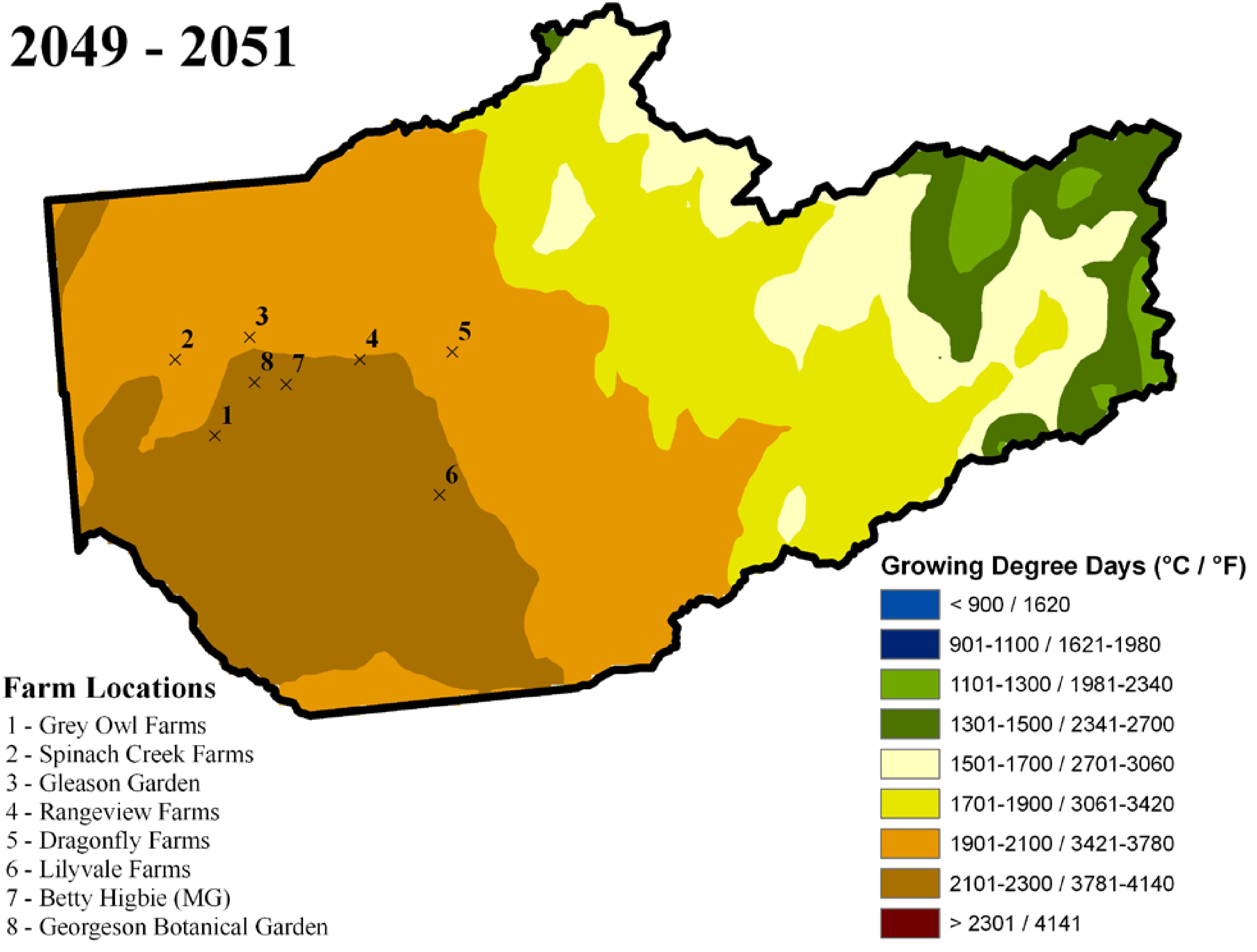
Farm Locations
1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden
Growing Degree Days (°C / °F)
< 900 / 1620
901-1100 / 1621-1980
1101-1300 / 1981-2340
1301-1500 / 2341-2700
1501-1700 / 2701-3060
1701-1900 / 3061-3420
1901-2100 / 3421-3780
2101-2300 / 3781-4140
> 2301 / 4141

2049 - 2051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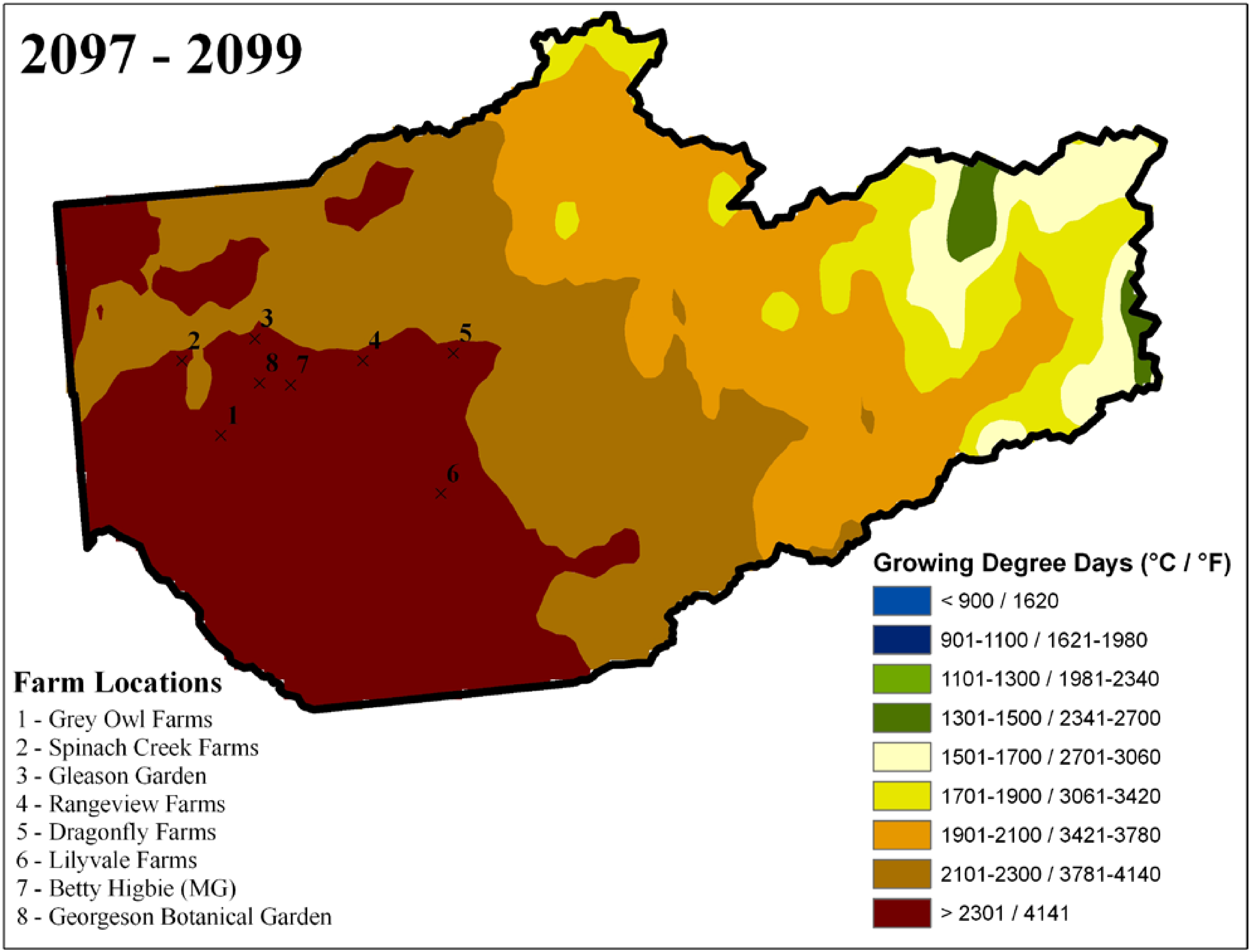
Farm Locations
1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden
Growing Degree Days (°C / °F)
< 900 / 1620
901-1100 / 1621-1980
1101-1300 / 1981-2340
1301-1500 / 2341-2700
1501-1700 / 2701-3060
1701-1900 / 3061-3420
1901-2100 / 3421-3780
2101-2300 / 3781-4140
> 2301 / 4141


2097 - 2099
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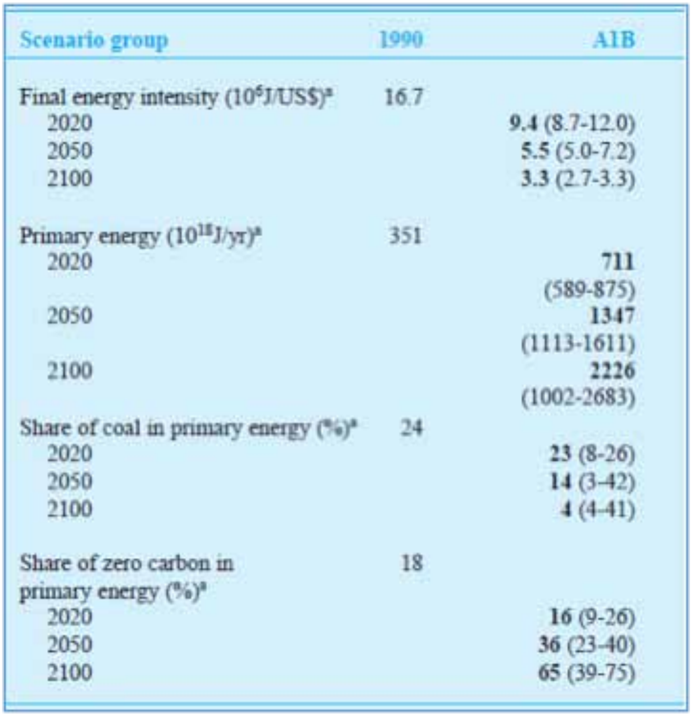
8
Farm Locations
1 - Grey Owl Farms
2 - Spinach Creek Farms
3 - Gleason Garden
4 - Rangeview Farms
5 - Dragonfly Farms
6 - Lilyvale Farms
7 - Betty Higbie (MG)
8 - Georgeson Botanical Garden
Growing Degree Days (°C / °F)
< 900 / 1620
901-1100 / 1621-1980
1101-1300 / 1981-2340
1301-1500 / 2341-2700
1501-1700 / 2701-3060
1701-1900 / 3061-3420
1901-2100 / 3421-3780
2101-2300 / 3781-4140
> 2301 / 4141

Appendix B – Acronym glossary

ACIA - Arctic Climate Impact Assessment
AOGCM - Atmospheric Ocean General Circulation Models
AR4 - Fourth Annual Report (by the IPCC)
CFC - chloroflourocarbons
CRU - Climate Research Unit
CSA - Community-supported Agriculture
DNR - Department of Natural Resources
EMIC - Earth System Models of Intermediate Complexity
ECMWF - European Center for Medium-Range Weather Forecast
FAO - Food and Agricultural Organization
GBG - Georgeson Botanical Garden
GDD - Growing Degree Day
GHG - Green House Gases
HFC - Hydrofluorocarbons
IIASA - International Institute for Applied Systems Analysis
IPCC - Intergovernmental Panel on Climate Change
LLGHG - Long-lived Greenhouse Gases
MMD - Multi-Model Data
NARC - North American Regional Climate
NRCS - National Resources Conservation Service
OSU - Oregon State University
PMC - Plant Materials Center
PRISM - Parameter-elevation Regressions on Independent Slopes Model
RCM - Regional Climate Model
RMSE - Root-Mean Square Error
SAT - Surface Air Temperature
SCM - Simple Climate Models
SD - Statistical Downscaling
SNAP - Scenarios Network for Alaska Planning
SRES - Special Report on Emission Scenarios
UNEP - United Nations Environment Program
WMO - World Meteorological Organization
WRCC - Western Region Climate Center

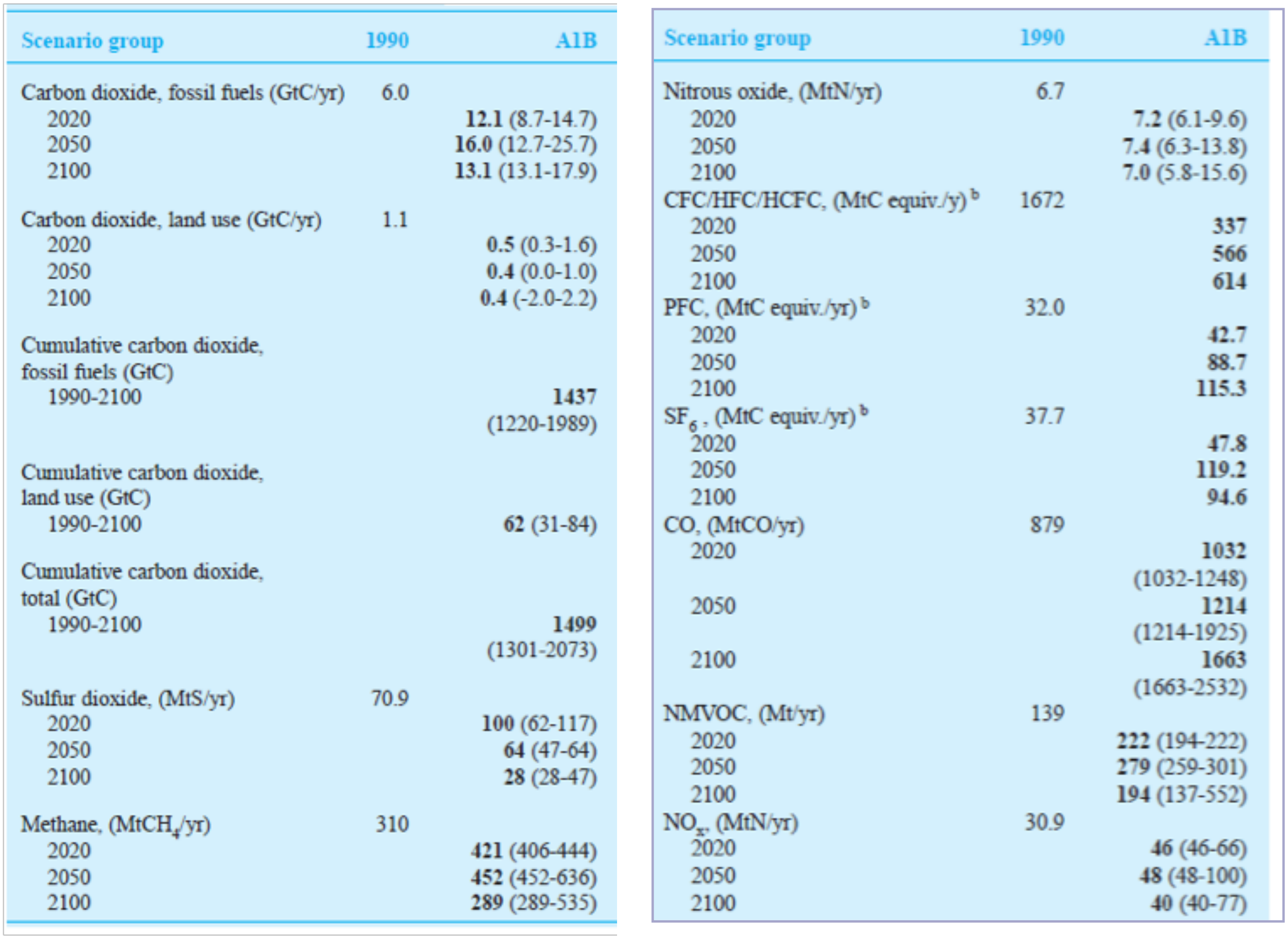
Appendix C – More A1B info

Figure 20, right. Numbers from the illustrative scenarios for the 26 harmonized SRES scenarios to show trajectory of A1B scenario. 1990 values from IPCC WGII SAR (Nakicenovic et al., 2000).



Scenario group	1990	A1B
Final energy intensity (10^6J/US\$)^{a}	16.7	
2020		**9.4** (8.7-12.0)
2050		**5.5** (5.0-7.2)
2100		**3.3** (2.7-3.3)
Primary energy (10^{18}J/yr)^{a}	351	
2020		**711** (589-875)
2050		**1347** (1113-1611)
2100		**2226** (1002-2683)
Share of coal in primary energy (%)^{a}	24	
2020		**23** (8-26)
2050		**14** (3-42)
2100		**4** (4-41)
Share of zero carbon in primary energy (%)^{a}	18	
2020		**16** (9-26)
2050		**36** (23-40)
2100		**65** (39-75)

Figure 21. Numbers from the illustrative scenarios of the 26 SRES scenarios to show trajectory of emissions under A1B scenario conditions. 1990 values from IPCC WGII SAR (Nakicenovic et al., 2000).



Scenario group	1990	A1B
Carbon dioxide, fossil fuels (GtC/yr)	6.0	
2020		**12.1** (8.7-14.7)
2050		**16.0** (12.7-25.7)
2100		**13.1** (13.1-17.9)
Carbon dioxide, land use (GtC/yr)	1.1	
2020		**0.5** (0.3-1.6)
2050		**0.4** (0.0-1.0)
2100		**0.4** (-2.0-2.2)
Cumulative carbon dioxide, fossil fuels (GtC)		
1990-2100		**1437** (1220-1989)
Cumulative carbon dioxide, land use (GtC)		
1990-2100		**62** (31-84)
Cumulative carbon dioxide, total (GtC)		
1990-2100		**1499** (1301-2073)
Sulfur dioxide, (MtS/yr)	70.9	
2020		**100** (62-117)
2050		**64** (47-64)
2100		**28** (28-47)
Methane, (MtCH$_4$/yr)	310	
2020		**421** (406-444)
2050		**452** (452-636)
2100		**289** (289-535)

Scenario group	1990	A1B
Nitrous oxide, (MtN/yr)	6.7	
2020		**7.2** (6.1-9.6)
2050		**7.4** (6.3-13.8)
2100		**7.0** (5.8-15.6)
CFC/HFC/HCFC, (MtC equiv./y)^{b}	1672	
2020		**337**
2050		**566**
2100		**614**
PFC, (MtC equiv./yr)^{b}	32.0	
2020		**42.7**
2050		**88.7**
2100		**115.3**
SF$_6$, (MtC equiv./yr)^{b}	37.7	
2020		**47.8**
2050		**119.2**
2100		**94.6**
CO, (MtCO/yr)	879	
2020		**1032** (1032-1248)
2050		**1214** (1214-1925)
2100		**1663** (1663-2532)
NMVOC, (Mt/yr)	139	
2020		**222** (194-222)
2050		**279** (259-301)
2100		**194** (137-552)
NO$_x$, (MtN/yr)	30.9	
2020		**46** (46-66)
2050		**48** (48-100)
2100		**40** (40-77)

Appendix D – Validation of GCMs and Uncertainty

Two notable projects have been undertaken to scrutinize the science behind global climate models: the CMIP3 and the RTMIP. During 2005 and 2006, the Program for Model Diagnosis and Intercomparison (PCMDI) completed the World Climate Research Programme (WCRP) phase three Coupled Model Intercomparison Project (CMIP3) also called the Multi-Model Data set (MMD) via an open process review of some of the current models. The focus of the experiment was climate response (as opposed to climate change rate) and aimed to gain feedback from the global scientific community on models projecting specific scenarios (Meehl et al., 2007). Much valuable feedback was obtained from this project, including the use of the MMD which allowed canceling of biases with the use of an average (Meehl et al., 2007).

The Radiative Transfer Model Intercomparison Project looked at forcing for LLGHGs, CO2, CH4, N2¬O, CFC-11, CFC-12, and water vapour in 20 AOGCMs (Meehl et al., 2007). An important conclusion from this project was that the diverse climate response seen in differing models is due primarily to different treatment of radiative transfer (Meehl et al., 2007).

Additionally, as that there is nothing to check the model simulations against for futuristic modeling (though other systems of model verification have been developed). Räisänen and Palmer (2001) used one model as the "correct" projection and used the ensemble to predict it (Meehl et al., 2007). Allen and Ingram (2002) found "emergent constraints", or consistencies that appeared when physical relationships were synced in multiple models (Meehl et al., 2007)

Sources of uncertainty between models:

- (#1) There is still much work to be done on tropical precipitation and cloud simulation (Randall et al., 2007)
- (#2) Confidence is generally lower pertaining to precipitation estimates, and in general models project too many days with low precipitation and too little precipitation total in larger storm events (Randall et al., 2007)
- Uncertainty due to potential future changes in carbon cycle: higher final stabilization of emissions would result in a greater impact on the cycle (Meehl et al., 2007)
- Uncertainty due to lack of complete understanding of aerosols and their interactions, especially carbon aerosols, which have effects on climatic elements such as African and Asiatic monsoons (Meehl et al., 2007)
- Difference in climate sensitivity and projected response due to differences of radiative forcing modeling in AOGCMs (Meehl et al., 2007)
- Little is understood pertaining to effects of processes like contrails of aircrafts, which are likely to increase in number due to dependence on air travel (Meehl et al., 2007)
- Poor model agreement on amount of sea ice thinning (Meehl et al., 2007)
- Model disagreement over AO-like or ENSO-like change pattern in polar region, mechanism of which is not yet fully elucidated (Meehl et al., 2007)
- AR4 and C4MIP models do not include land cover change impacts, which have been identified as having impacts on albedo, surface temperature (latent : sensible heat), the CO2 assimilation potential, but are not thought to be as significant as GHG impact (Meehl et al., 2007)

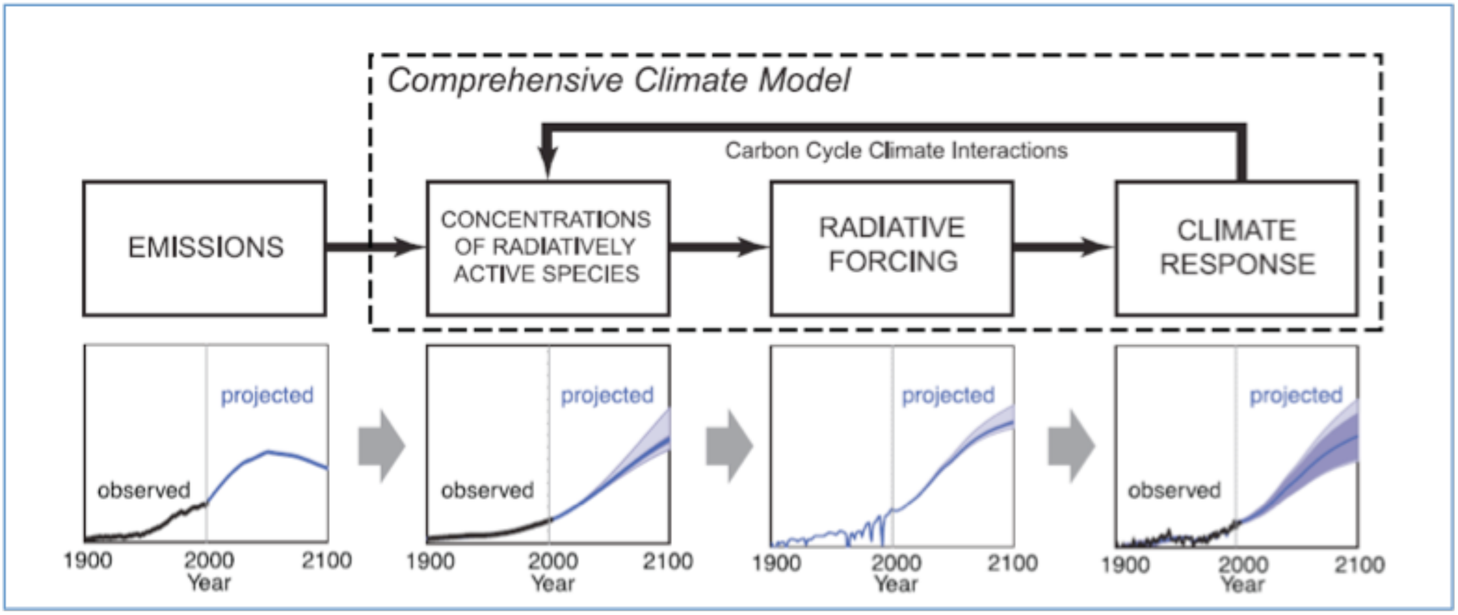


Figure 22. Depiction of various sources of uncertainty for the illustrative A1B scenario (Meehl et al., 2007).

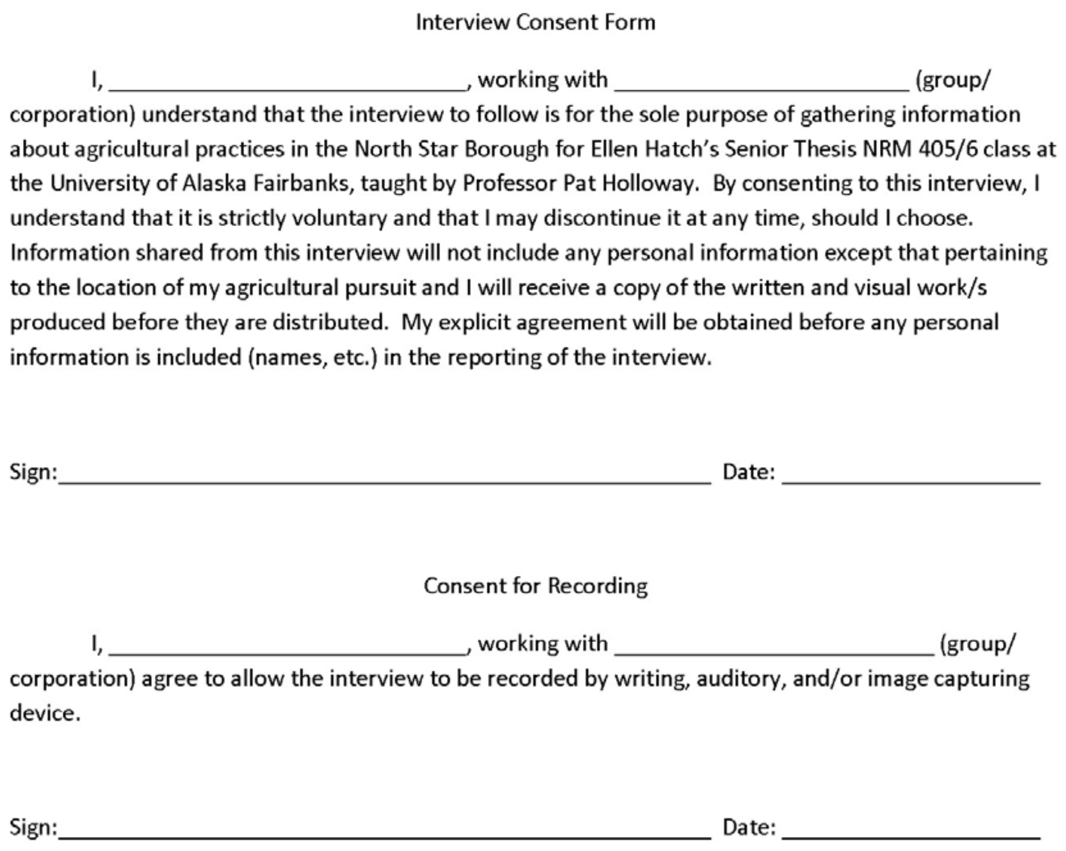
- There is still work to be done on ozone in the troposphere, especially dealing with non-methane hydrocarbons (NMHCs ; Meehl et al., 2007)
- Also per model: internal variability, missing processes, and biases exist (Meehl et al., 2007)
- Often per ensemble no solar or volcanic variability is accounted for, and methane release from permafrost or oceanic hydrates, which would have more late century impact than impact on the next few decades (Meehl et al., 2007)
- Differences in treatment of cloud feedback are the primary difference between equilibrium sensitivity in models (Randall et al., 2007)

Regardless of the uncertainty, AOGCMs are currently regarded as dependable sources of future estimates regarding temperature projections, cold air outbreaks, and frost days (Randall et al., 2007) which make AOGCMs an excellent tool for this project. However, the science of climate processes is ever progressing, as seen in the differences between AOGCMs as of the IPCC's Third and Fourth Assessment Reports. Additionally, other, more simplified programs, such as EMICs, are used to circumvent the limiting hardware constraints of AOGCMs by using lower resolution to provide checks and broader simulations (Meehl et al., 2007; Randall et al., 2007).

Specific to the Arctic

Polar climate naturally includes large variation on long timescales, which contributes to uncertainty in Arctic models. Important factors of this variability include NAM and ENSO shifts, the incomplete elucidation of the atmosphere-land-cryosphere-ocean-ecosystem interactions, and the relatively few observations of the Arctic region, especially pertaining to precipitation (Christensen et al., 2007; Anisimov et al. 2007; SNAP 2009a; SNAP 2009b). Additionally, high terrain areas in Alaska and Canada are less accurate and coarse orography in areas causes biases in storm tracks and sea ice cover (Christensen et al., 2007). For example, there is some disagreement among studies to what extent the Brooks Range isolates Alaska from North Pacific variability, likely due to attribution of these processes to different underlying mechanisms by different models (Christensen et al., 2007).

Appendix E – Interview Consent Form



Interview Consent Form

I, ______________________________, working with _________________________ (group/corporation) understand that the interview to follow is for the sole purpose of gathering information about agricultural practices in the North Star Borough for Ellen Hatch's Senior Thesis NRM 405/6 class at the University of Alaska Fairbanks, taught by Professor Pat Holloway. By consenting to this interview, I understand that it is strictly voluntary and that I may discontinue it at any time, should I choose. Information shared from this interview will not include any personal information except that pertaining to the location of my agricultural pursuit and I will receive a copy of the written and visual work/s produced before they are distributed. My explicit agreement will be obtained before any personal information is included (names, etc.) in the reporting of the interview.

Sign:____ Date: _____________________

Consent for Recording

I, ______________________________, working with ___________________________ (group/corporation) agree to allow the interview to be recorded by writing, auditory, and/or image capturing device.

Sign:____ Date: _____________________

Appendix F – Interview Questions

Community Supported Agriculture Interview
By Ellen Hatch
Fsewh2@gmail.com

The following interview is intended for major growers of the Fairbanks area, Summer 2009, in conjunction with Ellen Hatch's senior thesis for the University of Alaska Fairbanks Natural Resource Management 405/406 class. It is intended for High Latitude Agriculture, directly planted annual crops that are not temperature assisted (i.e. high tunnels, etc.) and primarily organically grown.

Information:

Name of Business: ______________________________
Owner: ______________________________
Location: ______________________________
Section/Township (if known): ______________________________
Date of interview: ______________

Prior Research:

Soil Types Present: ______________________________
Aspect of the Plot: ______________________________
Slope of the Plot: ______________________________

Questions:

Intro:

- How did you become a grower?
- Are you from Alaska? Have you grown any where else?
- What keeps you growing here, even though there are some tough challenges associated with being an Alaskan farmer?
- What has been your biggest challenge as an Alaskan grower?
- Would you share a favorite growing memory/experience or a major success during your time as a grower?
- Do you belong to any farming associations?

Historic:

- What was is the history of the land? What was it used for prior? When was it cleared and when was it established as agricultural land?
- How long has your establishment been here?
- What is your history of crops on this plot? (Date and crops, amt. produced)
- What have been the best and worst seasons you remember?
- What are typically your most successful crops?
    - How is this "success" measured?
- Have you ever had any trial crops that failed?
- What dates have you planted (direct seed) and harvested in the past?

- How has farming changed during your time as a grower?
    - Specifically in Alaska?

Work:

- What seasons are you producing? (include greenhouse, etc.)
- How many fulltime/part time workers do you employ?
    - Where are they mostly from (AK or Lower 48?)
    - Do you notice differences in training/ growing styles between the two sets of workers? (i.e. are there practices that often are habitual but don't work here in Alaska?)
- How many volunteer hours do you tend to have per year?
    - What kinds of work do volunteers do?

The Plot:

- Can the whole establishment be treated as one plot, or are treatments very different for different areas?
- When did you acquire this area?
    - (May I ask the price?)
- What modifications have you made to your plots and where/when/how often? Where is it obtained?
    - Fertilizer? (Type?)
    - Organic Matter? (Type?)
    - Compost? (Type, composition)
    - pH Changers?
    - Mulch? (Type?)
    - Tilling? (Mechanism?)
- Are there any difficulties with growing on the plot?
- What vegetation surrounds it?

Methods:

- Do you, as a farmer, utilize the extra hours of daylight in a particular way?
- What is the water source? How much water is given to the plants per day?
- What is your method of weed control?
    - Are there any species you find particularly invasive on this plot?
- What is your method of pest control?
    - Are there any species you find particularly invasive?
    - Do you aid beneficial insects in any manner?
- Have you had any problems from other pathogens (e.g. plant viruses)?
    - What crops? When? Where?
    - How did you determine the problem's origin? The solution?
- What types of machinery or technology do you use on your farm?
- Do you have a method for monitoring the weather and take specific actions for certain changes in the weather (e.g. you water a certain amount extra at a given low humidity/high temperature)?
- Do you record temperatures, humidity, or any other climate components for your plot?
- Do you have a procedure for strange Fairbanks weather (e.g. a July freeze)?

- Are there any other special methods/procedures to your growing scheme that may be unique to your farm that I've missed?

The Crops:

- What annuals will you direct seed this year? Cultivars/Varieties?
    - Where do you obtain your seed?
- What is new?
    - How do you determine what to try planting as a new crop?
    - Do you have any ideas about crops you'd like to try in the future?
    - Do you have any dream crops for the North Star Borough?
- Where will it be seeded on your plot?
- What date will you seed?
    - How is this date determined (e.g. traditional, climatic)?
    - Per species? Per location? Why?
- Do you record any information during the growing season on your establishment? (e.g. emergence, flowering, maturation)? If not, an estimate?
- What kinds of information are you particularly attentive to in regards to crop growth and climate information (newspaper, weather channel, other growers, publications, seed packets)?
    - Do you utilize the "days until maturation" of seeds? How?
    - When you have growing questions, who or where do you go?

Production:

- What are the destinations of your crops (all, including non-direct seeded, annual and perennial)? Approximate percents? Amounts?
    - Home?
    - CSA families?
    - Farmer's market?
    - Local businesses?
    - Other?
- Of the crops you mentioned producing (annual, direct seeded) what are the primary destinations?

Wrap-Up

- What do you think is the most unique aspect to being a producer in Alaska?
- What do you think is the most difficult aspect to being a producer in Alaska?
    - In the North Star Borough?
- What do you feel is especially unique about your establishment?
    - In general?
    - In regards to other local farmers?
- What visions do you have for Alaskan agriculture?

THANKS! ☺☺☺

XII. Works Cited

Allen, J.C. (1975). “A modified sine wave method for calculating degree days.” *Environmental Entomology* 5(3): 388-396.

Andrewartha, H.G. and L.C. Birch (1973). *The History of Insect Ecology*. Syndey, Austrailia, Zoology Department, University of Adelaide and School of Biological Sciences, University of Syndey, Australia: 38.

Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Vilhjálmsson and J.E. Walsh, 2007: Polar regions (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 653-685.

Barton, B. and M. Ball (2007). Yukon Agricultural Research and Demonstration: 2007 Progress Report, Yukon Energy, Mines and Resources - Agriculture Branch.

Brown, M. E. and C.C. Funk (2008). “Food Security Under Climate Change.” *Science* 319: 580-581.

Cathey, H. 1990. The 2003 US National Arboretum “Web Version” of the 1990 USDA Plant Hardiness Zone Map. [On-line] Available www.usna.usda.gov/Hardzone/alaska.html. Oct 15.

Challinor, A.J., F. Ewert, et al. (2009). “Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation.” *Journal of Experimental Botany* 60(10): 2775-2789.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Coop, L.B. 2010a. U.S. degree-day mapping calculator and publisher - Documentation Version 4.0. Oregon State University Integrated Plant Protection Center Web Site Publication E.10-04-2: http://uspest.org/wea/mapmkrdoc.html

Coop, L.B. 2010b. U.S. degree-day mapping calculator and publisher - Documentation Version 4.0. Oregon State University Integrated Plant Protection Center Web Site Publication E.10-04-2: http://uspest.org/wea/mapmkrdoc.html

Coop, L. and P. Jepson (2003). “Online Site-Specific Degree-day Predictions Using GIS and Climate Map Technologies.” Oregon IPM Newsletter. Retrieved March 10, 2010, from www.ipmnet.org/Newsletters/On-Line_Site-Specific_Degree_Day.pdf.

Curtis, J. and G. Taylor. (2009). “The NRCS PRISM Climate Mapping Project.” Retrieved March 17, 2010, from www.prism.oregonstate.edu/docs/przfact.html. Daly, C. (1996). “Overview of the PRISM Model.” Retrieved March 17, 2010, from www.prism.oregonstate.edu/docs/overview.html.

Daly, C., G. Taylor, et al. (1997). The PRISM Approach to Mapping Precipitation and Temperature. 10th Conference on Applied Climatology. Reno, Nevada, American Meteorological Society: 10-12.

DeFries, R.S., J.A. Foley, et al. (2004). “Land-Use Choices: Balancing Human Needs and Ecosystem Function.” *Frontiers in Ecology and the Environment* 2(5): 249-257.

DNR (2009). Newsletter. Alaska, Agricultural Division of the Alaska Department of Natural Resources. 1(6): 7.

Fischer, G., M. Shah, et al. (2005). “Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080.” *Philosophical Transactions Royal Society* 360: 2067-2083.

Goudriaan, J. and H.H. v. Laar (1994). *Modelling Potential Crop Growth Processes*. Boston, Kluwer Academic Publishers.

Harp, D.A., et al. 2002. An Updated Hardiness Zone Map for Dallas-Fort Worth Texas.

Hassol, S. (2004). *Impacts of a warming Arctic: Arctic Climate Impact Assessment*. Cambridge, U.K.: Cambridge University Press.

Hernandez, B. (2008). “Overview map of the Fairbanks North Star Borough based on the USGS 1:250,000 scale maps.” from www.co.fairbanks.ak.us/communityplanning/Mapping.htm.

Holloway, P. S., J. Hanscom, et al. (2009). Annual Vegetable Trials 2008. AFES Variety Trial. Fairbanks, Alaska, Agricultural and Forestry Experiment Station.

IPCC (2010). “History.” Retrieved Feb 15, 2010, from www.ipcc.ch/organization/organization_history.htm.

Juday, G.P. et al. 1997. Human Land Use and Management, Ch. 6. In: *Implications of Global Change in Alaska and the Bering Sea Region*. University of Alaska Press. Fairbanks, Alaska.

Juday, G.P., V. Barber, et al. (2005). Forests, Land Management, and Agriculture. *Arctic Climate Impact Assessment*. New York, Cambridge University Press: 781-862.

Krupnik, I. and D. Jolly (2002). *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change*. Fairbanks, Alaska, Arctic Research Consortium of the United States in cooperation with the Arctic Studies Center, Smithsonian Institution.

Krupnik, I. (2002). Ch 5: Watching Ice and Weather Our Way. *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change.* I. Krupnik and D. Jolly. Fairbanks, Arctic Research Consortium of the United States.

Lobell, D.B., M.B. Burke, et al. (2008). "Prioritizing Climate Change Adaptation Needs for Food Security in 2030." *Science* 319: 607-610.

Long, S.P., E.A. Ainsworth, et al. (2005). "Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields." *Philosophical Transactions Royal Society* 360: 2011-2020.

Matheke, G.E.M., J. Hanscom, et al. (2007). Vegetable Trials 2006. AFES Variety Trails. Fairbanks, Alaska, Agricultural and Forestry Experiment Station.

Matheke, G.E.M., J. Hanscom, et al. (2008). Annual Vegetable Trials 2007. AFES Variety Trial. Fairbanks, AK, Agricultural and Forestry Experiment Station.

McKenney, D.W., et al. 2006. The generation of USDA-equivalent extreme minimum temperature models and a comparison with Canada's plant hardiness zones. *Canadian Journal of Plant Science.* 86:511-523.

McKenney, D.W., et al. 2007. Beyond Traditional Hardiness Zones: Using Climate Envelopes to Map Plant Range Limits. *Bioscience*. 57(11):929-937.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Miller, P., W. Lanier, et al. (2001). *Using Growing Degree Days to Predict Plant Stages.* Bozeman, MT, Montana State University.

Nakicenovic, N., J. Alcamo, et al. (2000). *IPCC Special Report on Emissions Scenarios.* N. Nakicenovic and R. Swart.

Norton, D.W. (2002). Ch 4: Coastal Sea Ice Watch: Private Confessions of a Convert to Indigenous Knowledge. *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change.* I. Krupnik and D. Jolly. Fairbanks, Alaska, Arctic Research Consortium: 127-156.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor, 2007: Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Rupp, S., P. Duffy, et al. (2009). Validating SNAP Climate Models. Fairbanks, Alaska, Scenarios Network for Alaska Planning.

Sathaye, J., Najam, C. Cocklin, T. Heller, F. Lecocq, J. Llanes-Regueiro, J. Pan, G. Petschel-Held, S. Rayner, J. Robinson, R. Schaeffer, Y. Sokona, R. Swart, H. Winkler, 2007: Sustainable Development and Mitigation. In: *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovermental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, United Kingdom and New York, New York, USA.

Slingo, J.M., A.J. Challinor, et al. (2005). "Introduction: food crops in a changing climate." *Philosophical Transactions Royal Society* 360: 1983-1989.

SNAP (2009a). Alaska Regional Climate Projections. Fairbanks, AK, Scenarios Network for Alaska Planning.

SNAP (2009b). *Preliminary Report to the Governor's Sub-Cabinet on Climate Change.* Fairbanks, Alaska, Scenarios Network for Alaska Planning.

Sparrow, S., C. Lewis, et al. (2007). Climate Change and High Latitude Agriculture. Fairbanks, Alaska, ACIA.

Veldhuizen, R.M.V. and C.W. Knight (2004). "Performance of Agronomic Crop Varieties in Alaska 1978-2002." AFES Bulletin 111: 110.

Walsh, J.E., W.L. Chapman, et al. (2008). "Global Climate Model Performance over Alaska and Greenland." *Journal of Climate* 21: 6156-6174.

About the Agricultural and Forestry Experiment Station

The federal Hatch Act of 1887 authorized establishment of agricultural experiment stations in the U.S. and its territories to provide sicence-based research information to farmers. There are agricultural experiment stations in each of the 50 states, Puerto Rico, and Guam. All but one are part of the land-grant college system. The Morrill Act established the land-grant colleges in 1862. While the experiment stations perform agricultural research, the land-grant colleges provide education in the science and economics of agriculture.

The Alaska Agricultural Experiment Station was established in Sitka in 1898, also the site of the first experiment farm in Alaska. Subsequent stations were opened at Kodiak, Kenai, Rampart, Copper Center, Fairbanks, and Matanuska. The latter two remain. The Alaska station was not originally part of the Alaska land-grant college system. The Alaska Agricultural College and School of Mines was established by the Morrill Act in 1922. It became the University of Alaska in 1935. The Fairbanks and Matanuska farms are part the Agricultural and Forestry Experiment Station of the University of Alaska Fairbanks, which also includes the Palmer Research Center.

Early experiment station researchers developed adapted cultivars of grains, grasses, potatoes, and berries, and introduced many vegetable cultivars appropriate to Alaska. Animal and poultry management was also important. This work continues, as does research in soils and revegetation, forest ecology and management, and rural and economic development. Change has been constant as the Agricultural and Forestry Experiment Station continues to bring state-of-the-art research information to its clientele.

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