Georgia Basin

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Projected Climate Change, Extremes, and Historical Analysis

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T. Q. Murdock
S. R. Sobie
H. D. Eckstrand
Pacific Climate Impacts Consortium

E. Jackson
ICLEI Canada

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Note: in this April 2016 revision the RX1day and RX5day annual values were replaced with September values (the month of largest increase in both locations).

About PCIC

The Pacific Climate Impacts Consortium is a regional climate service centre at the University of Victoria that provides practical information on the physical impacts of climate variability and change in the Pacific and Yukon Region of Canada. PCIC operates in collaboration with climate researchers and regional stakeholders on projects driven by user needs. For more information see http://pacificclimate.org.

About ICLEI Canada

ICLEI – Local Governments for Sustainability, is an association of local governments from around the world that have made a commitment to sustainability. ICLEI's mission is to build and serve a worldwide movement of local governments to achieve tangible improvements in global sustainability through cumulative local actions. The ICLEI Canada office in Toronto works with local governments from coast to coast to coast.

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Disclaimer

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Executive Summary

Climate change projections have been provided in this report for Metro Vancouver and the Capital Regional District from several difference sources: Global Climate Models (GCMs) directly, high resolution elevation-corrected projections from GCMs, and Regional Climate Models. Historical climate information at selected stations of interest throughout the region is also provided for comparison.

Projected annual warming by the 2050s (compared to 1961-1990) for the two regions is similar, according to a set of 30 commonly used Global Climate Models (GCMs). Projections are given for both the 2050s and 2080s periods. For the 2050s, the range of projected change in Metro Vancouver is +1.4°C to +2.8°C in summer, +0.8°C to +2.7°C in winter, -5% to +16% in winter precipitation, and -25% to +5% in summer precipitation. For the 2050s, the range of projected change in the Capital Regional District (CRD) is +1.3°C to +2.6°C in summer, +0.8°C to +2.4°C in winter, -5% to +17% in winter precipitation, and -30% to +1% in summer precipitation. Compared to the ranges, the projected differences between regions are minor.

Maps of high resolution projections of change are provided for several variables of interest. Projections mid-century show changes in variables related to temperature: increased growing degree days, cooling degree days, and frost free period along with decreased heating degree days and precipitation as snow. The projected 2080s maps illustrate a future climate that does not resemble the present-day for most of these variables.

Regional Climate Models projections are used to provide projections of changes in temperature, precipitation, and indices of extremes. Extreme temperatures so warm that in the past they would be exceeded on average once every ten years (corresponding to about 32°C to 35°C) are projected to occur on average over twice as often in future in Metro Vancouver and almost four times as often in future in the CRD.

The amount of precipitation falling during very wet days is projected to increase by 21% in Metro Vancouver and 20% in CRD, while precipitation during extremely wet days is projected to increase by 28% in Metro Vancouver and 25% in CRD. More extreme precipitation events (with 3-hour duration) so intense than in the past they would be exceeded on average only once every 10 years are projected to occur on average three times as often in future in Metro Vancouver and about three and a half times as often in future in CRD.

The implications of these projected changes are briefly discussed for physical, social, economic, and ecological systems, and the ICLEI Canada climate adaptation planning methodology is described. This process, outlined in *Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation* is currently being undertaken by communities in Metro Vancouver and CRD. The information contained within this report supports Milestone Two of that process as is intended to assist with adaptation planning.

1. Introduction

Information about future climate impacts is being increasingly considered by local governments in long term planning. This report was commissioned by a group of British Columbia municipalities and regional districts that are located in Metro Vancouver and Southern Vancouver Island, specifically: City of Victoria, Capital Regional District, City of North Vancouver, City of Vancouver, Corporation of Delta, City of Surrey, and Metro Vancouver Regional District. The project has been funded by participants directly as well as through contributions from Natural Resources Canada and in-kind support from ICLEI Canada.

The objective of this project is to provide additional climate change information to the ongoing adaptation planning initiatives in these communities that was unavailable at the outset of their planning processes. To do so, we use high resolution gridded observations and future projections from Global Climate Models (Section 2, Appendix 1) as well as future projections of extremes from Regional Climate Models (Section 3, Appendix 2). Some additional context for interpreting these results is provided using historical observations at stations in Appendix 3. Each of these sources of information is described below, followed by results, discussion, and synthesis.

The analysis of future climate change projections and historical observations described in this report was conducted by the Pacific Climate Impacts Consortium (PCIC). ICLEI Canada has provided interpretation of what these results may mean for communities throughout the results and discussion (Sections 2.1 and 3.4) and in the summary (Section 4).

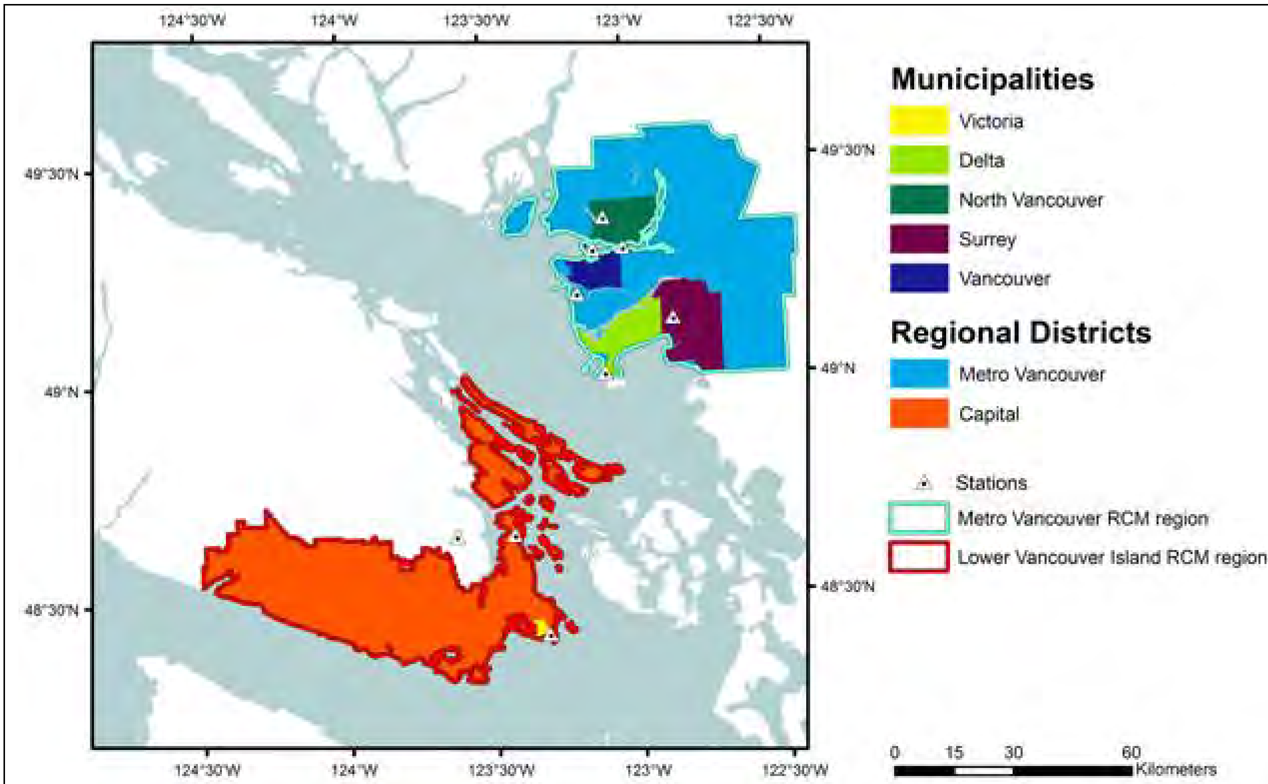

Figure 1: Project area map. The region outlines shown (regional district boundaries) are used for computing regional averages.

1.1 Range of projected climate change

The range of projected future climate change includes two major sources of uncertainty: one that arises from differences between climate models and the other that arises from different assumptions of future greenhouse gas emissions scenarios.

This report provides results from two sources of climate projections derived from a subset of the full range of projected change. First, three projections are used for illustrative purposes, to produce high resolution maps (Section 2 and Appendix 1). Second, a set of eight projections from Regional Climate Models is used to address extremes (Section 3 and Appendix 2).

The results provided in Sections 2 and 3 (and Appendices 1 and 2) are thus derived from a subset of the full range of future projections. An ensemble of 30 Global Climate Model (GCM) projections from PCIC's Plan2Adapt online tool better represents the range of projected change (Figure 2). Results from this ensemble are summarized in Table 1. Projected change is quite similar for both the Capital Regional District and Metro Vancouver. It is also apparent that the median changes are larger by the 2080s than the 2050s in all cases, and the projected range is wider (more uncertainty). Projected changes in precipitation have a strong seasonal difference, with mainly projected increases in winter and decreases in summer.

The individual projections from the ensemble upon which Table 1 is based are also shown in Figure 2 (red diamonds) alongside the full range of 140 available GCM projections[1] and the two smaller subsets described above. The blue diamonds indicate that the three projections (CGCM3 A2 run 4, HADCM3 B1 run 1, and HadGEM A1B run 1) used for high resolution maps cover much of the full range of projected change in annual and seasonal temperature and precipitation. Indeed, they were selected with this in mind; see Murdock and Spittlehouse (2011) for the rationale behind these three as the minimal set for illustrative purposes. There are, however, projections that indicate more or less change in most cases for both variables, depending on the season and time period. The fact that the three projections used represent a narrower range of uncertainty (Figure 2) should be considered when interpreting the results in Section 2.

Similarly, the projected changes in extremes described in Section 3 (and additional tables in Appendix 2), use a less than complete ensemble. While this set of eight total Regional Climate Model projections, driven by a total of four different GCM projections (green triangles in Figure 2 – left panel only) is larger, it generally represents a similar narrow range of uncertainty as the minimal set of three projections used for high resolution maps (Section 2 and Appendix 1). Therefore, a similar caveat applies to the results – that changes both larger and smaller than those provided here should be considered plausible and included in any full risk assessment.

[1] Note: these ~140 GCM projections refer to those available from the Coupled Model Intercomparison Project 3 (CMIP3), which were used to inform the Intergovernmental Panel on Climate Change Fourth Assessment Report. The next set of GCM projections (CMIP5) is partially complete. No CMIP5 projections were used here but future regional assessments will have these additional projections to draw information from.

Table 1: Projected future change compared to 1961-1990 baseline for both regional districts according to the www.Plan2Adapt.ca ensemble (accessed June 2012). The median and range are based on 30 projections from 15 Global Climate Models for each of the A2 and B1 emissions scenarios. The range is the 10th to 90th percentile of the 30 projections.

Variable	Future period	Metro Vancouver		Capital Regional District	
		Median	Range	Median	Range
Annual Temperature	2050s	+1.7°C	+1.0°C to +2.6°C	+1.6°C	+1.0°C to +2.3°C
	2080s	+2.7°C	+1.5°C to +4.2°C	+2.5°C	+1.4°C to +3.9°C
Summer Temperature	2050s	+2.1°C	+1.4°C to +2.8°C	+2.0°C	+1.3°C to +2.6°C
	2080s	+3.2°C	+2.0°C to +5.0°C	+3.0°C	+1.8°C to +4.6°C
Winter Temperature	2050s	+1.6°C	+0.8°C to +2.7°C	+1.5°C	+0.8°C to +2.4°C
	2080s	+2.3°C	+1.2°C to +4.1°C	+2.2°C	+1.0°C to +3.7°C
Annual Precipitation	2050s	+7%	-2% to +11%	+6%	-2% to +12%
	2080s	+8%	1% to +18%	+8%	-1% to +19%
Summer Precipitation	2050s	-15%	-25% to +5%	-18%	-30% to +1%
	2080s	-14%	-38% to -2%	-20%	-46% to +1%
Winter Precipitation	2050s	+6%	-5% to +16%	+5%	-5% to +17%
	2080s	+9%	+1% to +24%	+9%	-2% to +23%

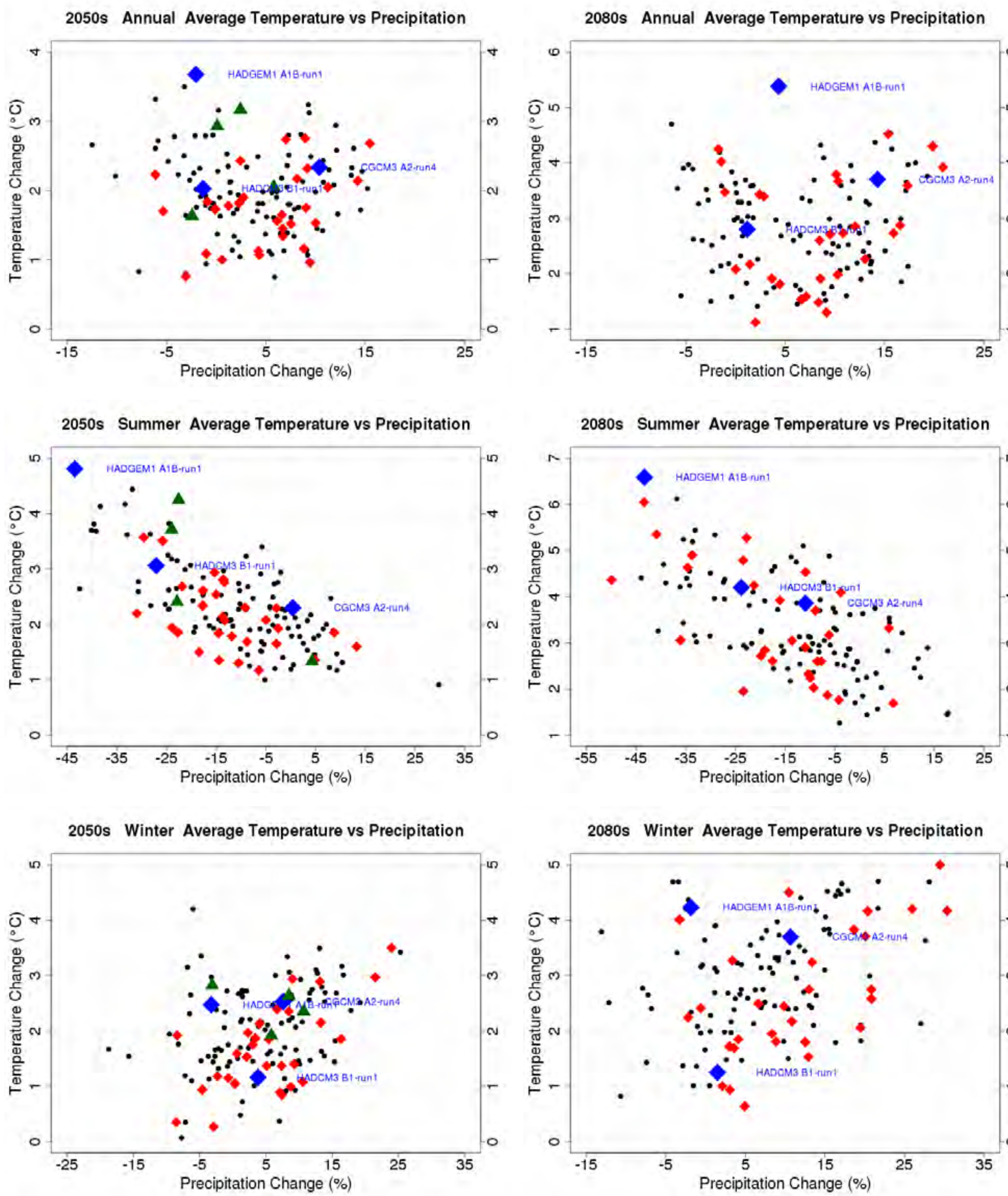

Figure 2: Comparison of all CMIP3 GCM projected future change in Lower Mainland / Southern Vancouver Island (combined region) to those used for high resolution maps (blue diamonds; Section 2), the Plan2Adapt ensemble (red diamonds; Table 2), and to drive RCMs (green triangles; Section 3).

2. High resolution projections

In this section, we discuss results from high resolution maps (Appendix 1). These maps are provided for historical (1961-1990) baseline climatologies based on the high resolution (~4 km grid) dataset known as PRISM (Daly et al. 2000); see Figure 3 for the temperature and precipitation baselines. Future projected change from three different Global Climate Models (GCMs) at a coarse (roughly 200 km grids) scale is applied to the historical climatology to obtain high resolution future projections. In this case the high resolution comes from the gridded historical observations only.

In other words, the projected *change* is near uniform throughout the region. This approach means that high resolution *feedbacks* (such as the loss of snow from locations that are normally snow-covered leading to additional warming due to a reduced reflectivity of the surface – also known as snow-albedo feedback) are not included in these projections.

Because the high spatial resolution is from the historical climatology and used only to assist with displaying how the coarse scale GCM projected change may look in a region of complex topography, the specific values at individual high resolution locations are not intended for direct use. The added value, then, of using coarse scale projected change in conjunction with high resolution historical observations is in the ability to see plausible future projections of total temperature, precipitation, and other variables, including values throughout areas with differing micro-climates.

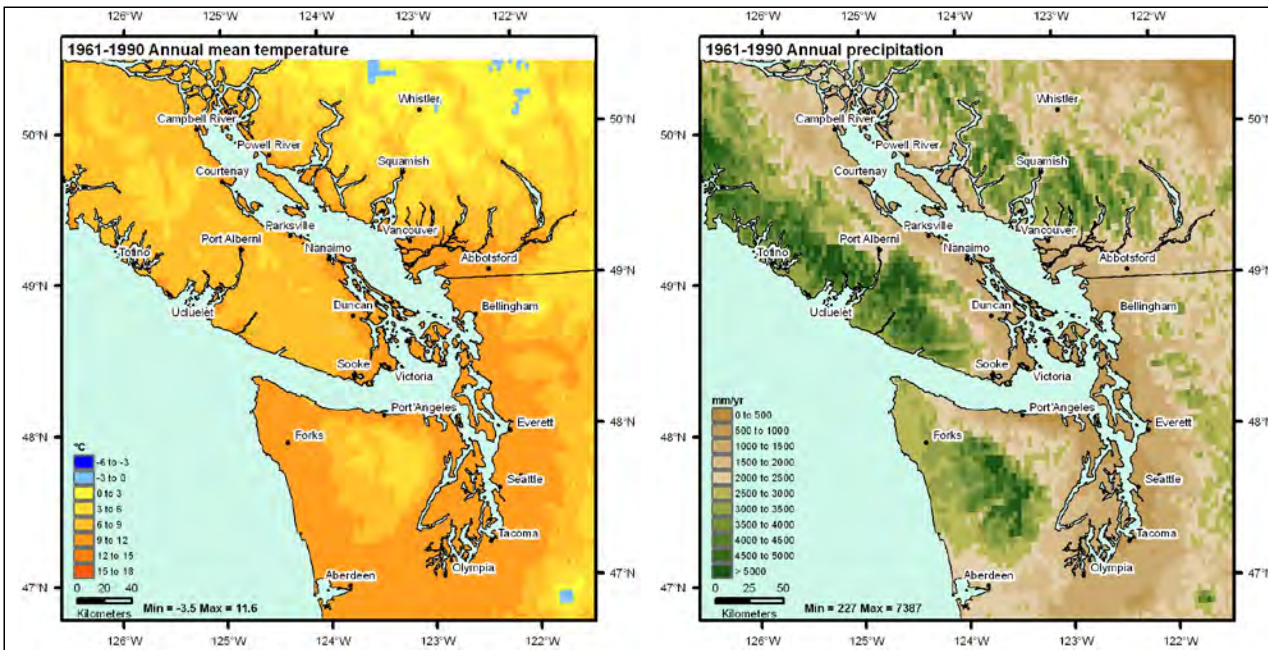

Figure 3: Annual temperature (left) and precipitation (right) for the 1961-1990 historical baseline (top left) from the high-resolution PRISM dataset.

2.1 Results

The high resolution maps for seven different variables[2] that were chosen by the local governments as relevant to adaptation planning are provided in Appendix 1 for the 1961-1990 baseline and for both the 2050s and 2080s periods from each of three GCM projections. Together, these maps provide a lot of information. In this section, we will first discuss two overall results that are common to most of the figures. Then, we present in Tables 2 and 3 the regionally-averaged results for each variable as well as temperature and precipitation (for comparison to Table 1). Finally, we summarize results for each variable.

First, most of the projected future maps look quite similar to each other, regardless of which one of the three future projections is considered. Although details differ between each projection - broad comparisons between any of the projections and the 1961-1990 average are quite similar for most variables. One reason that the differences between projections are not readily apparent on these maps is that the maps show projected future amounts, not changes. This follows from the way that the high resolution has been obtained – by applying coarse scale future changes to the high resolution baseline. If we were to show changes directly, we would lose the high spatial resolution. Since the Georgia Basin includes complex topography and large variations in microclimate, differences between projections are small compared to differences in climatology between different locations. For example, precipitation as snow during 1961-1990 varied throughout the region from a minimum of 10 mm to a maximum of over 3700 mm (Figures 8 and 9).

The regionally-averaged changes for the three projections used in the maps of Appendix 1 are provided below in Tables 2 and 3. Projected change is given in degrees Celsius for temperature variables. For precipitation and other variables, changes are given in two forms: in physical units (mm, or days) and also as a percentage of the 1961-1990 baseline value.

The second general finding for most variables is that projected change by the 2050s visually appears slightly different from the past but 2080s projections seem almost unrecognizable in comparison to the historical climate. This is particularly true for the temperature related variables.

[2] Annual precipitation as snow (PAS), Annual growing degree days (GDD), Annual heating degree days (HDD), Annual cooling degree days (CDD), January night-time low temperature (Tmin), Summer daytime high temperature (Tmax), and Annual frost free period (FFP)

Table 2: Summary of Metro Vancouver region average projected changes from each of the three high resolution projections for 2050s and 2080s. See Sections 2.1.1 through 2.1.4 for definitions of variables. The projection used for CGCM3 is A2 run 4, for HadCM3 B1 run 1, for HadGEM A1B run 1. Variables are temperature (T), precipitation (P), precipitation as snow (PAS), growing degree days (GDD), heating degree days (HDD), cooling degree days (CDD), night-time low temperature (Tmin), daytime high temperature (Tmax), and frost free period (FFP).

Var-iable	Season	Units	1961-1990	2050s			2080s		
				CGCM3	HadCM3	HadGEM	CGCM3	HadCM3	HadGEM
T	Winter	°C	2.2	2.7	0.8	2.3	4.0	0.9	4.0
T	Summer	°C	15.3	2.3	2.5	5.2	3.8	3.6	7.0
T	Annual	°C	8.5	2.5	1.8	3.8	3.8	2.6	5.6
Tmax	Summer	°C	20.2	2.4	2.5	5.2	4.2	3.6	7.0
Tmin	January	°C	-1.1	3.8	0.1	2.7	5.5	0.1	4.1
P	Winter	mm	882	72	26	-37	81	3	-29
P	Summer	mm	246	2	-57	-106	-24	-52	-118
P	Annual	mm	2381	250	-2	-85	356	60	69
PAS	Annual	mm	277	-167	-87	-170	-216	-110	-228
GDD	Annual	Days	1716	646	535	1158	1092	803	1710
HDD	Annual	Days	3524	-820	-560	-1097	-1221	-777	-1522
CDD	Annual	Days	55	78	100	329	181	208	575
FFP	Annual	Days	200	81	37	71	120	51	102
P	Winter	%	100	8	3	-4	9	0	-3
P	Summer	%	100	1	-23	-43	-10	-21	-48
P	Annual	%	100	11	0	-4	15	3	3
PAS	Annual	%	100	-60	-31	-61	-78	-40	-82
GDD	Annual	%	100	38	31	67	64	47	100
HDD	Annual	%	100	-23	-16	-31	-35	-22	-43
CDD	Annual	%	100	142	181	597	329	377	1043
FFP	Annual	%	100	41	18	35	60	25	51

Table 3: Summary of Capital Regional District region average projected changes from each of the three high resolution projections for 2050s and 2080s. See Sections 2.1.1 through 2.1.4 for definitions of variables. The projection used for CGCM3 is A2 run 4, for HadCM3 B1 run 1, for HadGEM A1B run 1. Variables are temperature (T), precipitation (P), precipitation as snow (PAS), growing degree days (GDD), heating degree days (HDD), cooling degree days (CDD), night-time low temperature (Tmin), daytime high temperature (Tmax), and frost free period (FFP).

Var-iable	Season	Units	1961-1990	2050s			2080s		
				CGCM3	HadCM3	HadGEM	CGCM3	HadCM3	HadGEM
T	Winter	°C	3.2	2.5	0.9	2.3	3.7	1.0	4.2
T	Summer	°C	15.1	2.2	2.4	4.2	3.8	3.5	5.8
T	Annual	°C	8.9	2.3	1.7	3.5	3.7	2.5	5.2
Tmax	Summer	°C	20.1	2.3	2.4	4.2	4.2	3.5	5.8
Tmin	January	°C	-0.1	3.4	0.2	2.7	4.9	0.3	4.2
P	Winter	mm	955	69	6	-7	95	-18	6
P	Summer	mm	149	1	-41	-61	-16	-40	-66
P	Annual	mm	2204	223	-38	-26	342	6	138
PAS	Annual	mm	150	-92	-52	-97	-116	-62	-125
GDD	Annual	Days	1733	664	529	1080	1126	796	1662
HDD	Annual	Days	3377	-803	-560	-1095	-1169	-762	-1535
CDD	Annual	Days	39	79	91	252	188	197	432
FFP	Annual	Days	206	81	37	81	116	52	116
P	Winter	%	100	7	1	-1	10	-2	1
P	Summer	%	100	1	-28	-41	-11	-27	-44
P	Annual	%	100	10	-2	-1	16	0	6
PAS	Annual	%	100	-61	-35	-64	-77	-41	-83
GDD	Annual	%	100	38	31	62	65	46	96
HDD	Annual	%	100	-24	-17	-32	-35	-23	-45
CDD	Annual	%	100	203	234	648	483	508	1112
FFP	Annual	%	100	39	18	39	56	25	56

2.1.1 Annual precipitation as snow (PAS)

Precipitation as snow is derived from (historical and projected) temperature and precipitation. Most of the Metro Vancouver and Capital Regional District areas already had low amounts of precipitation as snow in the past (Tables 2 and 3), and most of the projected decreases to precipitation as snow that are apparent in Figure **7** are therefore outside of the region of study. Note, however, that by the 2050s, precipitation as snow is projected to decrease in the North Shore Mountains. By the 2080s (Figure 8), projected precipitation as snow declines are considerable in large parts of mid- and high-elevation locations, even in CGCM3 which projects increased total winter precipitation. All three projections indicate decreased precipitation as snow within the two regions of interest, from -31% to -64% by the 2050s and -40% to -83% by the 2080 from baselines of 277 mm in Metro Vancouver and 150 mm in the CRD (Tables 2 and 3). The wide range in results is due in part to less winter warming projected by HadCM3 than the other two projections (Figure 2; Tables 2 and 3).

2.1.2 Annual growing degree days (GDD) and annual frost free period (FFP)

Growing degree days (GDD) are a measure of heat accumulation that is useful for agriculture. GDD are determined by the accumulation of degrees over 5°C each day (although different baselines may also be used for different crops). For example, if a day had an average temperature of 11°C, that day would have a value of 6 GDD. Annual GDD are accumulated this way for each day of the year and then summed. All three projections indicate projected increases in GDD throughout the study region and the surrounding areas. Within the regions of interest the increases from the three projections range from +31% to +67% by the 2050s and +46% to +100% by the 2080s from baselines of just over 1700 degree-days (Tables 2 and 3).

Frost Free Period is defined as the length of time (in days) between the last winter/spring frost and the first fall/winter frost of the same year. The majority of the year (roughly 200 days per year) was already frost free on average in 1961-1990 in the areas of interest. Future projections of average frost-free period in these areas indicate conditions where the new normal is a climate that is almost entirely frost-free (about 270 to 320 days per year in the 2080s).

2.1.3 Annual heating and cooling degree days (HDD and CDD)

Heating and cooling degree days are useful measures for energy demands required for heating and cooling. Heating degrees days (HDD) are a measure of the number of degrees below 18°C per day. The rationale behind this measure is that when the temperature is below 18°C, indoor heating is likely required to compensate for the cold temperatures outside and the further past this threshold the more heat is required. Conversely, cooling degree days (CDD) are a measure of the number of degrees above 18°C per day and similarly provide an indication of when cooling might be required (an average daily temperature above this threshold would normally mean some hours above warmer temperatures when cooling is likely to be used).

The historical degree days are roughly 3400 to 3500 degree-days in the study region, with fewer HDD in the Capital Region than Metro Vancouver (Tables 2 and 3). Decreased HDD are projected in both regional districts of with reductions according to the three projections of -16% to -32% by the 2050s and -22% to -45% by the 2080s.

Historically, there is very little cooling demand in the regions of interest. This is reflected in the low baseline CDD with an average 39 degree-days in the Capital Region and 55 degree-days in Metro

Vancouver (Tables 2 and 3). The average projected increase by the 2050s varies from an increase of +78 degree-days to +329 degree-days. The large relative increases and wide range (142% to 648%) are partly the result of the fact that the historical baselines are so small. By the 2080s, the results differ even more between projections (+181 degree-days to +575 degree-days) and all represent a considerable departure from the past (relative increases of 329% to 1112%). The HadCM3 and CGCM3 projections are generally similar to each other with HadGEM projecting the increases on the higher end (it also projects considerably more summer warming than the other two as shown in Tables 2 and 3).

2.1.4 January night-time low (T_{min}) and summer daytime high temperature (T_{max})

As with cooling degree days, the maps of January night-time low temperatures in future show more differences between projections than most variables. HadCM3 seems very similar to the present, in agreement with the small January temperature increase according to this particular projection (Tables 2 and 3). However, the other two projections indicate considerably warmer, or "less cold" winters in future. The values reflect the models' position within the ensemble of all GCM projections for winter, with HadCM3 at the lower end of the range, while the other two models tend to be warmer than the ensemble average (Figure 2). Note that HadCM3 projects much less warming in January night-time low temperature than in average winter temperature (Tables 2 and 3). This also explains why HadCM3 projects considerably smaller decreases in precipitation as snow than the other two projections, as discussed above. By the 2080s, HadCM3 still projects little difference from the past, whereas the other two maps suggest that winters by the end of the century in both regions will be completely unlike those of the past (Figures 15 and 16).

Projected increases in average summer (June-July-August) day-time high temperatures indicate a summer climate warmer than present-day Seattle by the 2050s according to the two projections with the least summer warming (CGCM3 and HadCM3) and warmer than San Diego[3] by the 2080s. In the case of HadGEM, a summer climate warmer than San Diego is projected already by the 2050s and warmer than present-day Nice, France by the 2080s (Tables 2 and 3).

2.2 Discussion

With decreased precipitation as snow, possible water shortages could impact those areas in the Capital Region and Metro Vancouver that rely on snow pack for their water supply. Some smaller 'run-of-river' facilities have limited storage and require continuous flow; these may be impacted by a decrease in annual precipitation as snow (Walker and Sydneysmith 2008). In addition, those industries relying on winter tourism could be affected. Inadequate snowfall would also reduce the number of suitable skiing days.

Increases in January night-time low temperatures will also have implications on water supplies that depend on snowpack. Milder weather may have some positive impacts on transportation in the region where a decrease in motor-vehicle accidents could occur as a result of the less harsh driving conditions (Dyer 2006). Likewise a decrease in potential free-thaw cycles could also reduce winter road maintenance costs.

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[3] According to a comparison of 1961-1990 June-July-August daytime high temperature climatology between Environment Canada's Victoria International Airport (21.0°C) and Vancouver International Airport (20.9°C) stations with the National Climatic Data Centre's (NCDC) 1961-1990 climate normals ("TD9641 Clim 81") and global climate normals for Seattle-Tacoma WSCMO Airport (23.0°C), San Diego WSO Airport (24.0°C), Nice, France (25.4°C), and Rome, Italy (27.6°C).

It is likely that crop production areas will adjust to accommodate a changing climate and that some producers will be able to take advantage of new opportunities to grow different, and perhaps more valuable, crops. Perennial crops are limited primarily by winter minimum temperatures, but also by length of growing season and growing degree days. Projected changes in growing degree days may indicate potential to grow new crops in the study area. Decreases in frost free period might also present opportunities for agriculture. On the other hand, invasive species that depend on frost to keep under control may experience an expansion into the area. Furthermore, in looking at opportunities for agriculture, these must be combined with other possible impacts such as water shortages and the spread of invasive species prior to identifying any agricultural opportunities (Walker and Sydneysmith 2008).

Substantial shifts in energy demand are anticipated as a result of increasing temperatures, with heating energy demands decreasing and cooling energy demands increasing. Long term planning of energy infrastructure could be largely affected by the projected major shift in heating requirements. Demand for increased cooling may be a problem because BC's energy infrastructure has been built to accommodate peak demand in winter (Mines and Petroleum 2005). This could be further exacerbated if cooling demand increases in other regions and if hydro power capacity is decreased due to reduced snow packs in storage reservoirs and declining glaciers. Seasonal and longer term energy demands for buildings (e.g. increased summer cooling needs, lower heating requirements) will change across the province in response to changing climate.

Although heat stress may appear less threatening on the coast then in areas that already experience hot summers, it is precisely because much of the population is less acclimatized to high numbers of hot days. Urban populations in the areas of interest may be particularly vulnerable. Non-respiratory emergency room visits in Vancouver currently increase with high summer temperatures and are expected to increase further with an aging population (Liu et al. 2003).

3. Extremes

In the previous section, we have considered projected change in long term (30-year) averages of selected variables according to Global Climate Models, displayed at high resolution by using a 4-km gridded historical baseline. In this section, we are going to look at the frequency of occurrence of selected indices of extremes. To do so, we make use of Regional Climate Model (RCM) projections. An RCM is a limited area model. In this case, each model was run for North America as part of the NARCCAP project[4] at a resolution of 50 km by different climate modelling centres. The RCMs take coarse resolution (~200km) GCM simulations and produce higher resolution projected future changes over their limited area. The projected changes over the region for four GCM runs that were used to drive a total of eight RCM simulations (all that were available at the time of analysis) are shown above in Figure 2. Although the 50 km resolution of the RCMs is considerably higher than GCMs, the relatively small size of the study area means that the regions of interest are only four to six grid boxes each (Figures 4 and 5). For this reason, we present projected changes in extremes primarily as regional averages. It is apparent from Figures 4 and 5 that projected warming in annual average temperature is fairly uniform throughout the region. Note that different models have different grid box centres which results in slightly different configurations of grid cells selected for regional averaging. Regionally averaged projected changes in extremes may be applied to any station within the region. Historical values of climate and some of the indices of extremes are provided in Section 5.

The regional climate model future simulations cover only the 2050s, are all driven by the A2 emissions scenario (Murdock and Spittlehouse 2011), and all projected changes are relative to a 1971-2000 baseline. This baseline differs from the 1961-1990 baseline used in the previous section, which complicates comparison of projected changes between Sections 2 and 3. Gridded CANGRID observations for these two periods, however, indicate that the two periods were very similar. For Metro Vancouver, for example (CRD shows very similar results), 1971-2000 was warmer than 1961-1990 by 0.2°C for day time highs, 0.3°C for night time lows, and had less precipitation in winter (-2%) and fall (-1%), and more in spring (+4%) and summer (+6%) compared with 1961-1990.

[4] North American Regional Climate Change Assessment Project: www.narccap.ucar.edu

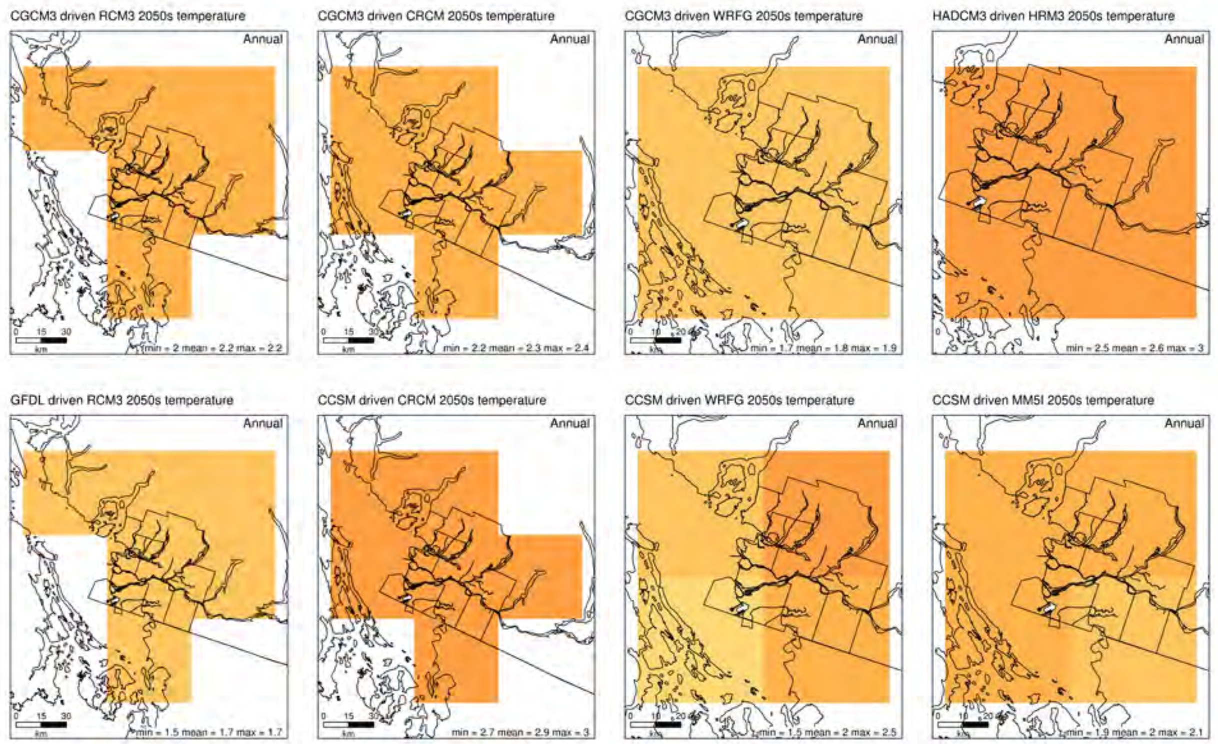
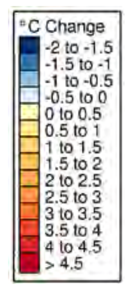


Figure 4: Regional Climate Model projections for 2050s annual temperature for the Metro Vancouver Regional District study area. Data source: NARCCAP.



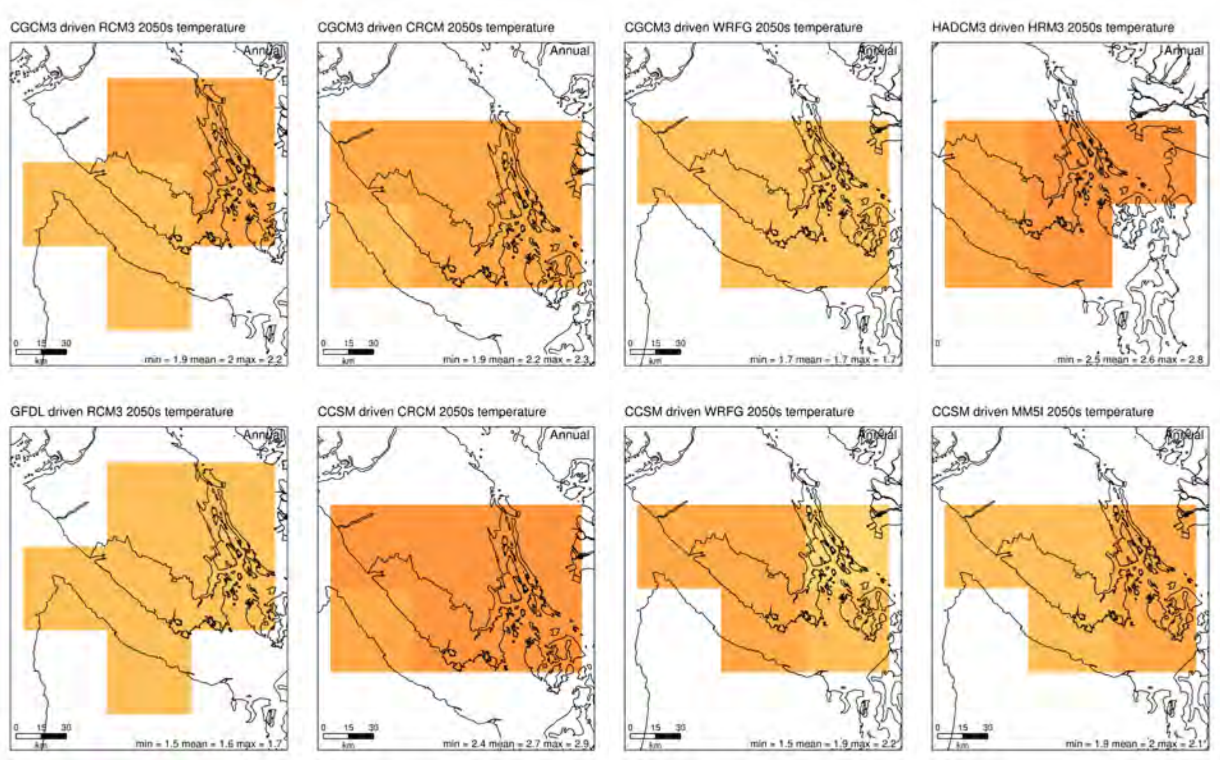
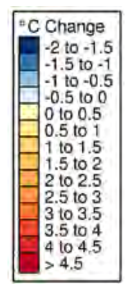


Figure 5: Regional Climate Model projections for 2050s annual temperature for the Capital Regional District study area. Data source: NARCCAP.



3.1 About the indices of extremes

3.1.1 CLIMDEX indices

Projected future changes and historical climatology of extremes are provided for five indices that are a subset of the a standard set of indices of extremes called CLIMDEX (Klein Tank et al. 2009).

1. Warm days - TX90p: occurrence of summer maximum temperature > 90p
2. Very wet day precipitation - R95pTOT: annual total precipitation when > 95p
3. Extremely wet day precipitation - R99pTOT: annual total precipitation when > 99p
4. Heaviest precipitation day - RX1day: September maximum 1-day precipitation
5. Heaviest 5-day precipitation - RX5day: September maximum consecutive 5-day precipitation

The index for warm days, TX90p, refers to 90th percentile temperatures for each day of the year (using a 5-day window centered on that day to get a higher sample size) during the 1971-2000 baseline, so this measures warm days relative to each day of the year rather than using a constant threshold throughout the year. For warm days in summer, the same procedure is followed but for summer months (June-July-August) only.

The two precipitation-related percentile indices, R95pTOT and R99pTOT, measure the *amount* of total precipitation that occurs per year during events in which daily precipitation exceeds the 95th or 99th percentile of all wet days (with precipitation above 1 mm) from 1971-2000. In the case of the precipitation indices, this is regardless of the day of the year in which the precipitation occurs. These measures indicate how much of the total precipitation in a year falls during these heavy events, which is a combination of *both* how often events occur that exceed baseline 95th and 99th percentile thresholds *and* the size of these events. The other two precipitation indices, RX1day and RX5day, describe the maximum precipitation during a single day or a 5 consecutive-day period, respectively. Each is computed separately for each month of the year. Here, monthly RX1day and RX5day values are reported for September only as the month with the largest increases.

3.1.2 Return periods

In addition to the CLIMDEX indices, return periods are investigated to provide an estimate of the change in extremely rare events. The return periods correspond to the maximum or minimum events so rare that they are expected to happen only once every 5, 10, or 25 years on average. These may also be interpreted as the events with a 20%, 10%, and 4% chance of occurring each year, respectively.

Return period duration refers to the sampling interval for which accumulations are reported (either once a day or once every 3 hours). Both durations are considerably larger than the minimum time step used in the models (typically 15-20 minutes) so temporal resolution is sufficient for their computation. Daily return periods were computed so that they could be compared with previous analysis by GCMs (Kharin and Zwiers 2000). For precipitation, both return periods were calculated from both daily and 3-hourly accumulation intervals as the latter better represents the extreme quantities experienced during an event (by avoiding averaging over a 24-hour period). Finally, changes in 3-hourly wind speed were computed as a preliminary way of investigating possible changes in storminess.

Return periods were estimated by fitting the annual maxima of RCM simulated values to the Generalized Extreme Value (GEV) distribution. This was done for both the historical and future periods separately. The GEV is a probability distribution that can be used to approximate the actual distribution of annual maxima using only three parameters (called the scale, shape, and location parameters). This is similar to how a normally distributed function can be represented by only its mean and standard deviation. The GEV distribution originates in statistical extreme value theory, and has been demonstrated to work well in many practical situations. By approximating the distribution of annual maxima with the GEV, we can then use known properties of the GEV distribution to estimate return periods. The GEV analysis was performed using the fExtremes package for the R software programming language which uses the method of L-moments (Hosking 1985) and uncertainty was assessed based on the standard errors and confidence intervals of estimates of the three GEV parameters.

3.2 Summary of Changes in Extremes

Projected regional average changes for the CLIMDEX indices described in section 4.1.1 are provided from each RCM projection individually as well as for the average of all eight projections in Tables 4 and 11 (Appendix 2). All projected changes are for the 2050s periods compared with 1971-2000.

More than a doubling is projected in the occurrence of summer warm days (TX90p) in most cases. On average summer warm days are projected to occur 2.2 times as often in the 2050s for Metro Vancouver and 2.7 times as often for CRD. Most of the individual projections are similar the averages, although there is a range from 1.8 to 4.9 (Tables 4 and 11).

Extreme precipitation is projected to increase according to most models for the four precipitation indices (Tables 4 and 11). The percent of the annual total precipitation that falls during events that are larger than the 95th percentile of events in the past (R95pTOT) is projected to increase by about +20% on average, but with individual projections ranging from +2% to +43%. Similarly for events larger than the 99th percentile (R99pTOT), the increase is +28% on average for Metro Vancouver and +25% for CRD, and with a wider range from -36% to +74%.

The annual RX1day and RX5day indices refer to the September maximum monthly precipitation throughout the year. The average increase in RX1day is +25% for Metro Vancouver and +31% for CRD and in RX5day is 16% for Metro Vancouver and 22% for CRD (Tables 4 and 11).

Projected regional median changes in occurrence of extremely rare events: 5-, 10- and 25- year return periods are provided as a ratio of frequency of occurrence in future to frequency in past. The regional median of upper and lower bounds are also provided. These are obtained during the fitting process of the GEV distribution when calculating the future return periods, and illustrate the range of uncertainty associated with estimating extreme events.

The regional median projected changes in extremely hot days are given in Tables 5 and 12. In Metro Vancouver, 5-, 10-, and 25- year return period daytime high hot events are projected to occur 2.4, 2.8, and 3.2 times as often, respectively. For the CRD, the ratios of projected increases are larger: 2.9, 3.5, and 3.6. Individual model projections are mostly similar to the average. There is, however, a wide range of uncertainty between the upper and lower bounds with return period events projected to decrease considerably in occurrence or to increase more than the projected values (Tables 5 and 12).

Projected changes in extremely wet days are given in Tables 6 and 13. In Metro Vancouver, 5-, 10-, and 25- year return period wet events are projected to occur 1.6, 1.9, and 2.5 times as often, respectively. For the CRD, the ratios of projected increases are 1.8, 2.1, and 2.6. As with temperature return periods, individual model projections are mostly similar but a wide range of uncertainty between the upper and lower bounds exists with return period events projected to decrease considerably in occurrence or to increase more than the projected values (Tables 6 and 13). Projected increases in occurrence of extremely wet 3-hourly duration precipitation events are generally larger in both regions with most relative increases close to double those of daily precipitation return periods (Tables 7 and 14).

Extreme wind speed was also investigated by computing projected changes in return periods of wind speed. These results require additional caution because simulated Regional Climate Model wind in the region may not match well with observed (He et al. 2010). In Metro Vancouver, results are mixed (Table 8), with projected increases of occurrence in wind speed return periods of up to 2.6 times as often as the past as well as projected decreases to as seldom as 0.2 as often in the past and even less than 0.1 times according to the WRFG RCM (both when driven by the CGCM3 and CCSM GCMs). In CRD, average projected occurrence of 5-, 10-, and 25- year return period events are 1.1, 12.2, and 1.5 times as often as the past, respectively. Overall these results imply little change in extremes of wind speed (as simulated by RCMs), but with slightly more increases in CRD than Metro Vancouver. Visual inspection of wind speed projections from the eight RCM projections (not shown) suggests that several models, and WRFG in particular, show larger increases in wind speed itself over the CRD than Metro Vancouver.

3.3 Temperature and Precipitation

Regionally averaged projections of annual and seasonal temperature and precipitation change are given for Metro Vancouver (Tables 9 and 10) and the Capital Region (Tables 16 and 17) from each of the RCMs as well as the average over all eight projections. These anomalies are for the 2050s (2041-2070) periods relative to a baseline period of 1971-2000 and provided so that they can be compared to projected change from the four GCM projections that drive the eight total RCM simulations as well as to larger ensembles (Figure 2).

Regional average changes for both regions are similar (compare Tables 2 and 3 to Tables 9, 10, 16, and 17). Annual average temperature is projected to increase by 1.7°C to 2.9°C, with an average of 2.2°C in Metro Vancouver and 2.1°C in CRD. Projected increases are largest in spring and smallest in fall while winter and summer season projections are generally similar to the annual average projected increases.

The eight RCM projections used indicate the largest increases in precipitation by the 2050s compared with the 1971-2000 baseline during the fall season with an average of +64% in Metro Vancouver and +33% in CRD. For the winter season, there is disagreement between projections as to the direction of change (projections from -40% to +37%) and an average of just +4% in Metro Vancouver and no change in CRD. Most RCMs project decreased spring precipitation, with an average of -18% in Metro Vancouver and -7% in CRD. Summer precipitation projections range from -15% to +24% in Metro Vancouver with an average of +4%, and from -7% to +6% in CRD with an average of -2%. These seasonal changes contribute to an average projected annual precipitation increase of +13% for Metro Vancouver and +6% for Vancouver Island.

In these cases where the range of uncertainty includes both projected increases and decreases, this is not an indication that the result should be disregarded but rather indication to plan for changes in both directions. Indeed, the analysis of historical trends in precipitation at stations (Section 5 and Appendix 3) indicates that considerable variability in precipitation is to be expected in the region.

4. Historical Analysis

To put the projected changes in extremes described in the previous section in context, the historical 1971-2000 climatology at several stations in the region are given in Appendix 2 (Tables 18 through 25). For example, very wet day precipitation (R95pTOT) is projected to increase by an average of 21% in Metro Vancouver and 20% in CRD by the 2050s compared to 1971-2000 (Table 4). The station climatology for R95pTOT (Tables 18 and 22) indicate that the amount of total precipitation that fell on average during a year in the past varies considerably throughout the region: for example, from 178 mm at Delta Beach, 272 mm at Vancouver Municipal Hall, to 622 mm on Grouse Mountain, and from 288 mm at Victoria Gonzales to 661 mm at Sooke Lake North.

Similarly, the extreme temperature and precipitation 5-, 10-, and 25- year return *levels* (that is, the values that correspond to events so rare they only occur on average once every 5-, 10-, and 25- years) are provided in Tables 19 and 23. For example, historically one-in-10-year extreme warm temperature events are projected to occur 2.3 times as often in future in Metro Vancouver (Table 5) and 3.9 times as often in CRD (Table 12). The temperature that is projected to occur this often in future is comparable to a temperature of 31.5°C at Vancouver International Airport, 34.5°C at Vancouver Municipal Hall, 34.9°C in Newton (Table 19), 32.6°C at Victoria International Airport, 33.8°C at Victoria Gonzales, and 35.3°C at Shawnigan Lake (Table 23) based on historical station data.

The seasonal and annual temperature and precipitation climatologies are given for comparison of stations to each other in Tables 20, 21, 24, and 25. Historical trends are also included in Appendix 3.

5. Summary

5.1 Impacts

Climate change projections have been provided in this report from several difference sources: Global Climate Models (Section 2: Table 1, Figure 2), high resolution elevation-corrected projections (Section 3: Tables 2 and 3, Figure 3; Appendix 1), and Regional Climate Models (Section 4: Figures 4 and 5; Appendix 2). Historical climate information at selected stations of interest throughout the region is provided for comparison (Section 5; Appendix 3).

5.1.1 Metro Vancouver

Projected annual warming by the 2050s (compared to 1961-1990) for the region according to a set of Global Climate Models (GCMs; section 2) ranges from +1.4°C to +2.8°C in summer and +0.8°C to +2.7°C in winter, along with a projected change of -5% to +16% in winter precipitation and -25% to +5% in summer precipitation (Table 1).

Projected change in high resolution projections are provided for several variables of interest for three selected projections (from models CGCM3, HadCM3, and HadGEM) from the larger set (Figure 2). These projections allow for comparisons in map form (Appendix 2) of historical values to future projections. HadCM3 projects less warming than the majority of the range of GCMs, while the other two are on the warmer end. Despite these differences, all three indicate considerable changes in variables related to temperature: increased growing degree days, cooling degree days, and frost free period along with decreased heating degree days and precipitation as snow.

Projected warming by the 2050s (compared to 1971-2000) according to a smaller set of Regional Climate Models (RCMs) is on average 2.2°C (Table 9 and Figure 2). Precipitation for the same period is projected to decrease on average by -18% in Spring, increase by +4% in Winter and Summer, and increase considerably in Fall by +64% according to the RCMs (Table 10 and Figure 2).

The projected average 2.3°C summer warming according to the RCM (Table 9) results in an associated number of warm days in summer (TX90p; above 20°C to 25°C depending on the location – Table 18) are projected to occur on average 2.2 times as often by the 2050s compared to 1971-2000. More extreme temperatures so warm that in the past it would be exceeded on average once every ten years (about 32°C to 35°C – Table 19) are projected to occur on average 2.3 times as often in future (Table 5).

The amount of precipitation falling during very wet days (R95pTOT) and extremely wet days (R99pTOT) is projected to increase by 21% and 28%, respectively (Tables 4 and 18). More extreme precipitation events (with 3-hour duration) so intense than in the past they would be exceeded on average only once every 10 years (see Table 19) are projected to occur on average 3.0 times as often in future (Table 7).

5.1.2 Capital Regional District

Projected annual warming by the 2050s (compared to 1961-1990) for the region according to a set of Global Climate Models (GCMs; section 2) ranges from +1.3°C to +2.6°C in summer and +0.8°C to +2.4°C in winter, along with a projected change of -5% to +17% in winter precipitation and -30% to +1% in summer precipitation (Table 1).

Projected change in high resolution projections are provided for several variables of interest for three selected projections (from models CGCM3, HadCM3, and HadGEM) from the larger set (Figure 2). These projections allow for comparisons in map form (Appendix 2) of historical values to future projections. HadCM3 projects less warming than the majority of the range of GCMs, while the other two are on the warmer end. Despite these differences, all three indicate considerable changes in variables related to temperature: increased growing degree days, cooling degree days, and frost free period along with decreased heating degree days and precipitation as snow.

Projected warming by the 2050s (compared to 1971-2000) according to a smaller set of Regional Climate Models (RCMs) is on average 2.1°C (Table 16 and Figure 2). Precipitation for the same period is projected to decrease on average by -7% in Spring and -2% in Summer (projected zero change in Winter on average), and to increase considerably in Fall by +33% according to the RCMs (Table 10 and Figure 2).

The projected average 2.3°C summer warming according to the RCM (Table 16) results in an associated number of warm days in summer (TX90p; above 21°C to 25°C depending on the location – Table 22) are projected to occur on average 2.2 times as often by the 2050s compared to 1971-2000. More extreme temperatures so warm that in the past it would be exceeded on average once every ten years (about 33°C to 35°C – Table 23) are projected to occur on average 3.9 times as often in future (Table 12).

The amount of precipitation falling during very wet days (R95pTOT) and extremely wet days (R99pTOT) is projected to increase by 20% and 25%, respectively (Tables 11 and 22). More extreme precipitation events (with 3-hour duration) so intense than in the past they would be exceeded on average only once every 10 years (see Table 23) are projected to occur on average 2.6 times as often in future (Table 14).

5.2 Interpretation

There are some general principles to consider when interpreting the projected climate changes described in sections 3 and 4. Changes in climate will impact a range of systems – physical, social, economic, and ecological. By looking at the variety of systems that are being affected in the community, impacts on one system can be understood in the context of their relationships with other systems (i.e. the effects of sewage system failures both on the physical sewer infrastructure and on the wider ecological system). This helps build an understanding of the effect and nature of the projected change and promotes organization taking coordinated responses. Repeated or continued stresses, such as those posed by climate change impacts, can increase vulnerability, particularly when they occur in combination with other stress-inducing factors (such as population growth) and at high enough frequencies to prevent recuperation.

Below a brief discussion of impacts on four specific systems:

Physical Systems

The projected changes outlined in this report will present a variety of challenges for the physical infrastructure of communities. Expected climate changes will increase maintenance and protection costs, replacement costs and the loss of assets across the country – in this sense, physical systems can include: dykes, culverts, roadways, bridges, buildings, sewer systems, and levees.

Social Systems

Expected changes in precipitation, water levels, and temperatures will affect the complex social systems in communities, with impacts including: the health of individuals (especially of vulnerable populations); incidents of environmental refugees and displaced persons; limitations in the livelihoods of certain populations while improving the livelihoods of others; and increases in the need for (and alteration of) emergency response plans. Impacts on social systems will also be exacerbated by non-climate related phenomenon (i.e. economic downturn, possible civil conflict, etc.).

Economic Systems

Economic systems may be impacted in a variety of ways: extreme events may cause significant economic losses; changing climate conditions will affect the production, price, and demand for goods and services; costs related to public health and safety will also result from climate change impacts. The insurance industry will need to be another important consideration – the cost of insurance for homes and businesses, for example, has increased in recent years in regions where new research shows that the expected future damage is higher than historical damage. In addition, as outlined in preceding sections, changes to traditional tourism industries will likely take place due to decreases in winter precipitation as snow and warmer January temperatures.

Ecological Systems

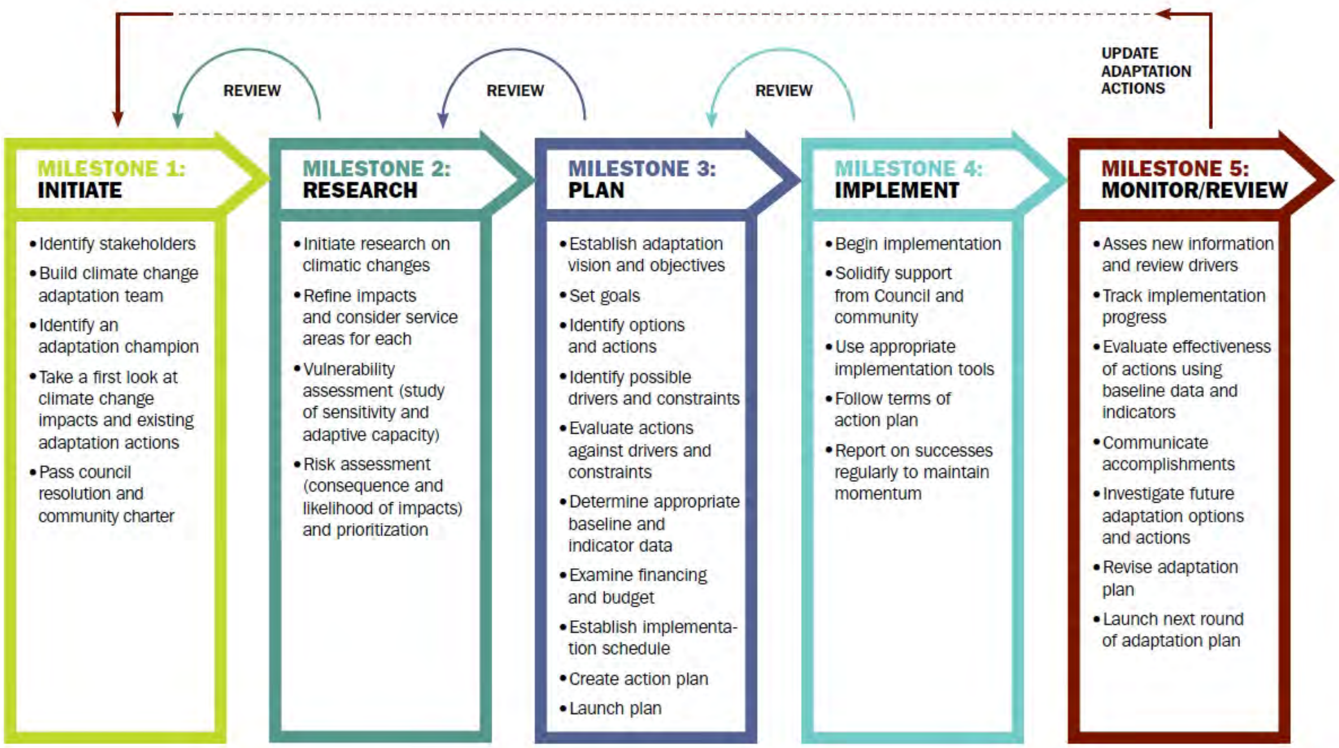
Perhaps some of the deepest affects stemming from projected climate change will be seen in ecological systems. Impacts can range from: changes in abundance and/or distribution of species, large shifts in species ranges, increased fragmentation of habitats, and wildfire frequency and severity. Temperature and precipitation fluctuations will affect growing seasons, plant productivity, as well as animal habitat, migration patterns, breeding and survival rates, the incidence of insect infestations, and habitat diversity. Ecological consequences provide prime examples of how climate change impacts will not be felt in isolation. For instance, vegetation and insects will shift in response to changes in climate and as a result, tourism and other recreational activities, will be affected along with sectors such as agriculture, forestry and urban park management.

Climate change is already being felt in towns and cities across the country. There are many indications that the projected changes outlined in this report are already underway: increasing temperatures, disappearing snowpack, earlier springs, and rising sea levels. Municipal services and infrastructure increasingly report being affected by these events.

The ICLEI Canada methodology, as outlined in *Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation* assists local governments in the creation and implementation of adaptation plans to address the relevant climate change impacts associated with their communities. The process is a five-milestone approach where each milestone represents a fundamental step in the adaptation planning process, starting with the initiation of an adaptation effort and culminating with a monitoring and review process that analyzes the successes and reviews the challenges of the adaptation plan and its implementation. The figure below shows the full methodology, and the individual tasks associated with each milestone.

The information contained within this report supports Milestone Two: *Research* and is meant to provide the seven participating local governments with downscaled data and projections to assist with refining their scenarios of possible impacts and consider relevant service areas within their organizations that will be affected by the change. Likewise, the information can be used to identify and support the prioritization of adaptation options and actions to be identified as part of Milestone Three: *Plan.* For subsequent local governments that may join the ICLEI Adaptation Initiative in future cohorts, this information will act as a building block for their efforts and will leverage the work and funding carried out by the initial seven local governments in the Georgia Basin.

Figure 6: Regional Climate Model projections for 2050s annual temperature for the Metro Vancouver Regional District study area. Data source: NARCCAP.



Appendix 1 – High resolution maps

Maps are provided in this section for each of the following seven variables.

- Annual precipitation as snow (PAS)
- Annual growing degree days (GDD)
- Annual heating degree days (HDD)
- Annual cooling degree days (CDD)
- January night-time low temperature (Tmax)
- Summer daytime high temperature (Tmin)
- Annual frost free period (FFP)

In each figure, the 1961-1990 average (based on PRISM data) is shown in the top left, along with projections for the 2050s or 2080s for the three GCM projections described above (CGCM3 A2 run 4, HadCM3 B1 run 1, and HadGEM A1B run 1).

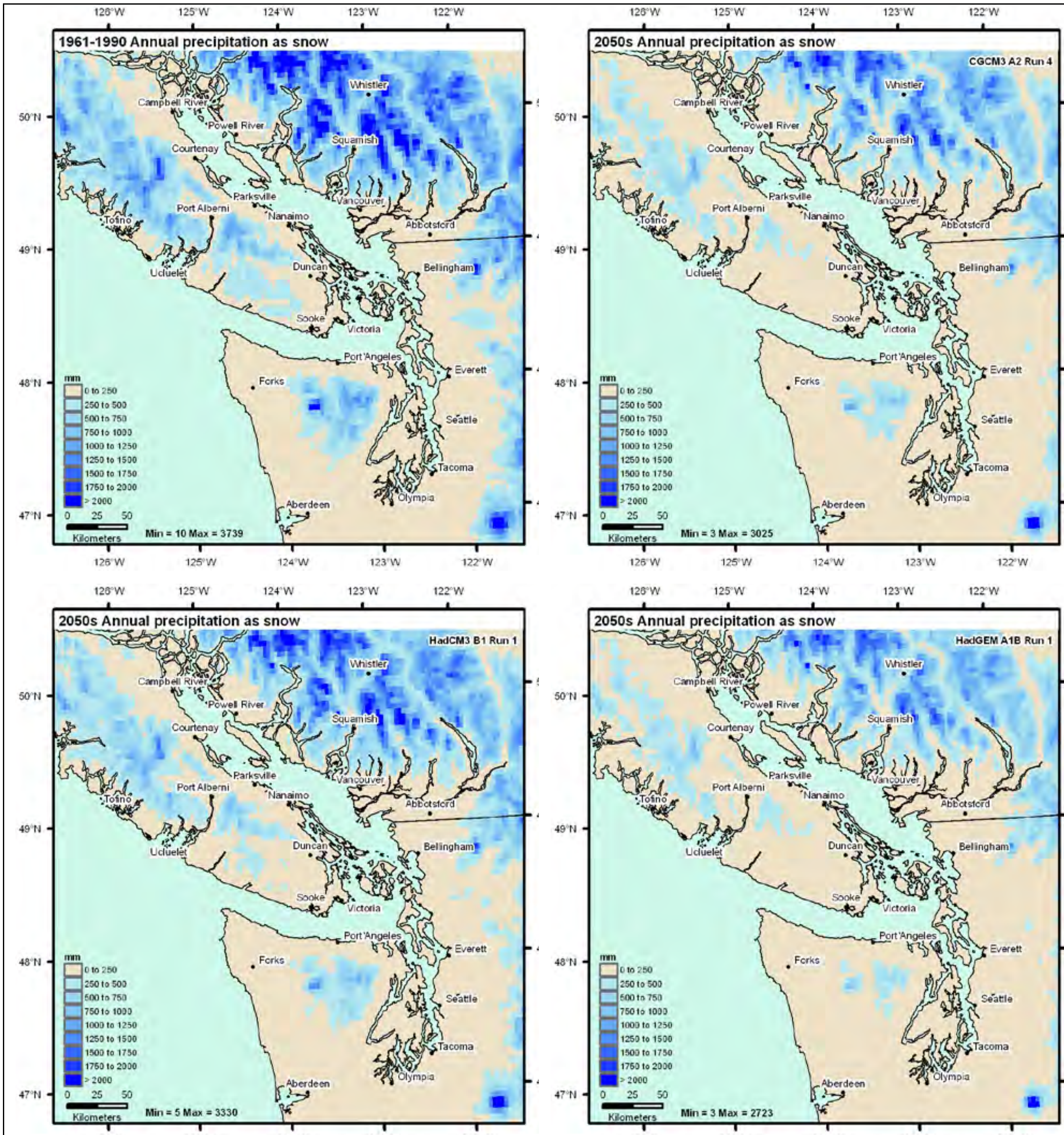


Figure 7: Annual precipitation as snow for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

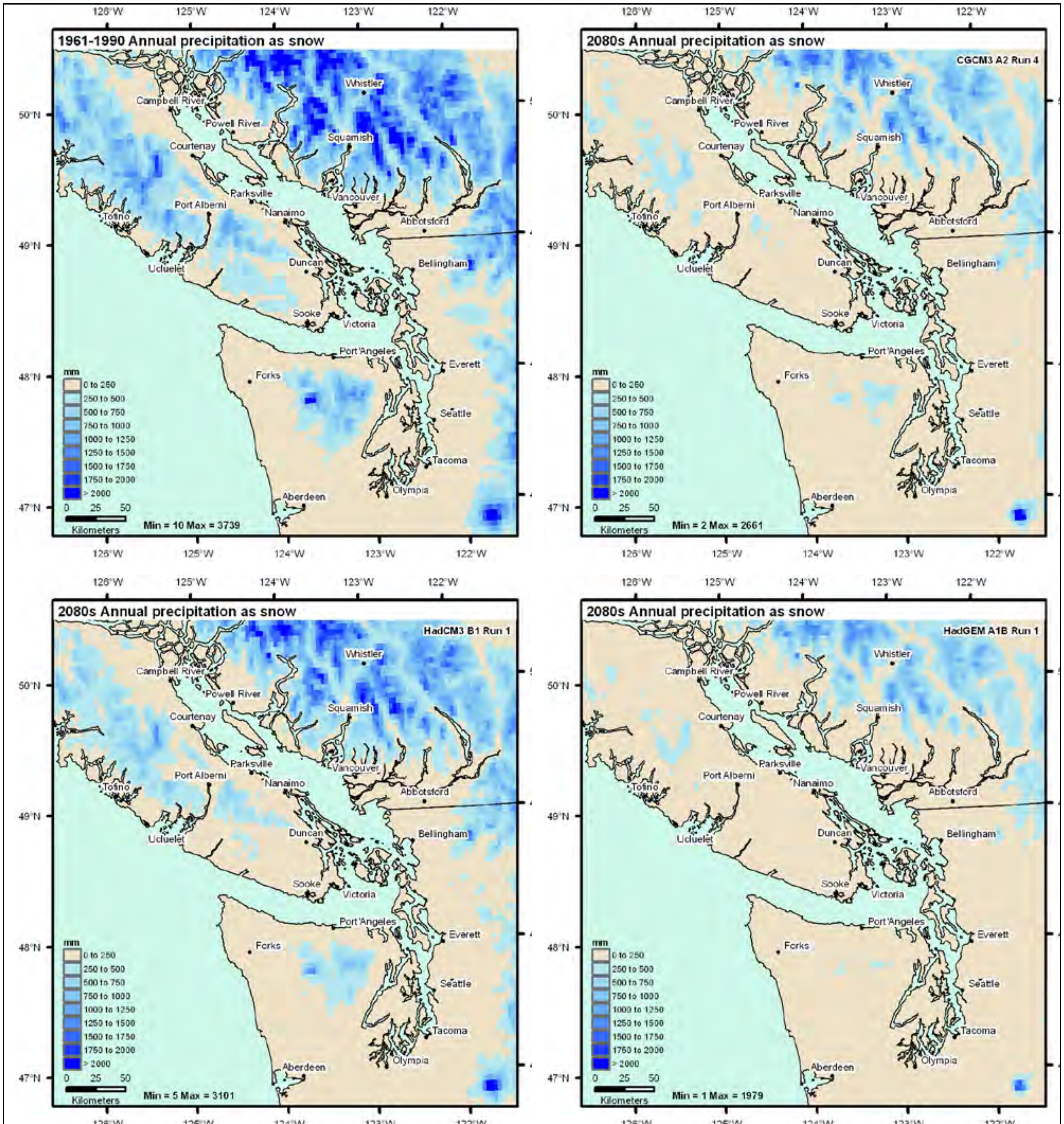


Figure 8: Annual precipitation as snow for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

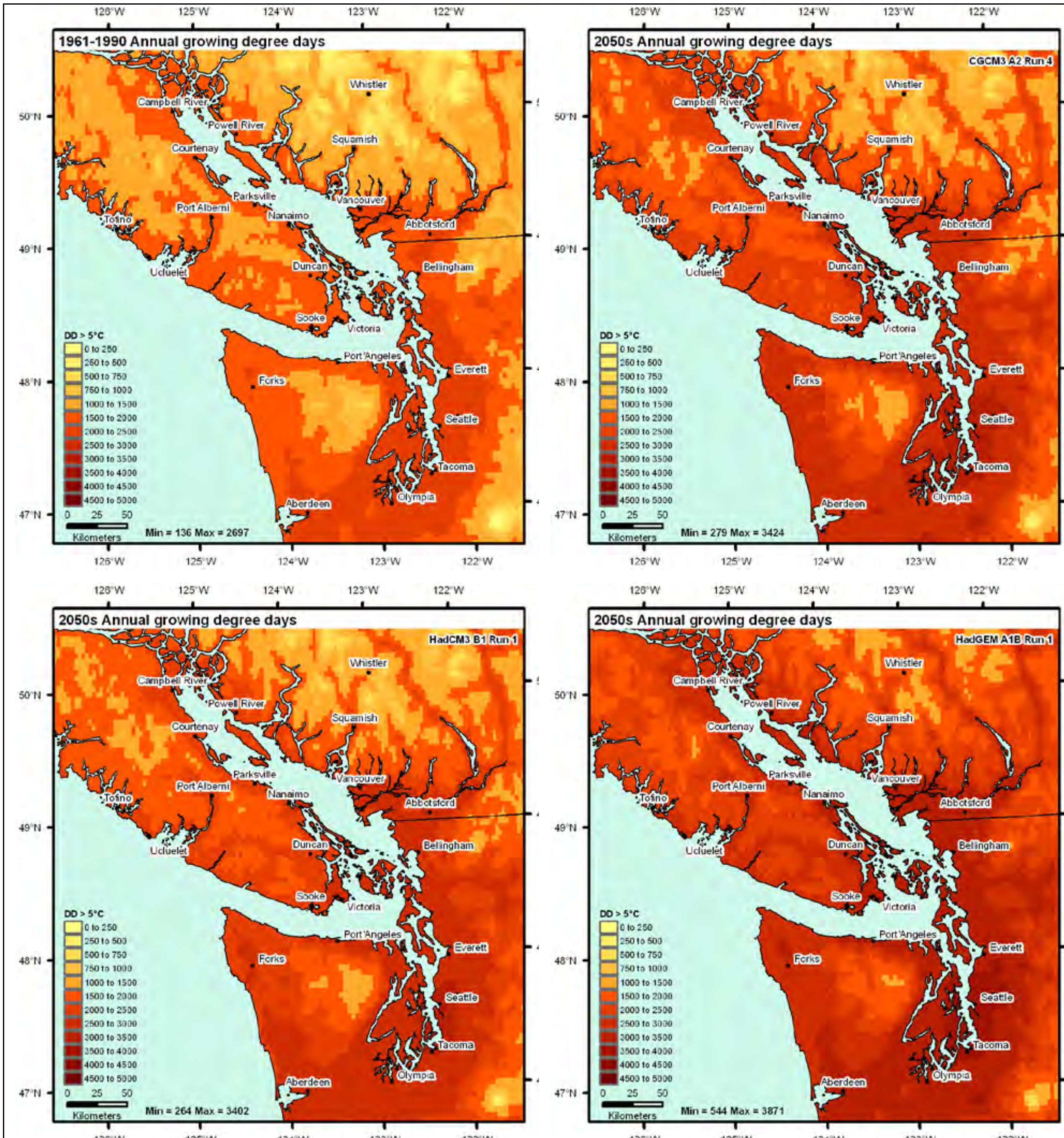


Figure 9: Annual growing degree days for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

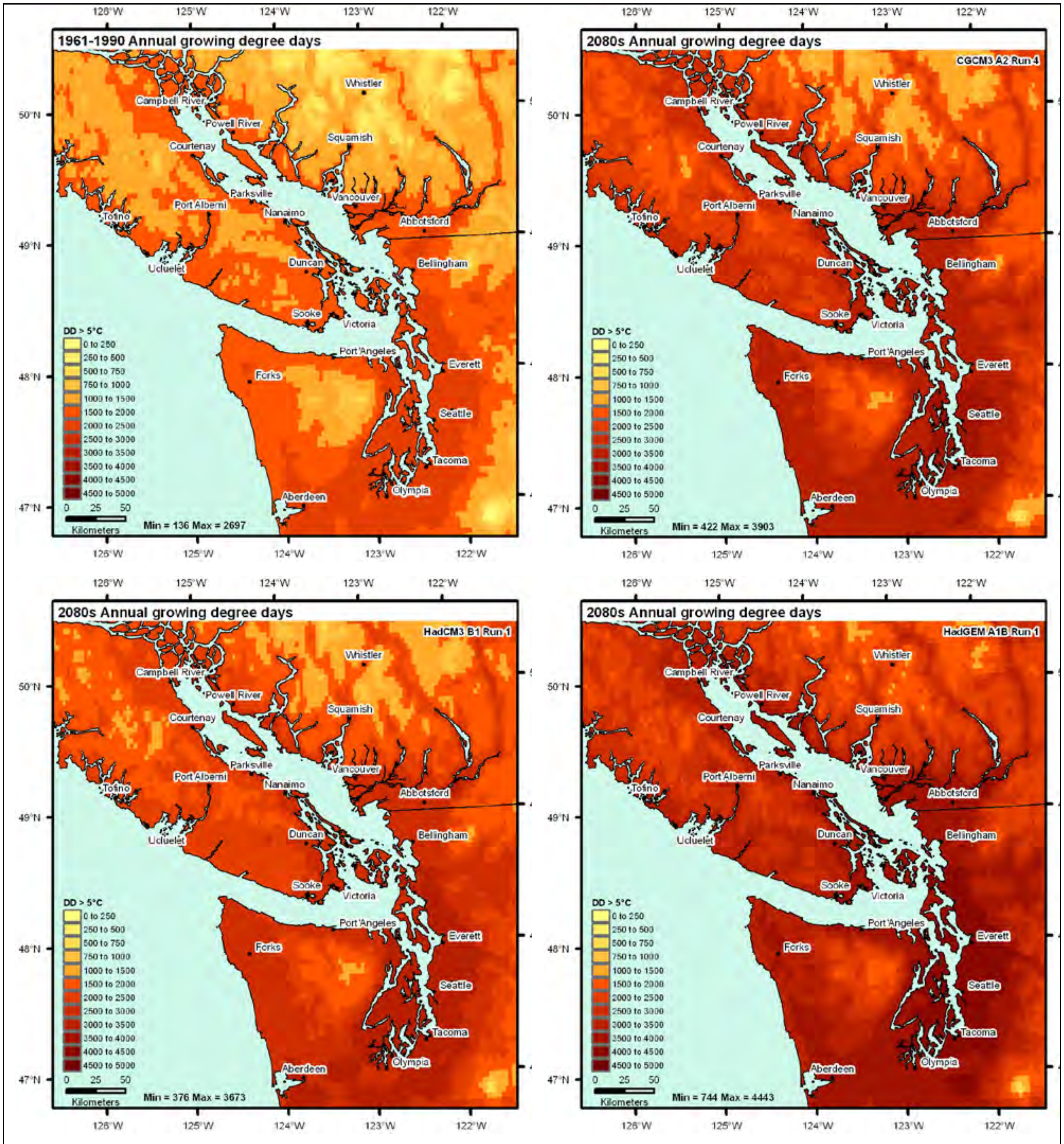


Figure 10: Annual growing degree days for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

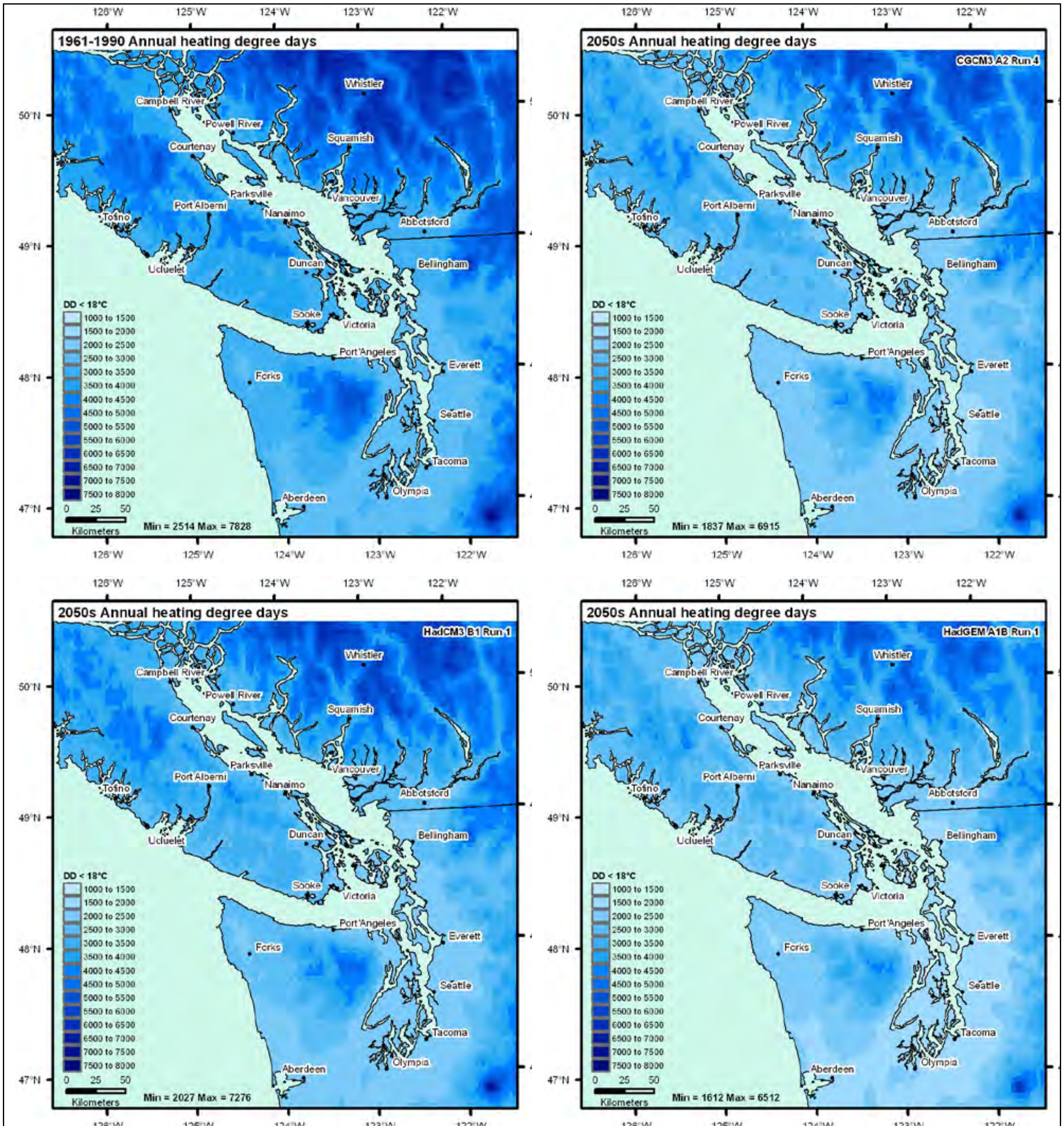


Figure 11: Annual heating degree days for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

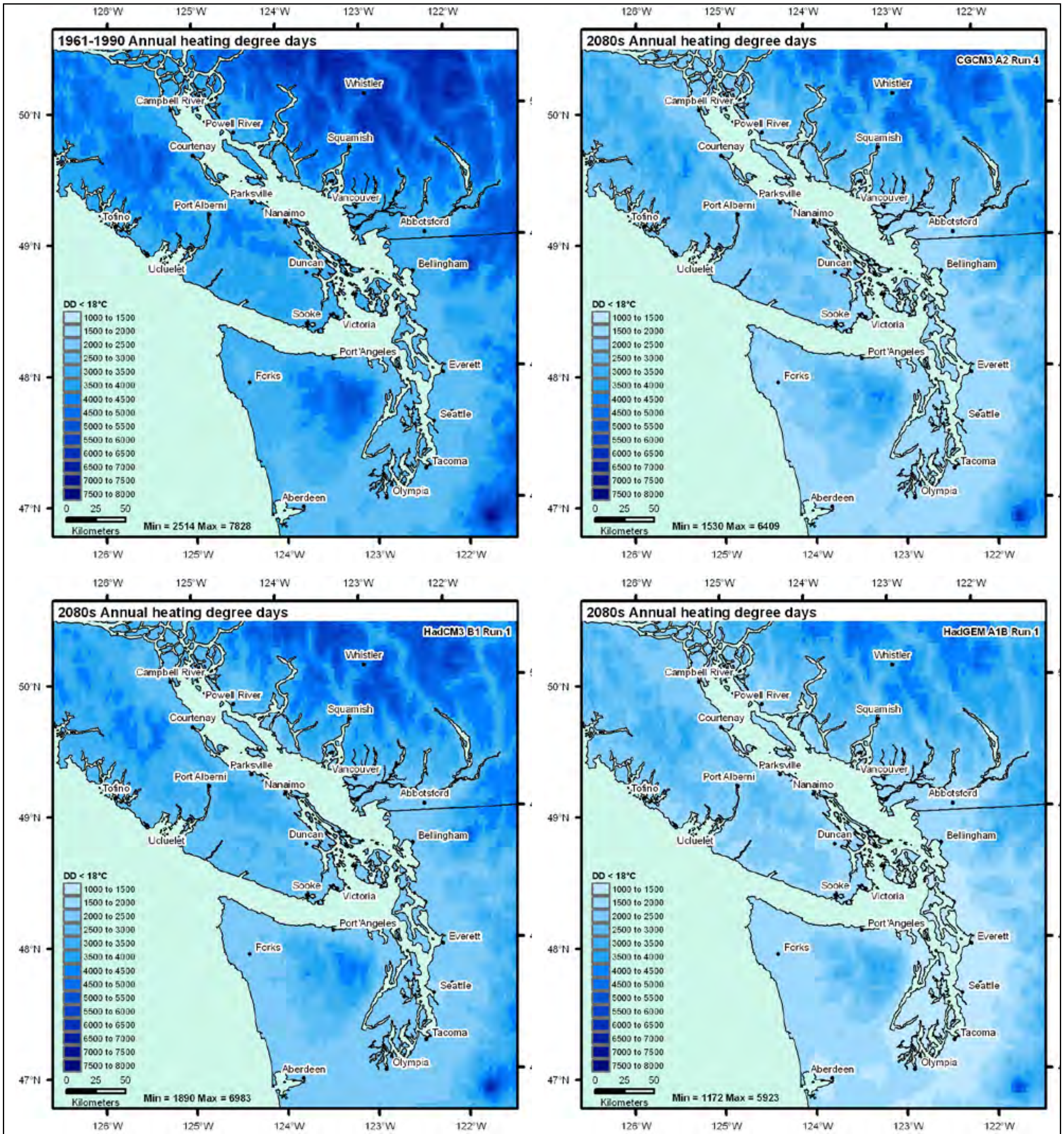


Figure 12: Annual heating degree days for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

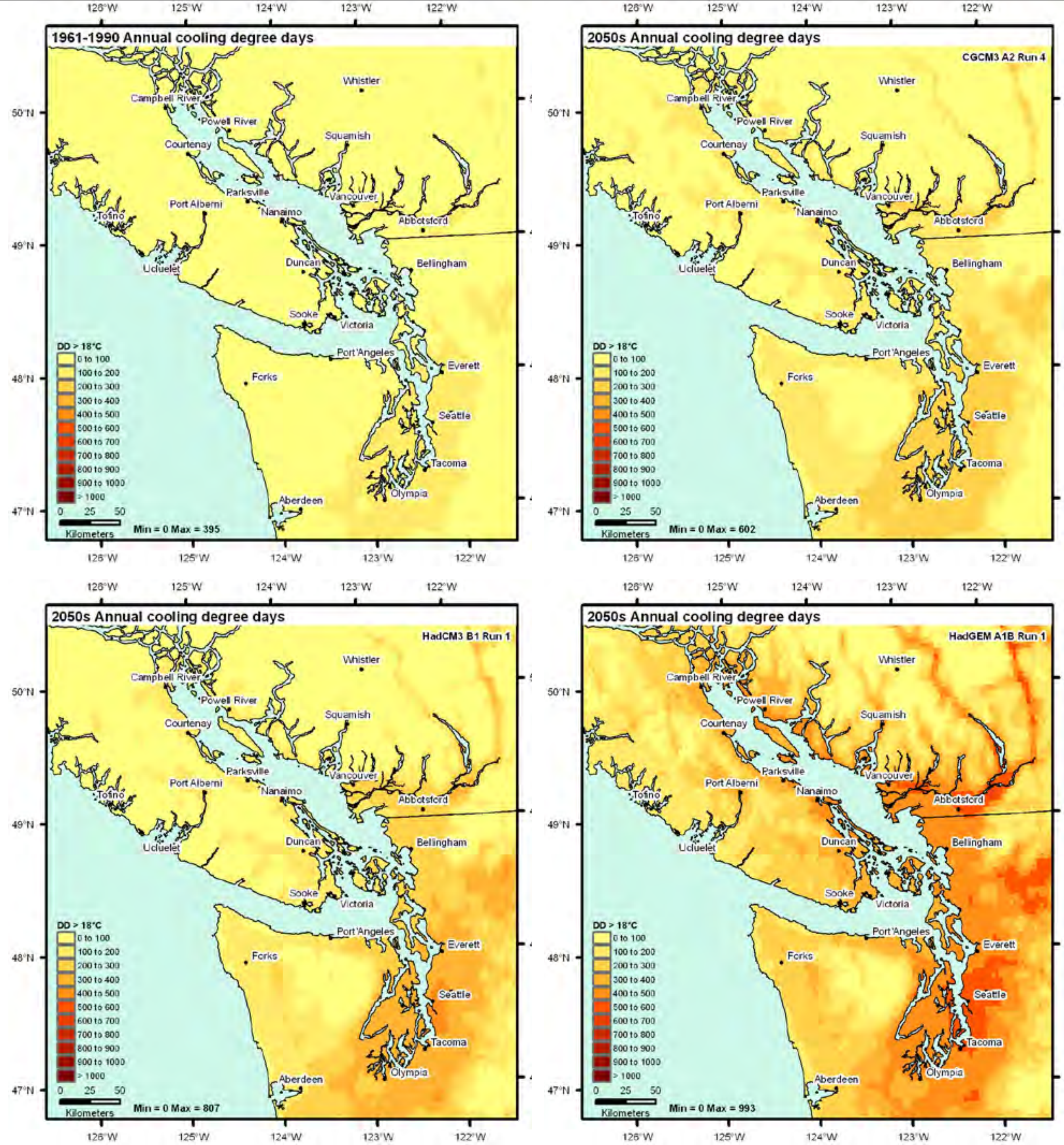


Figure 13: Annual cooling degree days for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

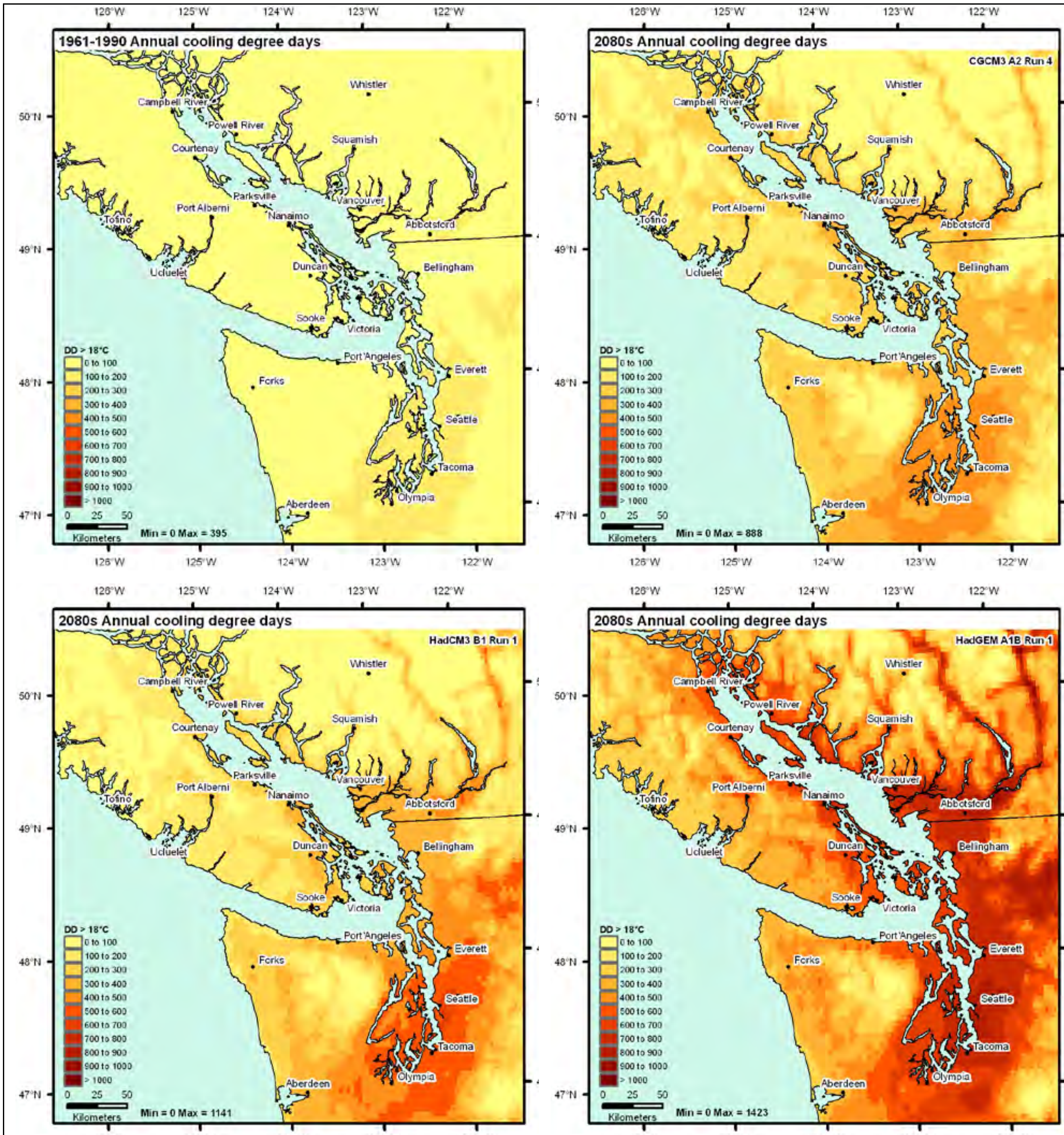


Figure 14: Annual cooling degree days for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

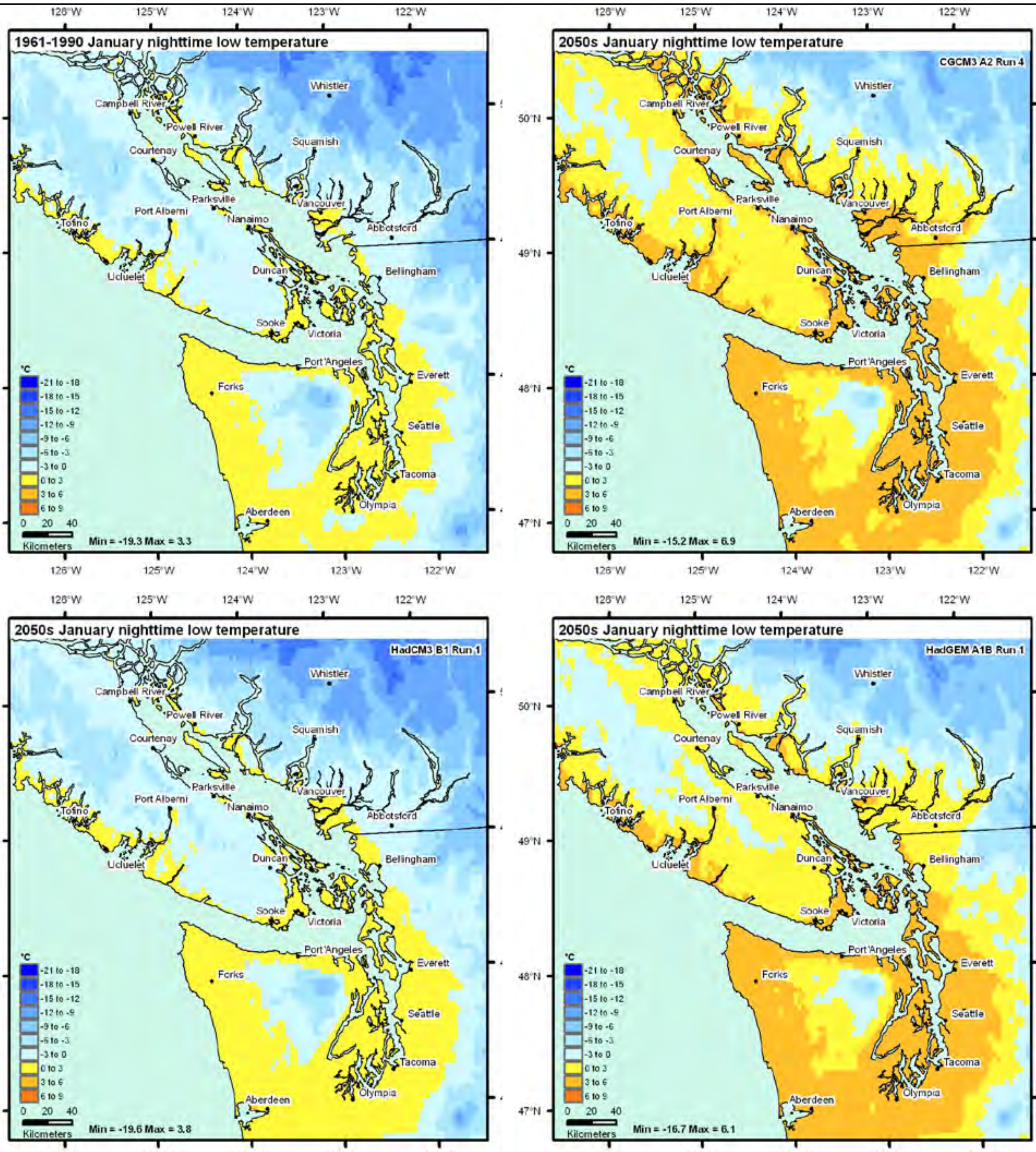


Figure 15: January night-time low temperature for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

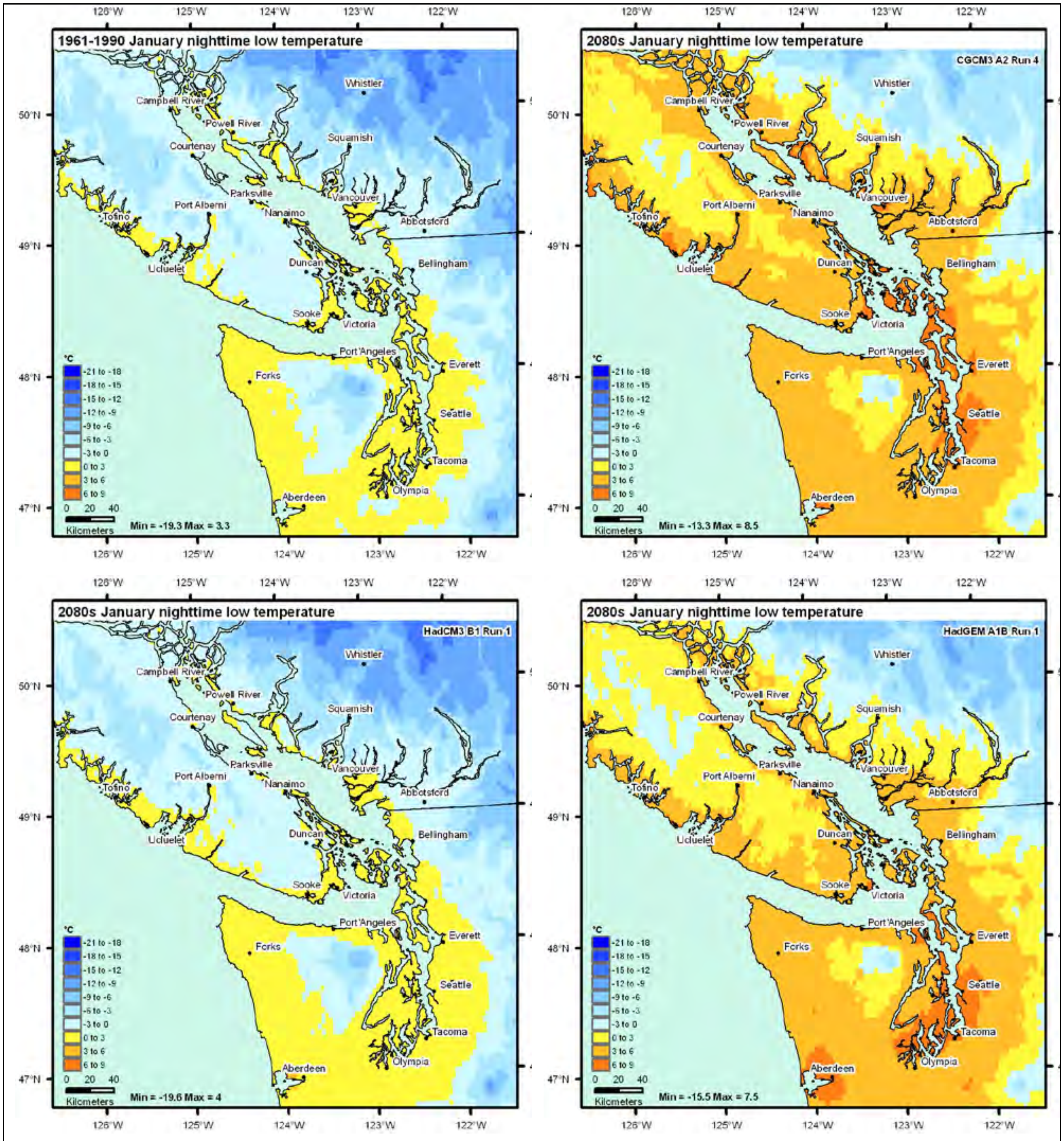


Figure 16: January night-time low temperature for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

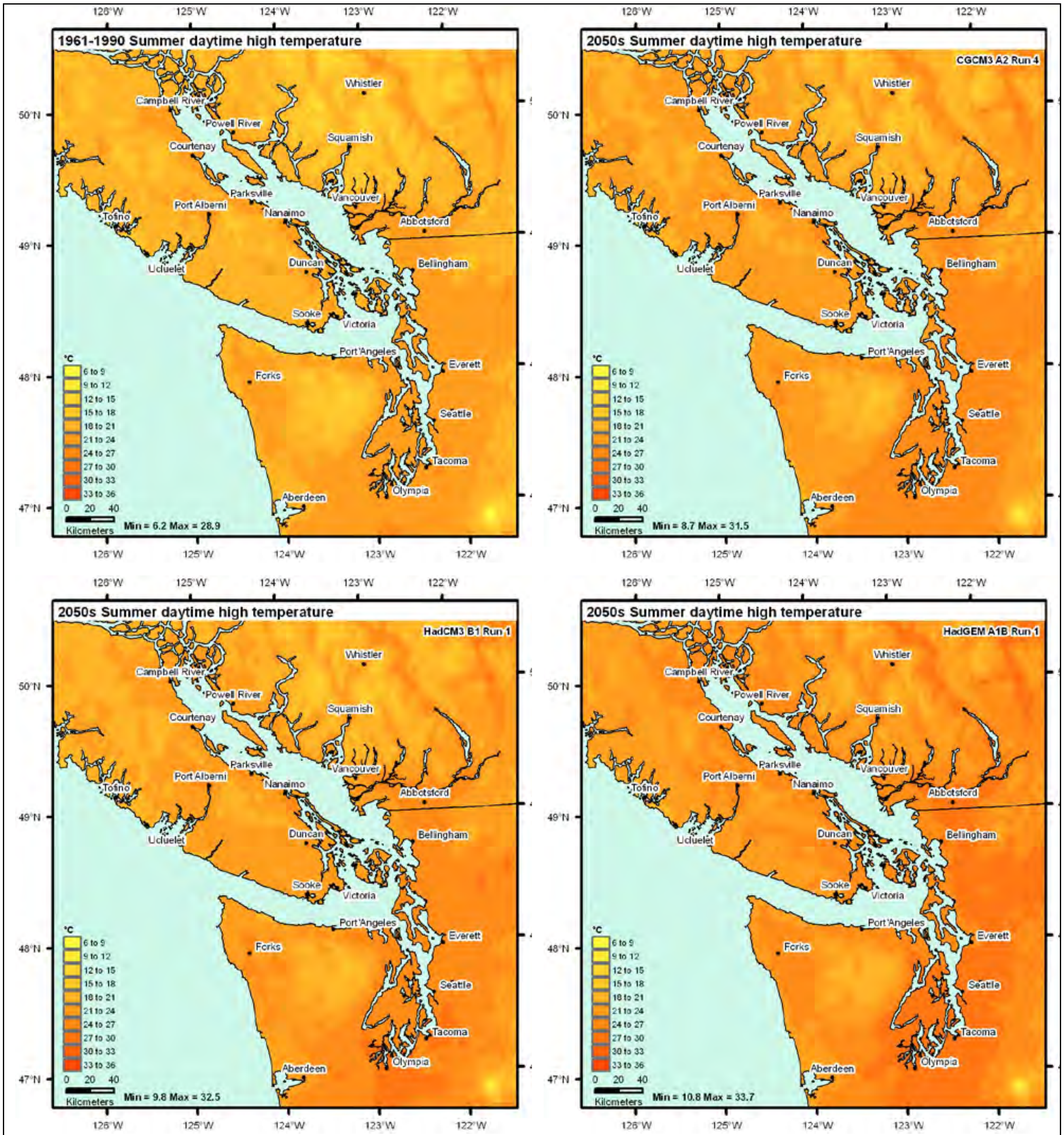


Figure 17: Summer day-time high temperature for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

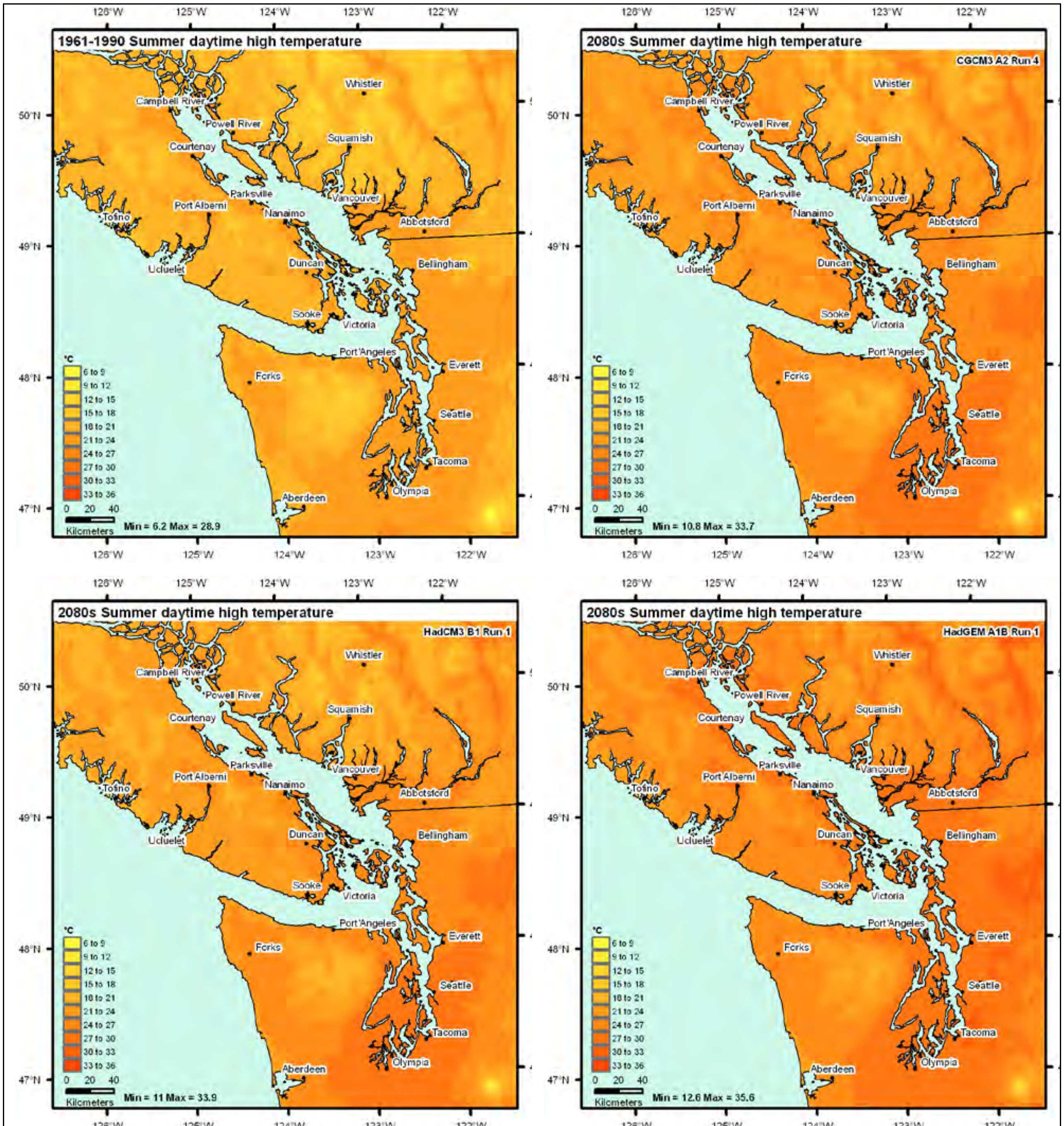


Figure 18: Summer day-time high temperature for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

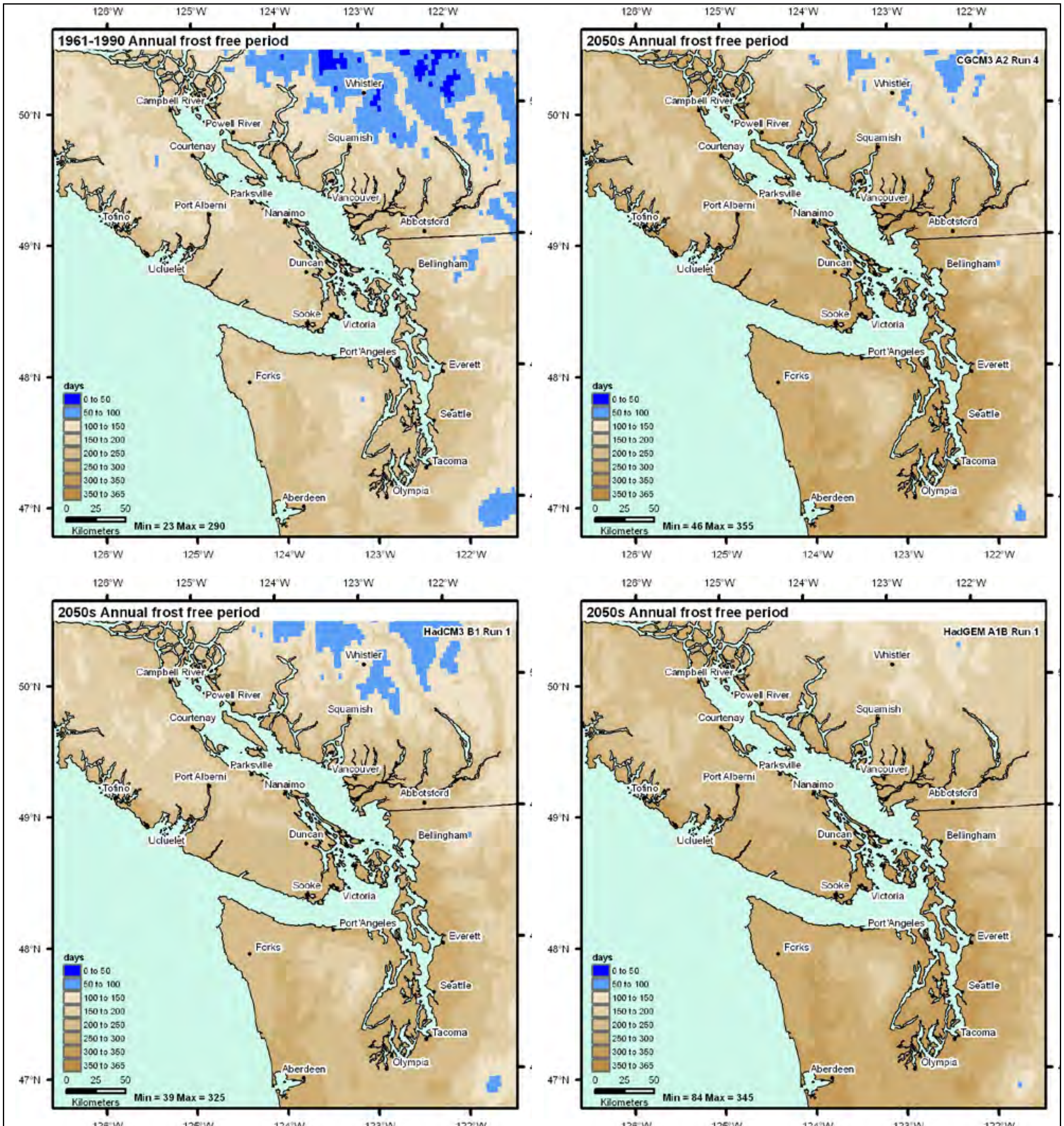


Figure 19: Annual frost-free period for 1961-1990 historical baseline (top left) and future 2050s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

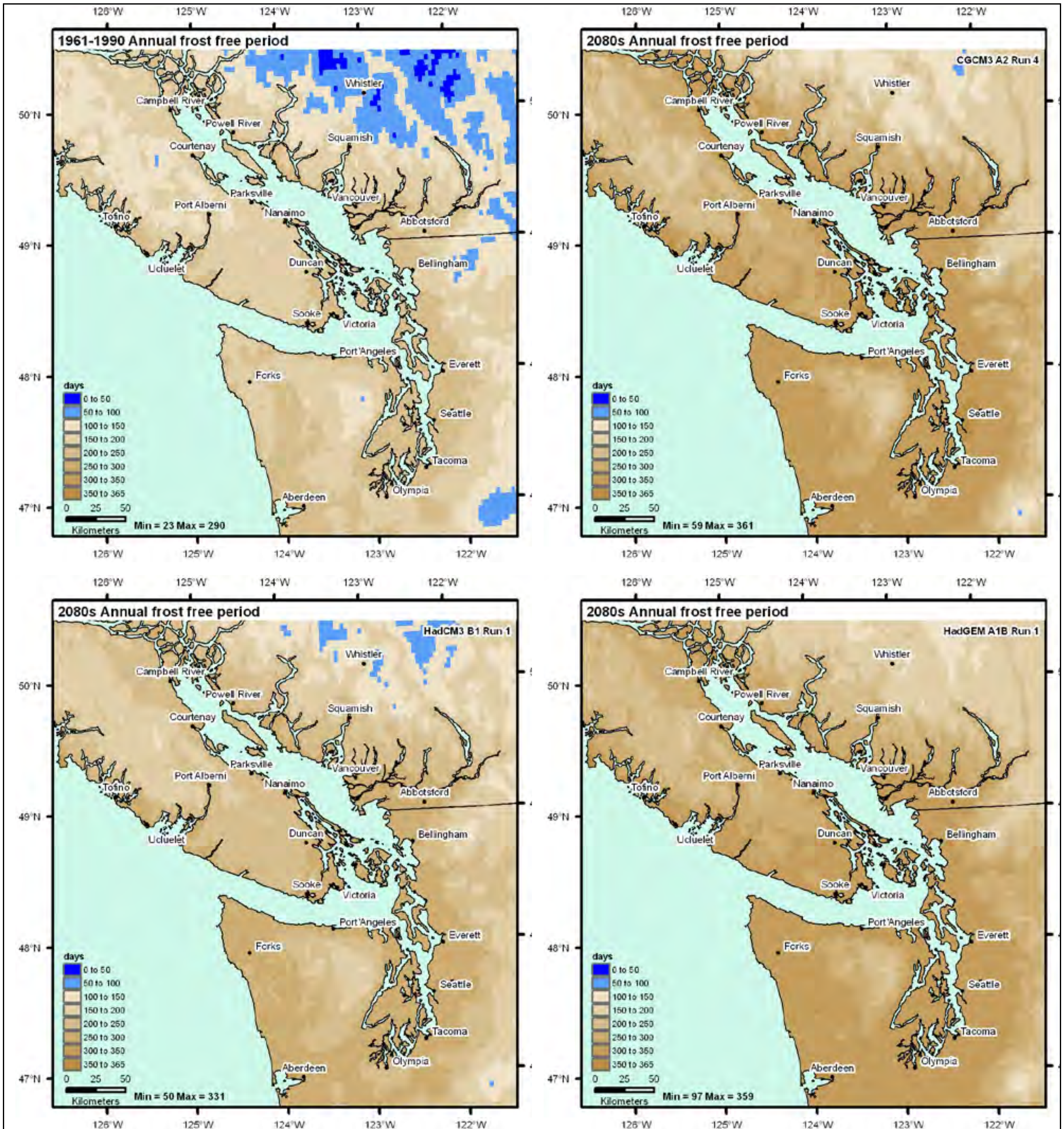


Figure 20: Annual frost-free period for 1961-1990 historical baseline (top left) and future 2080s projections according to CGCM3 A2 run 4 (top right), HadCM3 B1 run 1 (bottom left) and HadGEM A1B run 1 (bottom right).

Appendix 2 – Regional Climate Model Projections

A2.1 Metro Vancouver

Table 4: Summary of projected changes for regional averages of CLIMDEX indices of extremes in Metro Vancouver.

GCM-RCM	TX90p summer (ratio)	RX1day sept (%)	RX5day sept (%)	R95pTOT annual (%)	R99pTOT annual (%)
cgcm3-crcm	2.0	42	27	32	70
cgcm3-rcm3	2.2	43	40	22	20
cgcm3-wrfg	1.8	47	37	43	92
ccsm-crcm	2.7	-11	-22	7	-17
ccsm-mm5i	2.0	34	24	15	28
ccsm-wrfg	2.0	23	2	31	57
hadcm3-hrm3	3.0	9	5	14	-3
gfdl-rcm3	1.9	13	12	2	-23
average	2.2	25	16	21	28

Table 5: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year daily temperature return period events, expressed as a ratio of frequency of occurrence in past for Metro Vancouver.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.4	0.3	<.1	2.2	1.9	0.8	2.2	1.9	2.5
cgcm3-rcm3	0.4	0.2	<.1	2.8	3.0	2.5	2.8	3.0	3.3
cgcm3-wrfg	0.4	0.1	<.1	0.9	0.9	1.3	1.7	2.2	3.2
ccsm-crcm	0.2	0.1	<.1	3.1	4.4	6.4	3.1	4.4	6.4
ccsm-mm5i	0.2	<.1	<.1	2.2	1.7	1.0	2.2	1.8	2.9
ccsm-wrfg	0.3	0.2	<.1	2.1	1.8	0.3	2.1	2.0	2.6
hadcm3-hrm3	0.1	<.1	<.1	3.3	4.8	6.9	3.3	4.8	6.9
gfdl-rcm3	0.3	0.1	<.1	2.9	4.2	6.4	2.9	4.2	6.4
average	0.3	0.1	<.1	2.4	2.8	3.2	2.5	3.0	4.3

Table 6: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year daily precipitation return period events, expressed as a ratio of frequency of occurrence in past for Metro Vancouver.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.6	0.1	<.1	2.3	2.5	2.3	2.3	2.5	2.9
cgcm3-rcm3	0.8	0.6	0.3	1.0	0.9	0.5	1.1	1.3	1.7
cgcm3-wrfg	0.8	0.6	0.2	2.8	3.7	4.9	2.8	3.7	4.9
ccsm-crcm	0.7	0.5	0.1	0.7	0.5	0.2	1.2	1.2	1.4
ccsm-mm5i	0.7	0.3	<.1	1.5	1.9	2.4	1.6	1.9	2.4
ccsm-wrfg	0.7	0.2	<.1	2.2	3.0	4.6	2.2	3.0	4.6
hadcm3-hrm3	0.3	0.2	0.2	0.8	1.3	2.4	1.4	2.1	3.9
gfdl-rcm3	0.7	0.4	<.1	1.1	1.6	3.0	1.2	1.6	3.0
average	0.7	0.4	0.1	1.6	1.9	2.5	1.7	2.2	3.1

Table 7: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year 3-hourly precipitation return period events, expressed as a ratio of frequency of occurrence in past for Metro Vancouver.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.8	0.4	<.1	1.9	2.4	3.5	2.2	3.1	4.8
cgcm3-rcm3	0.6	0.2	0.2	2.1	2.5	2.5	2.1	2.5	3.3
cgcm3-wrfg	0.7	0.3	<.1	2.9	3.3	2.9	2.9	3.3	2.9
ccsm-crcm	0.9	0.6	0.2	2.9	4.8	9.3	2.9	4.8	9.3
ccsm-mm5i	0.6	0.3	<.1	2.5	3.2	4.4	2.6	3.2	4.4
ccsm-wrfg	0.6	0.2	0.2	4.2	7.1	15.	4.2	7.1	15.
hadcm3-hrm3	0.6	0.1	0.1	2.2	2.9	4.6	2.2	2.9	4.6
gfdl-rcm3	0.9	0.7	0.5	1.6	1.6	1.0	1.6	1.6	1.7
average	0.7	0.4	0.2	2.5	3.5	5.5	2.6	3.6	5.8

Table 8: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year 3-hourly wind speed return period events, expressed as a ratio of frequency of occurrence in past for Metro Vancouver.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.3	0.1	<.1	1.9	2.2	2.6	1.9	2.2	2.8
cgcm3-rcm3	0.1	<.1	<.1	0.7	1.0	1.9	2.3	3.2	6.1
cgcm3-wrfg	<.1	<.1	<.1	<.1	<.1	<.1	1.6	1.9	3.0
ccsm-crcm	0.3	0.2	<.1	2.1	2.7	3.3	2.1	2.7	3.3
ccsm-mm5i	0.4	0.2	<.1	0.5	0.3	0.2	1.6	2.0	2.9
ccsm-wrfg	<.1	<.1	<.1	<.1	<.1	<.1	1.8	2.2	2.7
hadcm3-hrm3	0.3	0.2	<.1	0.5	0.3	<.1	1.8	1.9	2.7
gfdl-rcm3	0.3	<.1	<.1	0.7	0.6	0.5	2.3	2.9	3.1
average	0.2	0.1	<.1	0.8	0.9	1.1	1.9	2.4	3.3

Table 9: Summary of projected changes for regional average 2050s temperature (°C) in Metro Vancouver.

GCM-RCM	Winter	Spring	Summer	Fall	Annual
cgcm3-crcm	2.6	2.6	2.1	2.2	2.4
cgcm3-rcm3	2.9	4.0	2.2	-0.5	2.2
cgcm3-wrfg	2.6	2.9	2.1	-0.3	1.8
ccsm-crcm	3.0	3.2	3.0	2.4	2.9
ccsm-mm5i	2.4	3.9	1.7	-0.2	2.0
ccsm-wrfg	3.1	4.1	2.2	-0.4	2.3
hadcm3-hrm3	2.4	2.6	3.5	2.2	2.7
gfdl-rcm3	2.3	3.5	1.4	-0.8	1.7
average	2.7	3.3	2.3	0.6	2.2

Table 10: Summary of projected changes for regional average 2050s precipitation (%) in Metro Vancouver.

GCM-RCM	Winter	Spring	Summer	Fall	Annual
cgcm3-crcm	31	18	-1	22	17
cgcm3-rcm3	33	-22	11	82	26
cgcm3-wrfg	37	-3	24	92	37
ccsm-crcm	-16	-11	-11	37	0
ccsm-mm5i	-40	-52	11	114	8
ccsm-wrfg	-14	-50	7	92	8
hadcm3-hrm3	17	-14	-15	30	3
gfdl-rcm3	-13	-11	5	41	6
average	4	-18	4	64	13

A2.2 Capital Regional District

Table 11: Summary of projected changes for regional averages of CLIMDEX indices of extremes in Capital Regional District.

GCM-RCM	TX90p summer (ratio)	RX1day sept (%)	RX5day sept (%)	R95pTOT annual (%)	R99pTOT annual (%)
cgcm3-crcm	2.2	36	21	39	74
cgcm3-rcm3	2.4	51	44	23	40
cgcm3-wrfg	2.2	77	50	27	46
ccsm-crcm	2.9	-10	-12	20	18
ccsm-mm5i	2.4	40	42	21	50
ccsm-wrfg	2.4	35	27	21	26
hadcm3-hrm3	4.9	4	-3	5	-16
gfdl-rcm3	2.1	13	4	2	-36
average	2.7	31	22	20	25

Table 12: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year daily temperature return period events, expressed as a ratio of frequency of occurrence in past for Capital Regional District.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.5	0.2	<.1	2.6	2.4	0.8	2.6	2.4	3.1
cgcm3-rcm3	0.3	0.2	<.1	3.3	4.0	3.4	3.3	4.0	3.4
cgcm3-wrfg	0.4	0.2	<.1	0.8	0.5	0.3	1.9	2.4	3.1
ccsm-crcm	0.3	0.2	0.1	3.9	4.6	4.6	3.9	4.6	4.6
ccsm-mm5i	0.3	<.1	<.1	3.1	2.7	1.3	3.1	2.7	3.1
ccsm-wrfg	0.4	0.1	<.1	2.9	3.7	4.2	2.9	3.7	4.2
hadcm3-hrm3	0.2	0.1	<.1	3.6	5.0	6.6	3.6	5.0	6.6
gfdl-rcm3	0.2	<.1	<.1	3.1	4.8	7.8	3.1	4.8	7.8
average	0.3	0.1	<.1	2.9	3.5	3.6	3.1	3.7	4.5

Table 13: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year daily precipitation return period events, expressed as a ratio of frequency of occurrence in past for Capital Regional District.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.9	0.7	<.1	2.2	2.4	2.8	2.2	2.4	2.8
cgcm3-rcm3	0.9	0.7	0.5	2.5	3.9	6.9	2.5	3.9	6.9
cgcm3-wrfg	0.6	0.2	0.1	2.0	2.3	2.5	2.0	2.3	2.8
ccsm-crcm	0.7	0.3	<.1	2.0	2.2	2.1	2.0	2.2	2.1
ccsm-mm5i	0.7	0.4	0.2	1.9	2.3	2.7	2.2	2.7	3.3
ccsm-wrfg	0.7	0.3	<.1	1.9	1.6	1.1	1.9	1.6	2.3
hadcm3-hrm3	0.5	0.1	<.1	0.9	1.0	1.3	1.5	2.4	4.7
gfdl-rcm3	0.7	0.5	0.1	0.7	0.8	1.0	1.2	1.5	2.2
average	0.7	0.4	<.1	1.8	2.1	2.6	1.9	2.4	3.4

Table 14: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year 3-hourly precipitation return period events, expressed as a ratio of frequency of occurrence in past for Capital Regional District.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.5	0.2	<.1	1.9	2.1	2.2	1.9	2.1	3.0
cgcm3-rcm3	0.6	0.1	0.1	2.6	4.0	7.1	2.6	4.0	7.1
cgcm3-wrfg	0.8	0.5	0.2	1.8	2.0	2.1	1.8	2.0	2.3
ccsm-crcm	0.4	0.3	<.1	3.3	5.6	9.6	4.2	6.7	10.9
ccsm-mm5i	0.6	0.2	<.1	2.6	3.7	6.9	3.3	5.0	8.6
ccsm-wrfg	0.7	0.3	<.1	2.9	3.7	6.4	2.9	4.4	6.9
hadcm3-hrm3	0.6	0.2	0.1	1.7	1.9	2.0	1.7	1.9	2.5
gfdl-rcm3	0.6	0.1	<.1	0.9	0.9	0.9	1.3	1.9	3.1
average	0.6	0.2	<.1	2.2	3.0	4.7	2.5	3.5	5.6

Table 15: Summary of projected regional median change in future frequency of occurrence of historical 5, 10, and 25-year 3-hourly wind speed return period events, expressed as a ratio of frequency of occurrence in past for Capital Regional District.

GCM-RCM	Lower bound			Return period			Upper Bound		
	5	10	25	5	10	25	5	10	25
cgcm3-crcm	0.1	<.1	<.1	0.9	1.2	2.1	1.8	2.4	3.7
cgcm3-rcm3	0.4	0.1	<.1	1.0	1.2	1.6	1.9	2.1	3.2
cgcm3-wrfg	0.3	<.1	<.1	0.9	1.1	1.5	1.9	2.3	3.5
ccsm-crcm	0.3	<.1	<.1	1.4	1.5	1.6	1.8	2.1	2.6
ccsm-mm5i	0.3	0.1	<.1	1.2	1.0	0.4	1.9	2.3	2.7
ccsm-wrfg	0.3	0.1	<.1	1.3	1.6	2.2	1.9	2.3	3.4
hadcm3-hrm3	0.1	0.1	<.1	0.8	1.0	1.5	1.7	2.3	3.4
gfdl-rcm3	0.2	<.1	<.1	1.1	1.2	1.3	1.9	2.2	3.2
average	0.2	0.1	<.1	1.1	1.2	1.5	1.8	2.3	3.2

Table 16: Summary of projected changes for regional average 2050s temperature (°C) in Capital Regional District.

GCM-RCM	Winter	Spring	Summer	Fall	Annual
cgcm3-crcm	2.6	2.1	2.0	2.0	2.2
cgcm3-rcm3	2.6	3.6	2.1	-0.3	2.0
cgcm3-wrfg	2.0	2.6	2.1	0.1	1.7
ccsm-crcm	2.8	2.6	3.0	2.4	2.7
ccsm-mm5i	2.1	3.5	2.0	0.1	1.9
ccsm-wrfg	2.3	3.5	2.3	-0.3	2.0
hadcm3-hrm3	2.2	2.3	3.6	2.4	2.6
gfdl-rcm3	2.2	3.2	1.5	-0.7	1.6
average	2.4	2.9	2.3	0.7	2.1

Table 17: Summary of projected changes for regional average 2050s precipitation (%) in Capital Regional District.

GCM-RCM	Winter	Spring	Summer	Fall	Annual
cgcm3-crcm	20	20	-4	16	13
cgcm3-rcm3	3	-4	3	38	10
cgcm3-wrfg	2	4	6	47	15
ccsm-crcm	-2	-12	-7	24	1
ccsm-mm5i	-12	-27	-2	57	4
ccsm-wrfg	-17	-27	-2	53	2
hadcm3-hrm3	14	-7	-8	14	2
gfdl-rcm3	-5	-4	-6	13	-1
average	0	-7	-2	33	6

Appendix 3 – Station-based analysis

A3.1 About station data

Observations were obtained from weather stations through Environment Canada's Canadian Daily Climate Data (CDCD) repository. Each station was evaluated to ensure it possessed a record as complete as possible from 1951-2010. In addition to standard temperature and precipitation observations, a number of temperature and precipitation based indices were calculated to assist with interpretation of how changes in daily temperature and precipitation climatologies may affect different stakeholders in the Georgia Basin. These parameters include quantities such as Growing Degree Days, Cooling Degree Days and Wet Days among others. At each of the stations, trends were fitted to each of the observed quantities' time series using Zhang's method of slope estimation (Zhang et al. 2000) and the statistical significance of each trend for the 5% significance level was computed. Due to the existence of fewer weather stations possessing complete records of daily temperature observations, analysis of temperature and temperature related indices were only calculated at 12 stations, instead of at 23 stations as was the case for precipitation.

Overall the trends in the various temperature-based indices can be traced back to the long-term increasing trend in daily temperatures over the 60 years of 1951-2010. The trends with the largest magnitudes typically occur at stations with the highest elevations (e.g. Grouse Mountain) or stations somewhat further from the ocean (e.g. Surrey Newton). Precipitation trends display much weaker trajectories over the latter half of the 20th century, primarily due to the greater variability in the observational records. While small to moderate trends are present at some sites, few of these are statistically significant at the 5% significance level.

Weather stations were chosen based on length of the observational record and completeness of the data as defined by the World Meteorological Organization (WMO) code, which measures how many years of data are missing. Stations from each region were selected if they possessed observations at least between 1971 and 2000, were assigned a WMO of 'B' or higher, and recorded all precipitation and/or temperature variables.

The weather station analysis was conducted to illustrate the climatological conditions in Metro Vancouver and the Capital Regional District during the recent past. It serves as a point of reference for the projected changed generated by the global and regional climate model simulations. The station analysis and choices of stations used does not influence the projected changes according to GCMs or RCMs in any way as the climate models are not based on extrapolation from station observations. See (Murdock and Spittlehouse 2011) for more information on using results from climate models.

It is also possible to use gridded historical data to assess the ability of the RCMs to simulate the historical climate (Murdock and Sobie 2012) although that type of analysis was beyond the scope of the current study.

A3.2 Climatology – Metro Vancouver

Table 18: Summary of 1971-2000 historical averages of CLIMDEX indices in Metro Vancouver.

Station	TX90p summer (°C)	R95pTOT annual (%)	R99pTOT annual (%)	RX1day sept (%)	RX5day sept (%)
delta_beach	NA	178	49	14	26
van_intl	23.2	227	68	22	38
seymour_falls	NA	884	264	59	119
cleveland	NA	504	151	39	71
grouse	20.0	622	189	55	99
narrows	NA	388	114	31	54
wharves	NA	368	109	29	53
muni_hall	24.6	272	75	22	38
newton	24.5	283	81	23	42
van_harbour	23.3	347	105	25	44

Table 19: Summary of historical (1971-2000) 5, 10, and 25-year return levels at stations in Metro Vancouver for daytime high temperature and daily precipitation.

Station	Temperature (°C)			Precipitation (mm)		
	5	10	25	5	10	25
delta_beach	NA	NA	NA	44	49	52
van_intl	30.7	31.5	32	67	78	87
seymour_falls	NA	NA	NA	211	260	301
cleveland	NA	NA	NA	120	134	143
grouse	31.6	32.5	33	142	153	159
narrows	NA	NA	NA	97	108	115
wharves	NA	NA	NA	86	99	108
muni_hall	34	34.5	34.7	73	85	95
newton	34.8	34.9	35	70	80	88
van_harbour	31.5	32.1	32.4	95	121	145

Table 20: Summary of 1971-2000 temperature (°C) for stations in Metro Vancouver.

Station	Winter	Spring	Summer	Fall	Annual
delta_beach	5.2	10.4	17.3	11.3	11
van_intl	3.9	9.3	16.8	10.3	10.1
seymour_falls	NA	NA	NA	NA	NA
cleveland	NA	NA	NA	NA	NA
grouse	-0.8	3.4	12.1	5.9	5.2
narrows	NA	NA	NA	NA	NA
wharves	NA	NA	NA	NA	NA
muni_hall	3.7	9.5	16.7	10.6	10.1

newton	3.6	9.4	16.6	10.2	10
van_harbour	5	10	17.3	11	10.8

Table 21: Summary of 1971-2000 precipitation (mm) for stations in Metro Vancouver.

Station	Winter	Spring	Summer	Fall	Annual
delta_beach	341	187	102	277	912
van_intl	444	240	122	348	1154
seymour_falls	1491	805	347	1247	3881
cleveland	910	522	252	716	2360
grouse	789	533	354	815	2508
narrows	707	387	184	562	1834
wharves	649	377	181	533	1747
muni_hall	483	292	146	395	1310
newton	532	302	159	415	1409
van_harbou	571	328	155	449	1513

A3.3 Climatology - Capital Regional District

Table 22: Summary of 1971-2000 historical averages of CLIMDEX indices in Capital Regional District.

Station	TX90p summer (°C)	RX1day sept (mm)	RX5day sept (mm)	R95pTOT annual (mm)	R99pTOT annual (mm)
shawnigan	24.9	14	27	287	85
vic_intl	23.3	12	23	200	62
gonzales	21.0	11	19	151	53
sooke_lake_n	NA	16	31	359	110

Table 23: Summary of historical (1971-2000) 5, 10, and 25-year return levels at stations in Capital Regional District for daytime high temperature and daily precipitation.

Station	Temperature (°C)			Precipitation (mm)		
	5	10	25	5	10	25
shawnigan	34.7	35.3	35.6	82	93	101
vic_intl	32.3	32.6	32.8	68	78	86
gonzales	33.1	33.8	34.2	82	93	101
sooke_lake_n	NA	NA	NA	104	119	129

Table 24: Summary of 1971-2000 temperature (°C) for stations in Capital Regional District.

Station	Winter	Spring	Summer	Fall	Annual
shawnigan	3.2	8.5	16.6	9.9	9.5
vic_intl	4.3	8.9	15.8	10	9.7
gonzales	5.3	9.5	15.1	10.8	10.2
sooke_lake_n	NA	NA	NA	NA	NA

Table 25: Summary of 1971-2000 precipitation (mm) for stations in Capital Regional District.

Station	Winter	Spring	Summer	Fall	Annual
shawnigan	564	222	87	360	1232
vic_intl	393	152	73	260	878
gonzales	288	103	54	206	643
sooke_lake_n	661	281	95	438	1483

A3.4 Temperature Parameters

A3.4.1 Extreme Temperature

Extreme maximum and minimum temperatures represent the annual average of the highest and lowest temperatures recorded each month, and differ from the maximum or minimum temperature parameters that represent the monthly average of daily extreme temperatures. Throughout the Georgia Basin, all of the weather stations recorded positive, statistically significant trends in extreme maximum temperature (except for Shawnigan Lake) with most stations experiencing increases of 0.2°C to 0.4°C per decade. The largest trend at 0.7°C per decade was recorded at the Grouse Mountain (highest elevation) station, while the lowest was at Vancouver International Airport with a 0.2°C per decade increase. Extreme minimum temperature also increased at all of the selected stations, though a different pattern in the magnitude of the trends was observed. The largest trend in extreme minimum temperature was 0.7°C per decade at Surrey Newton whereas the rest of the stations recorded trends ranging from 0.2°C per decade to 0.4°C per decade, with the trend at Victoria International Airport not significant.

A3.4.2 Mean Temperature

Mean temperature or simply the daily average recorded temperature also experienced positive trends at all stations in the basin. In this case the range of values was narrower, with most stations observing increases of 0.2°-0.3°C per decade, which was the case at all of the stations on Vancouver Island (Figure 21). The largest trends occurred at Grouse Mountain and Surrey Newton, both of which experienced increases in mean temperature of 0.5C° per decade (Figure 22).

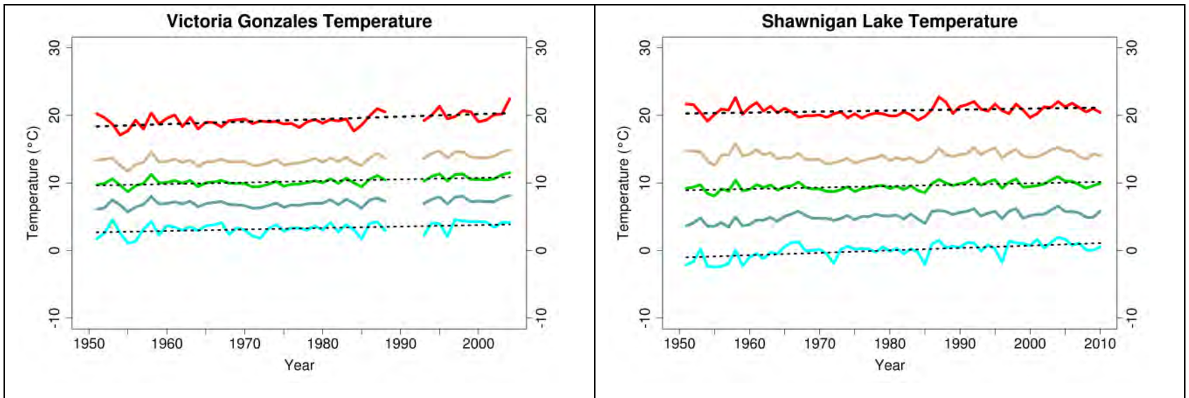


Figure 21: Annual mean temperatures for selected stations on southern Vancouver Island. Each of the lines in the graph represents temperature levels. From top to bottom: Extreme monthly maximum, average monthly maximum, mean, average monthly minimum and extreme monthly minimum temperatures. All stations and temperature levels possess positive, increasing trends.

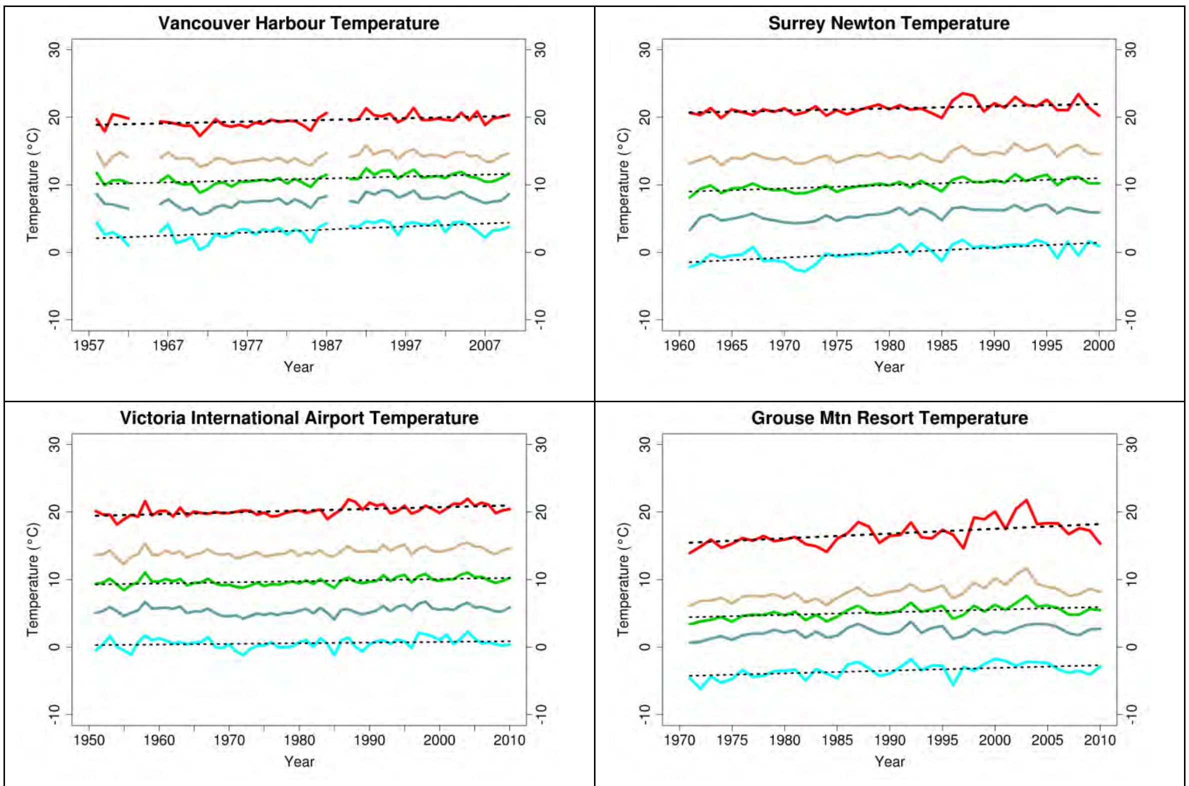


Figure 22: Annual mean temperatures for selected Metro Vancouver weather stations. Same layout as the previous figure.

A3.4.3 Growing Degree Days

Over the past 60 years growing degree days have steadily increased in amount following long-term increases in temperature observed at all of the weather stations in southwestern BC. On Vancouver Island GDD values have grown by 50-70 GDD per decade with the greatest increase seen at Victoria Gonzales.

Similar trends were recorded at mainland stations, with notable exceptions at Grouse Mountain (a not statistically significant increase of 23 GDD per decade) and a much larger trend at Surrey Newton (110 GDD per decade).

A3.4.4 Heating Degree Days

Heating Degree Days experienced a decreasing trend at all stations over the latter half of the 20th century, except for the station at Vancouver Harbour (whose positive trend of 22 HDD per decade was not statistically significant). Declining trends ranged from 50 HDD per decade to decreases of 210 HDD per decade at Surrey Newton and 300 HDD per decade at Grouse Mountain. Stations on Vancouver Island displayed fairly consistent downward trends of 60-80 HDD per decade at all sites.

In the case of Vancouver Harbour, the unusual upward trend may be the result of an anomalous decrease in HDD values during the 1960's to 1970's that is not observed at any other site.

A3.4.5 Cooling Degree Days

Cooling Degree Days have grown in number over the last 60 years as illustrated by increasing trends in their numbers at all stations in southwestern BC. On Vancouver Island cooling degree days varied considerably by station. Generally larger trends were recorded on the mainland, with increasing trends of 4-13 CDD per decade observed with most stations experiencing trends above 6 CDD per decade. Surrey Newton saw the largest increase of 13 CDD per decade. In many cases, the initial values of cooling degree days in the beginning of the record (1950's) were small (e.g. <20 CDD annually at Victoria Gonzales). As a result of the increasing temperature trends, CDD values have nearly doubled at several stations and increased relatively substantially at most others.

A3.4.6 Cold Days

Cold Days describe the relatively rare (in southwestern BC at least) days when daily maximum temperature does not exceed 0°C. Several of the weather stations with complete temperature records observed few instances of these events(~ 4 per year) with some years recording no cold days at all. This was primarily the case at low elevation stations such as the airports. In contrast, the cooler average temperatures at Grouse Mountain Resort resulted in over 50 cold days per year in the early part of the observed record.

All of the weather stations except for Grouse Mountain experienced trends in cold days that were either constant or displayed small decreasing trends, which was not surprising given how few days there were initially. The station at Grouse Mountain (with the highest initial number of annual cold days at > 50 Cold Days per year) recorded the most significant declining trend of 6.4 Cold Days per decade. Given the elevation of this site, its proximity to the freezing level and the surrounding regions' importance for water storage as snow, this trend could have significant implications for water resources in Metro Vancouver.

A3.4.7 Summer High Temperature

Summer high temperatures saw across the board increasing trends at all stations examined with the largest trends observed at Victoria Gonzales (0.4°C per decade), and Grouse Mountain (0.7°C per decade). Other stations experienced still substantial trends of 0.2°C to 0.5°C per decade over the same period.

A3.4.8 January Low Temperature

A similar pattern as that of Summer High Temperature occurs with the all positive trends and the largest increases at Grouse Mountain (0.8°C per decade). Most of the other stations recorded positive trends of 0.3°C to 0.5°C per decade with the increases generally being 0.1°C per decade larger than those observed for Summer High Temperature. Some of the sites at lower elevations (Victoria and Vancouver International Airports) reported statistically insignificant trends, though the occurrence of very cold average temperatures was much less frequent during the later part of the record.

A3.4.9 Frost Free Period

Frost Free Period length is directly linked to daily minimum temperature and follows a similar increasing trend observed in that quantity. Frost Free Period length increased at all stations over the last 60 years, with the largest increases observed at Grouse Mountain (9.5 days per decade) and Surrey Newton (11.2 days per decade). Most of the other stations recorded increasing trends of 6-7 days per decade, though Victoria International Airport saw only a 0.8 days per decade growth in frost free period. This smaller increase may be due to a warm period during the 50's and 60's where frost free period length rose for a brief interval.

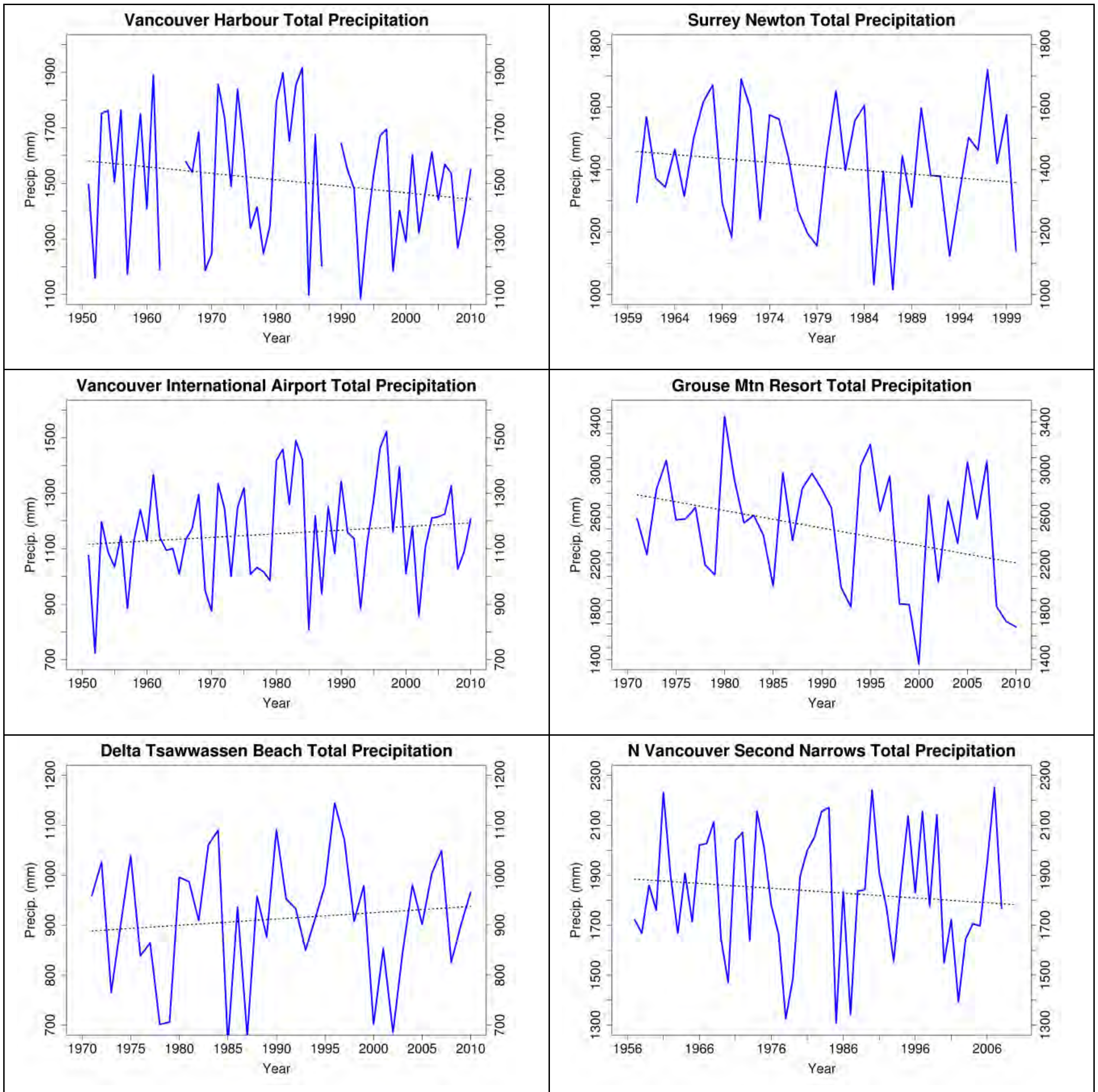


Figure 23: Annual total precipitation from selected stations in Metro Vancouver. Note that none of the trends in these plots are statistically significant.

Shawnigan Lake

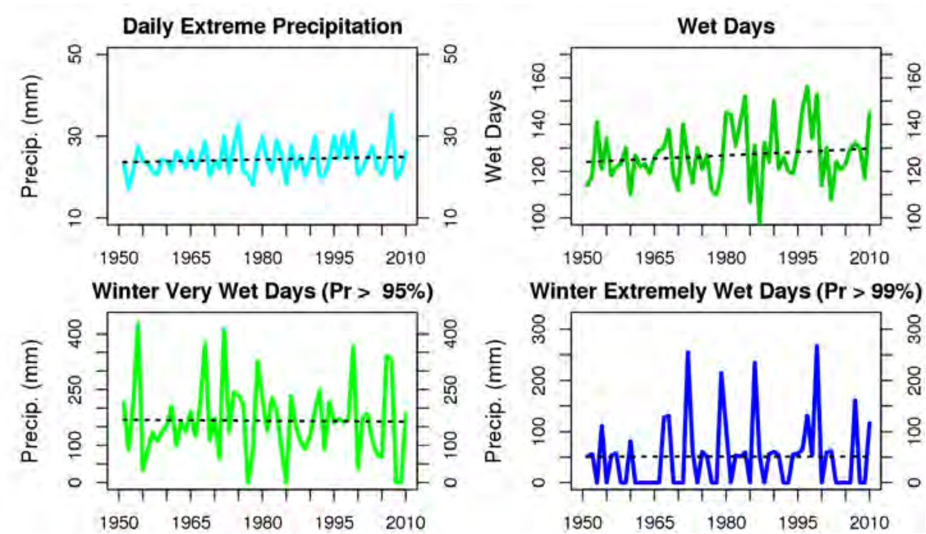


Figure 24: Shawnigan Lake precipitation parameters. Same layout as the previous figure and again none of the trends is statistically significant.

Victoria Gonzales

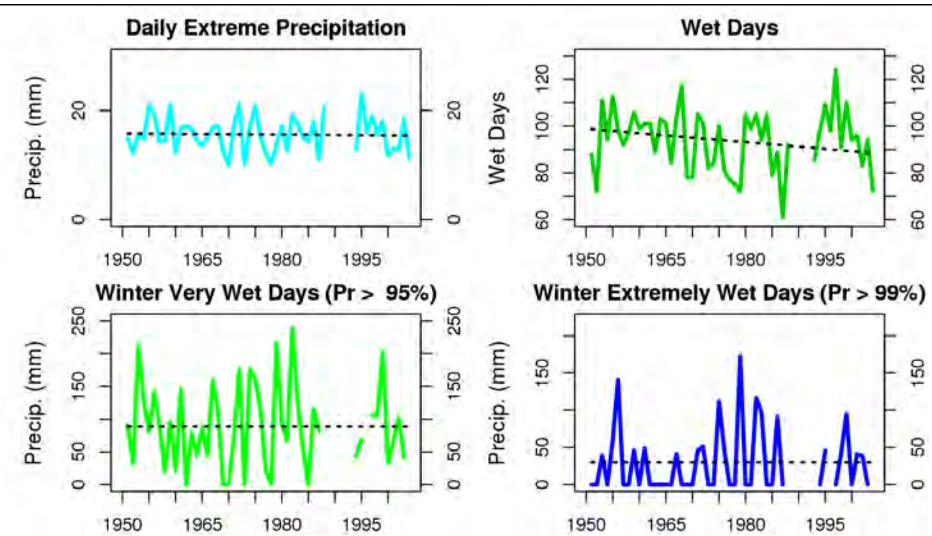


Figure 25: Victoria Gonzales precipitation parameters. Same layout as the previous figure and again none of the trends is statistically significant.

Vancouver Harbour CS

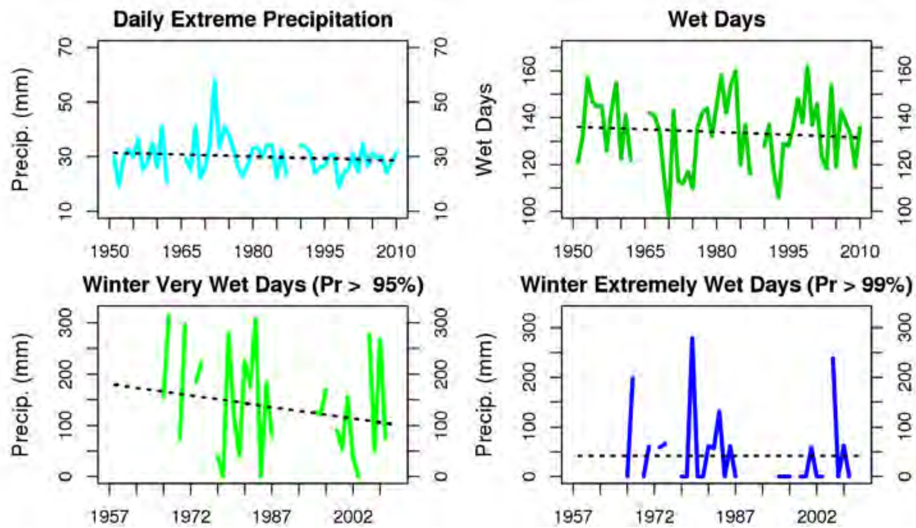


Figure 26: Vancouver Harbour precipitation parameters. Same layout as the previous figure and again none of the trends is statistically significant.

Surrey Newton

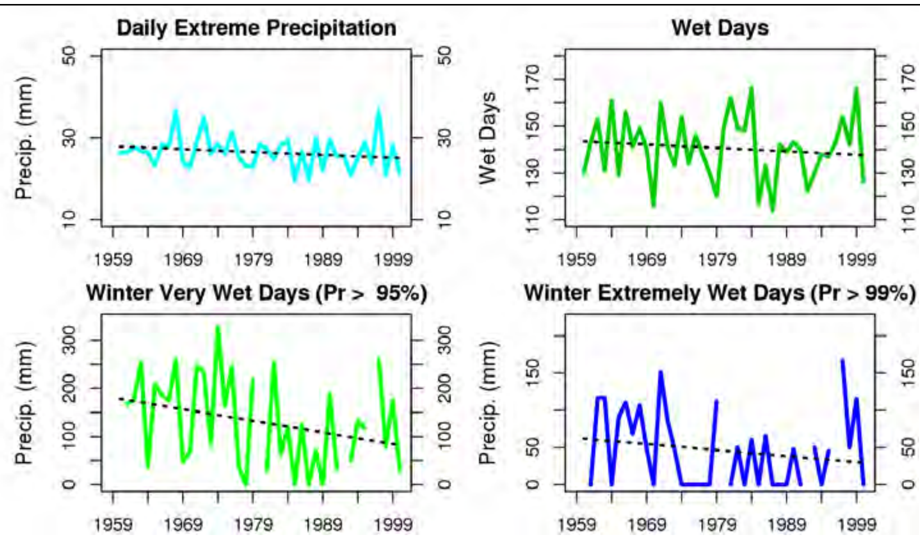


Figure 27: Surrey Newton precipitation parameters. Same layout as the previous figure and again none of the trends is statistically significant.

Grouse Mountain Resort

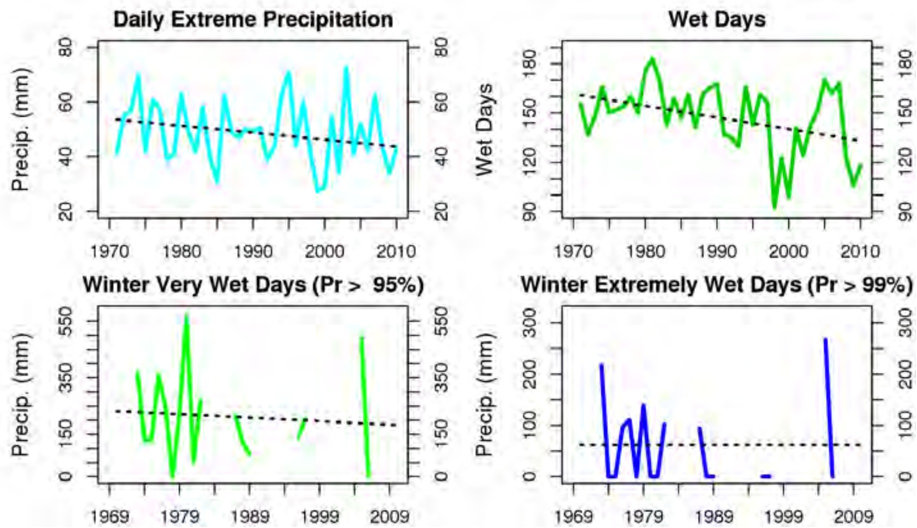


Figure 28: Grouse Mountain Resort precipitation parameters. Same layout as the previous figure and again none of the trends is statistically significant.

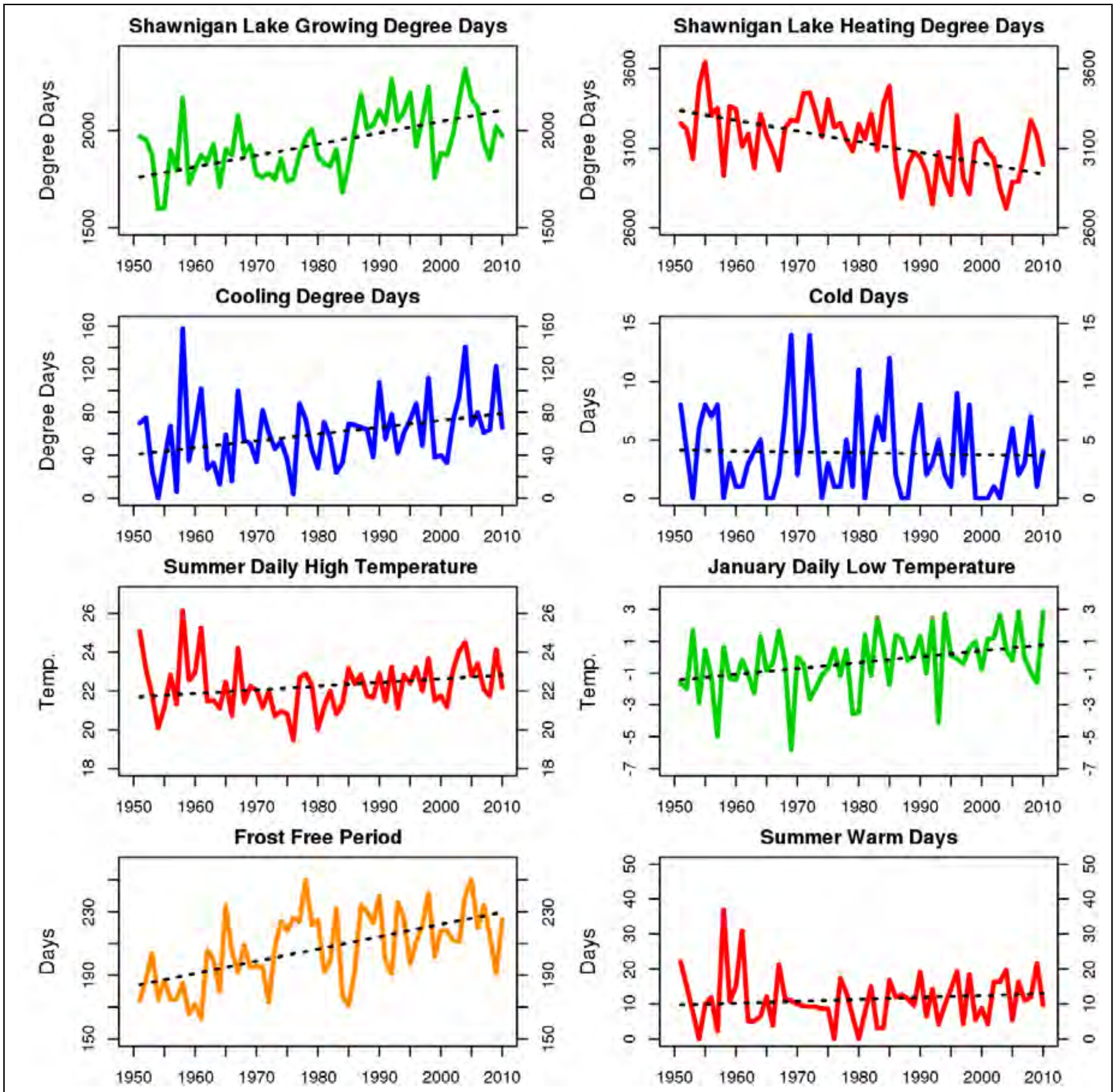


Figure 29: Shawnigan Lake temperature-based parameters.

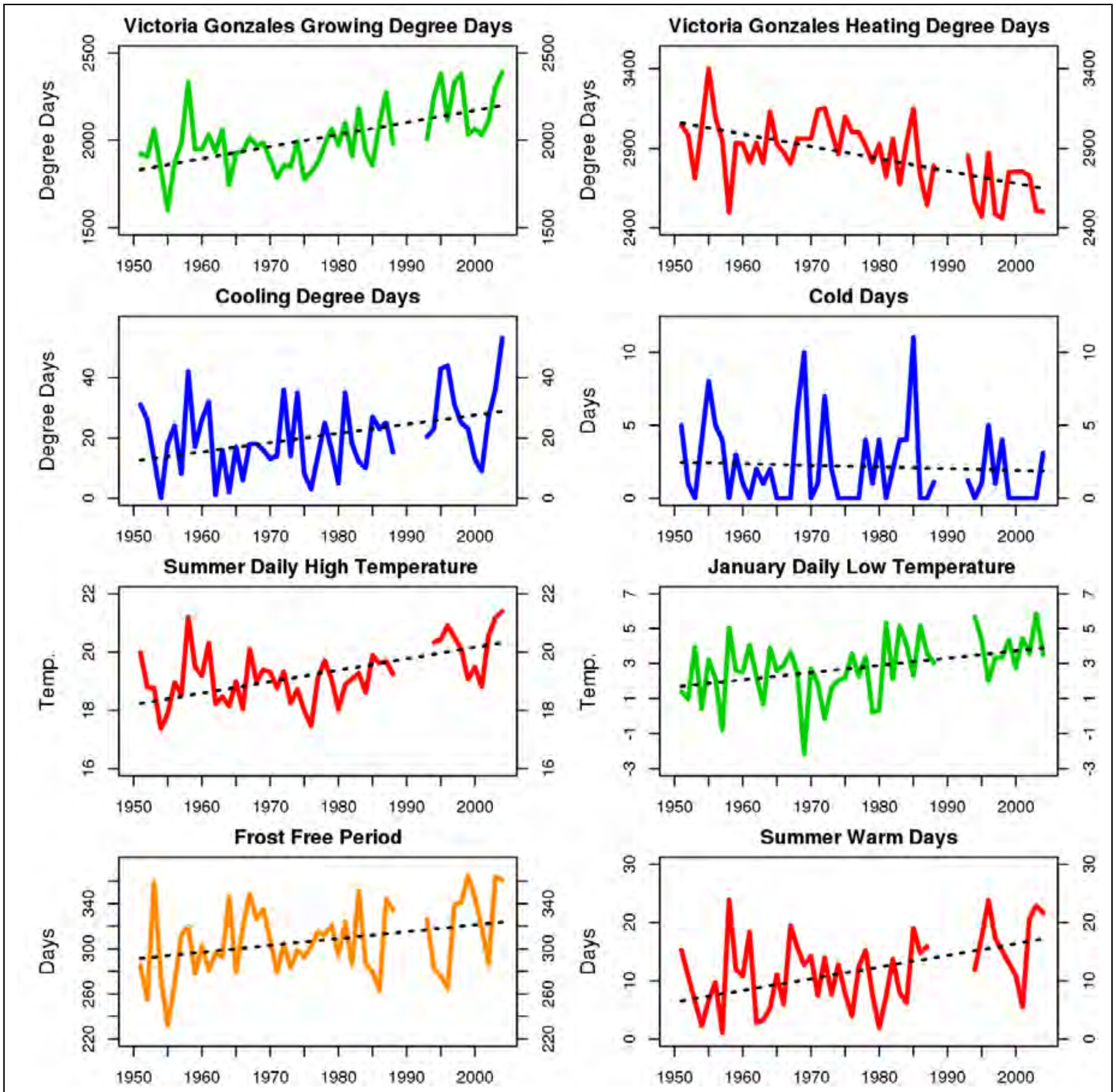


Figure 30: Victoria Gonzales temperature-based parameters.

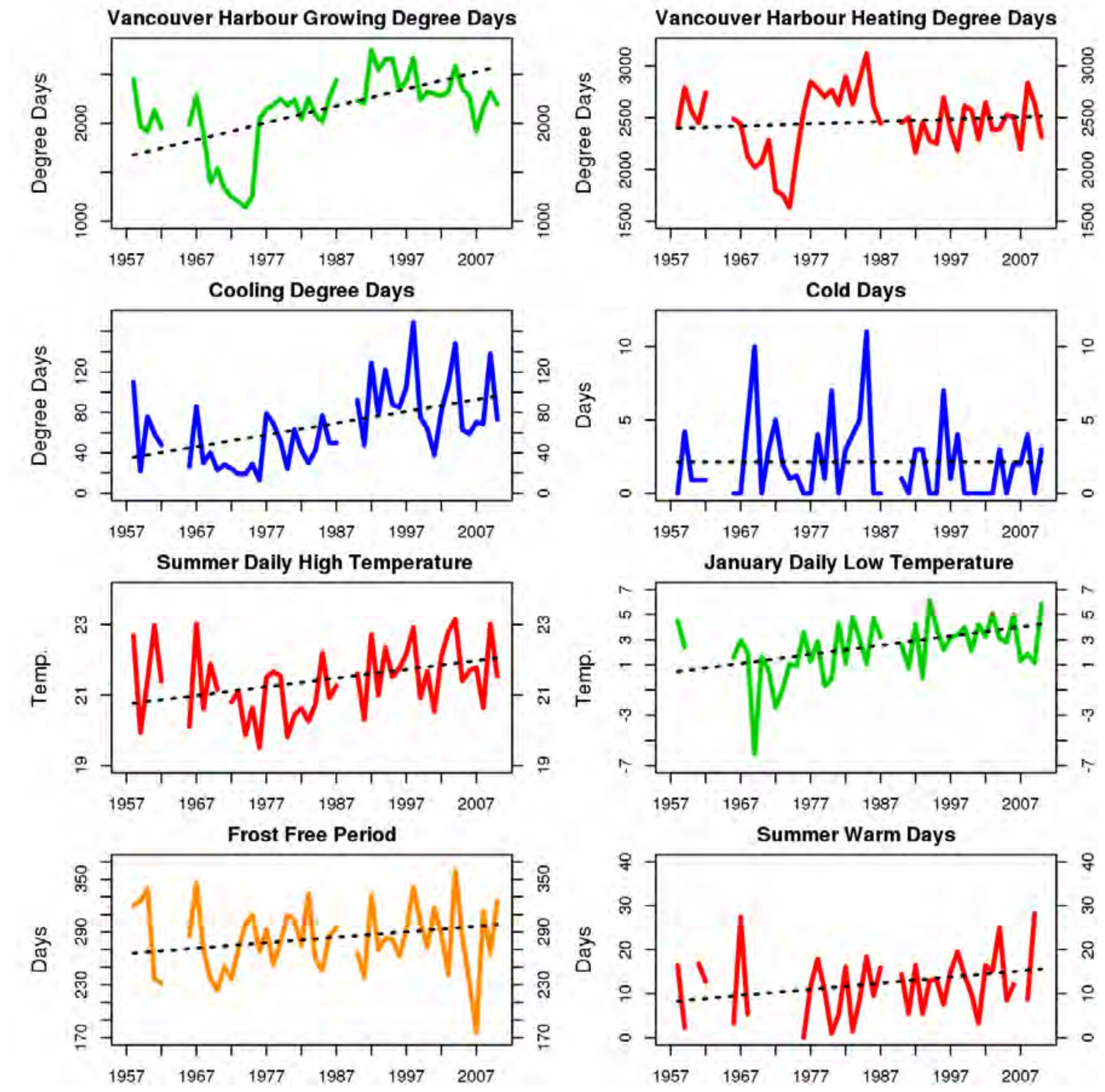


Figure 31: Vancouver Harbour temperature-based parameters.

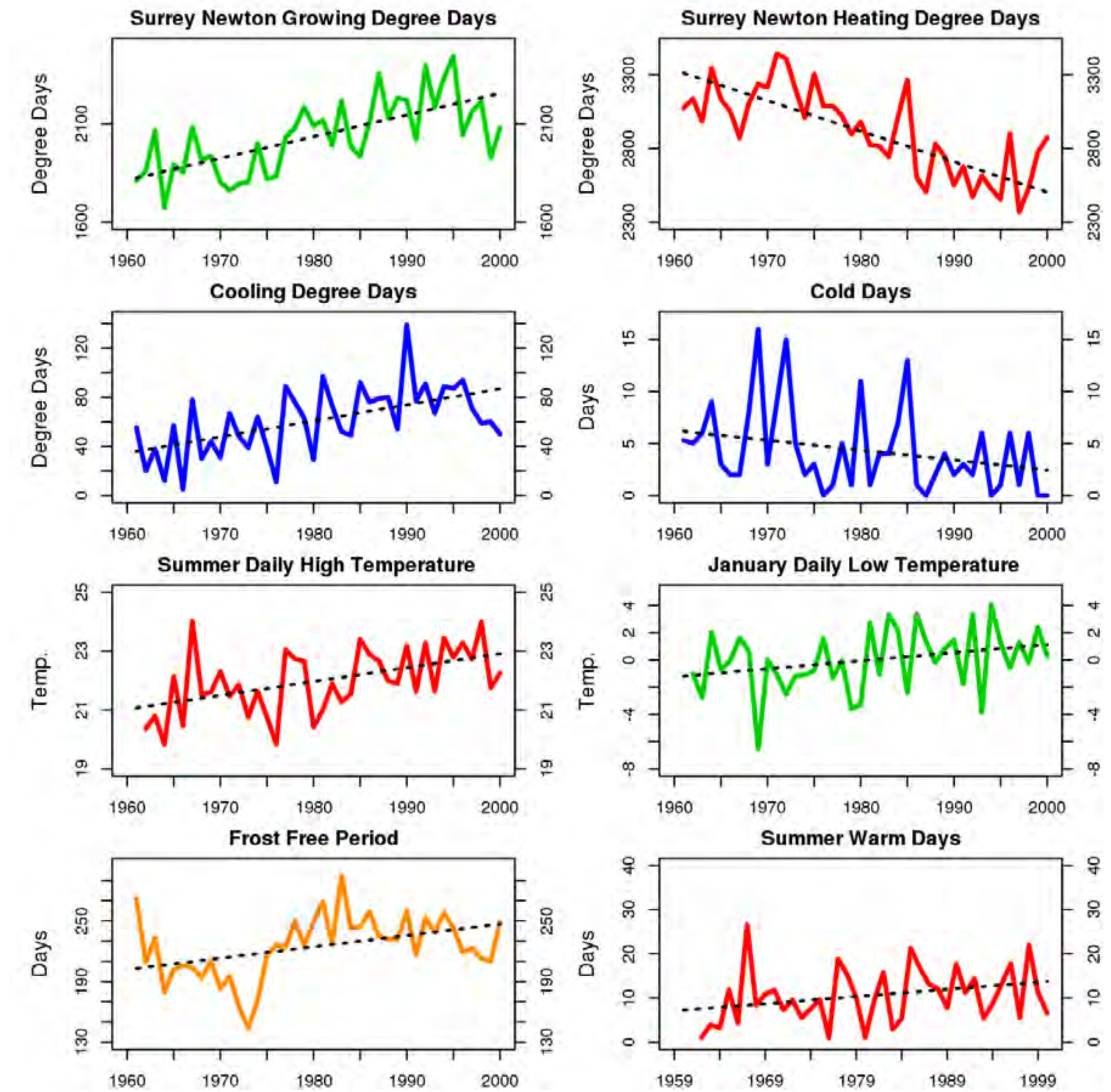


Figure 32: Surrey Newton temperature-based parameters.

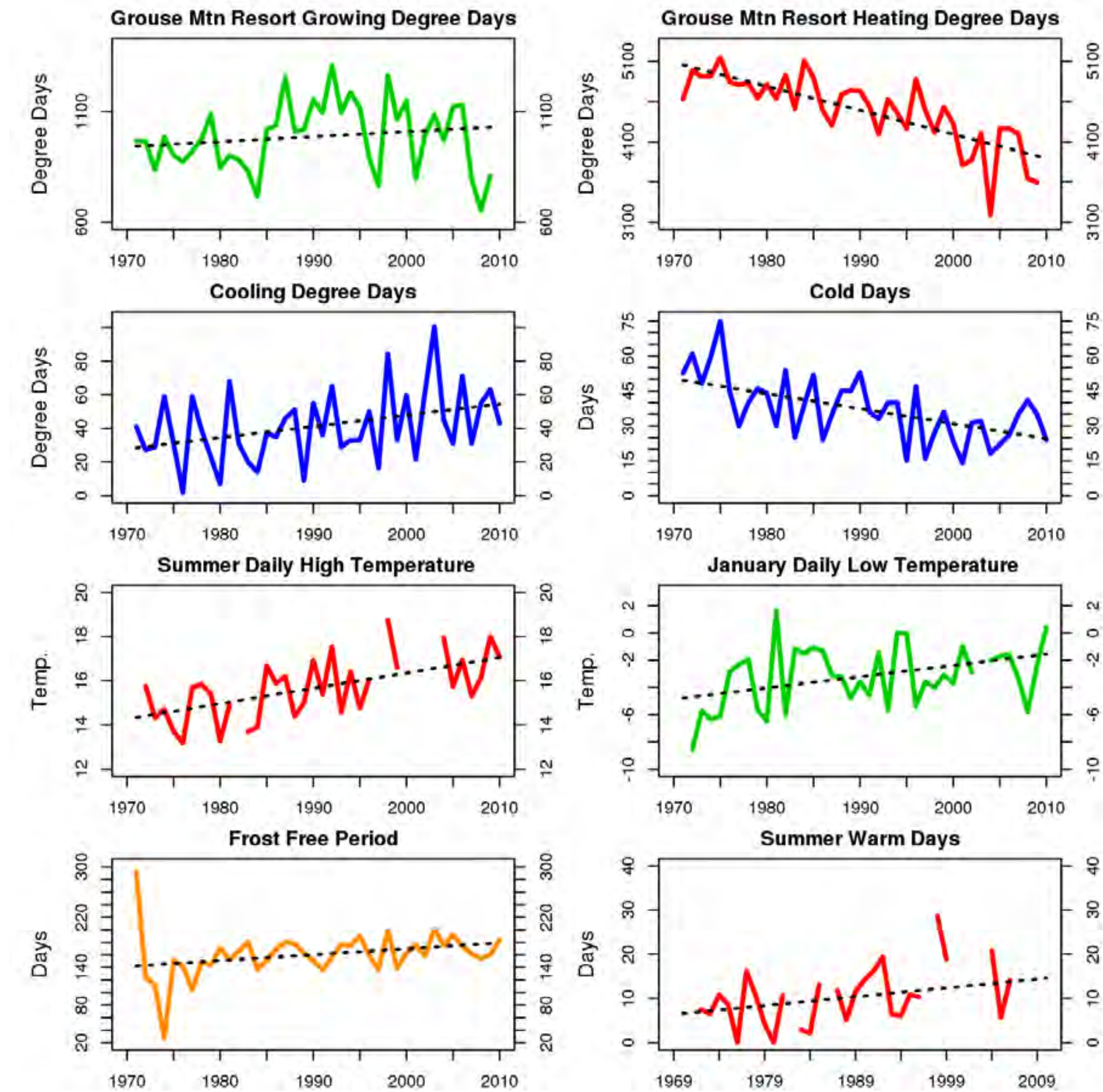
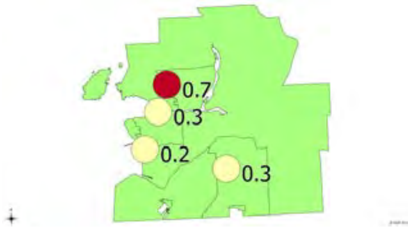
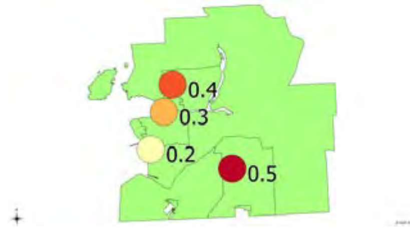


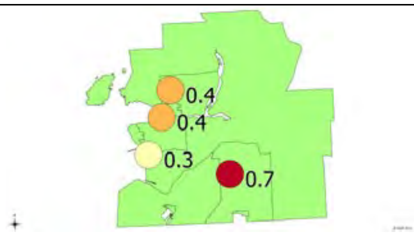
Figure 33: Grouse Mountain Resort temperature-based parameters.



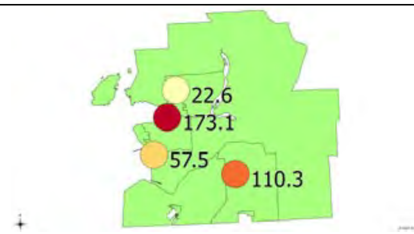
Extreme Maximum Temp. (°C per decade)



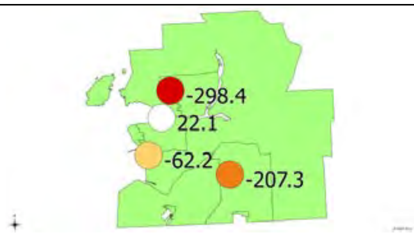
Mean Temperature (°C per decade)



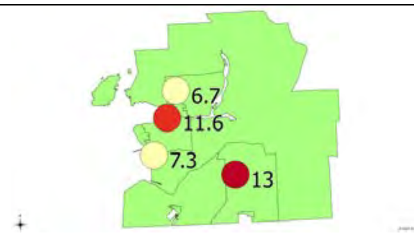
Extreme Minimum Temp. (°C per decade)



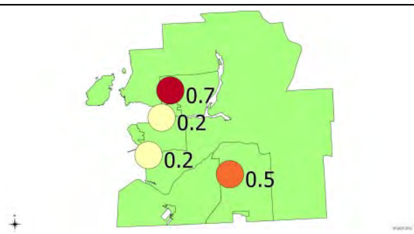
Growing Degree Days (GDD per decade)



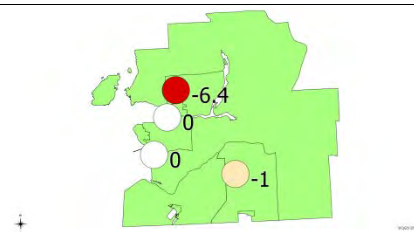
Heating Degree Days (HDD per decade)



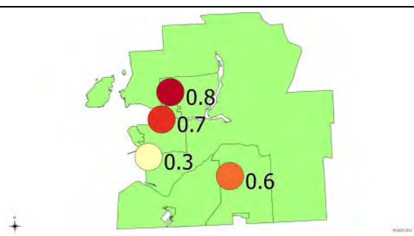
Cooling Degree Days (CDD per decade)



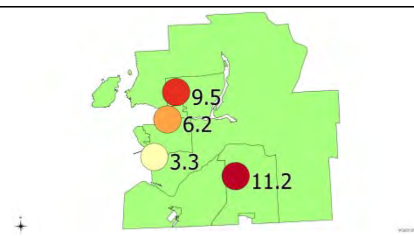
Summer High Temp. (°C per decade)



Cold Days (Days per decade)

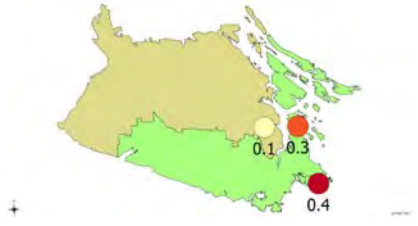


January Low Temp. (°C per decade)

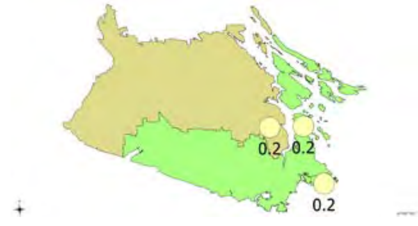


Frost Free Days (Days per decade)

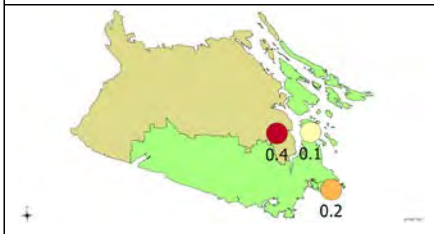
Figure 34: Trends in temperature-based parameters for weather stations in Metro Vancouver. The stations from north to south are: Grouse Mountain Resort, Vancouver Harbour, Vancouver International Airport and Surrey Newton.



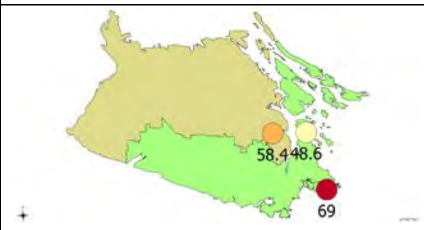
Extreme Maximum Temp. (°C per decade)



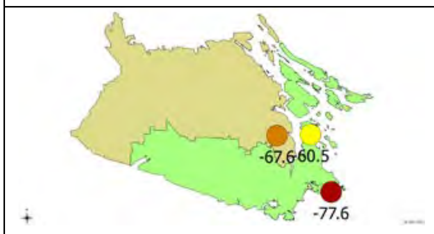
Mean Temperature (°C per decade)



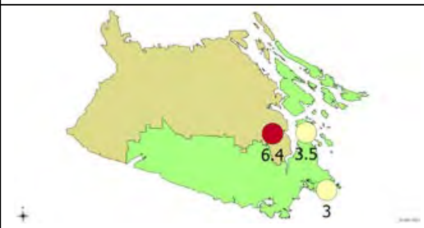
Extreme Minimum Temp. (°C per decade)



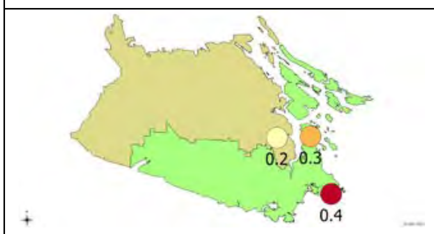
Growing Degree Days (GDD per decade)



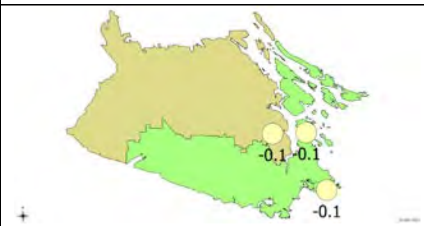
Heating Degree Days (HDD per decade)



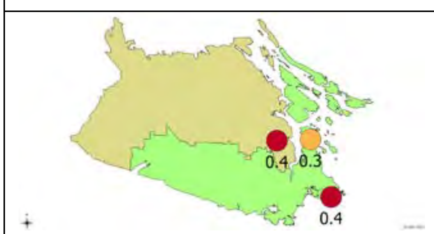
Cooling Degree Days (CDD per decade)



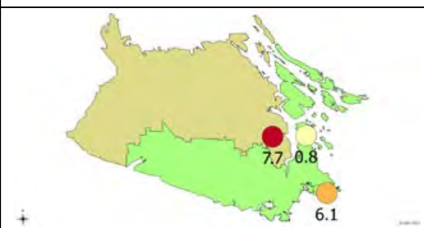
Summer High Temp. (°C per decade)



Cold Days (Days per decade)



January Low Temp. (°C per decade)



Frost Free Days (Days per decade)

Figure 35: Trends in temperature-based parameters for weather stations on Vancouver Island. The stations from west to east are: Shawnigan Lake, Victoria International Airport and Victoria Gonzales.

A3.5 Precipitation Parameters

While observed precipitation underwent substantial changes over the 60-year record at some sites within the Georgia Basin, few stations displayed statistically significant trends over the period of 1951-2010. This was due to the relatively small changes in precipitation at most of the weather stations coupled with the much more variable nature of precipitation statistics compared to those of temperature related parameters. As a result, only one or two stations have clearly significant trends. In the case of the others, the small shifts could be significant over longer time intervals and their trends could increase in response to the effects of climate change.

A3.5.1 Precipitation Total

Vancouver Island experienced increases in annual total precipitation (with variable trends) at all stations except for Victoria Gonzales. The most southerly site of the region, Gonzales saw a decline of 17 mm/decade during the latter half of the 20th century while the other stations on the island saw positive trends though none were statistically significant at the 5% level (Figure 36).

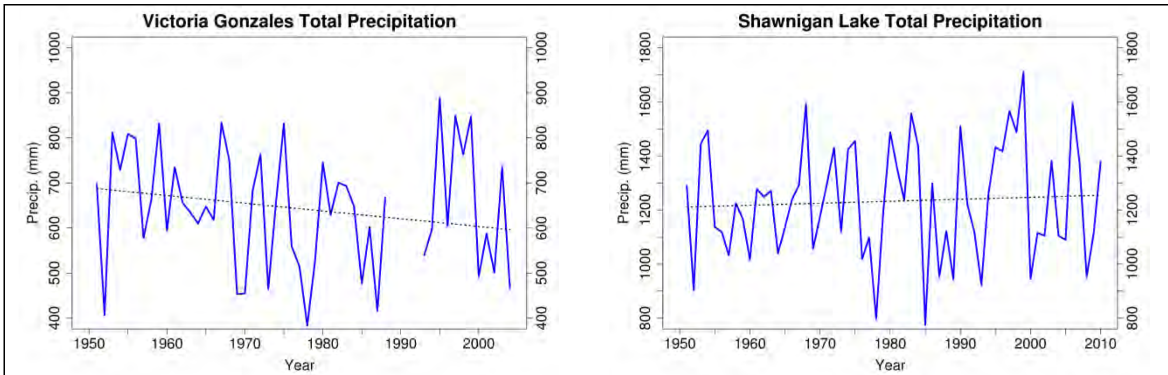


Figure 36: Annual total precipitation for selected Vancouver Island weather stations.

On the mainland, south of Burrard Inlet, there was a west to east gradient in the annual precipitation total trend with increasing values observed in Delta and decreasing trends observed in Surrey and to the east. The more northerly stations also experienced declining precipitation intensity with the greatest decreases experienced at the higher station of Grouse Mountain (-147 mm/decade). In contrast to these substantial declines, Delta Tsawwassen Beach recorded an increasing trend in annual precipitation of 12 mm/decade, similar to the trend observed at Vancouver International Airport. The nearby station of Delta Ladner South recorded the largest trend at 150 mm/decade; however the short length of this record suggests that this site's trend may be influenced by short-term variability more strongly than the other sites possessing longer records.

A3.4.2 Wet Days

Wet Days, precipitation occurrence, or days with measured precipitation exceeding 1 mm, displayed a range of long-term trends both positive and negative. On Vancouver Island the trends in precipitation occurrence were small, with little change in the annual totals from 1951-2010. Victoria Gonzales and Victoria International Airport saw overall decreasing trends of 2 days/decade and 1.1 days/decade, respectively. Across Saanich Inlet, Shawnigan Lake recorded a small increasing trend of 1 day/decade. In Metro Vancouver trends in precipitation occurrence followed a similar pattern to precipitation intensity trends, with some exceptions. Surrey and the North Shore stations experience declines in wet days with decreases ranging from -1 day/decade to -7 days/decade. Stations in Delta and the airport saw increases in precipitation intensity mostly in the range of 1-3 days/decade, while sites in the city of Vancouver recorded small declining trends of 0-5 days/decade.

The sites with opposite trends in precipitation intensity and occurrence are: Victoria International Airport, Haney East, Seymour Falls, North Vancouver Wharves and Vancouver City Hall.

A3.4.3 Climdex R95p

Extremes in precipitation were examined using climatological indices from the suite of CLIMDEX values designed to represent statistics of significant meteorological events. Moderate extremes in precipitation were represented by R95p and R99p, which is defined as the amount of precipitation that occurs above the 95^{th} and 99^{th} percentiles of daily precipitation. The observations in R95p displayed trends similar to precipitation total, however there was a greater range of values in the magnitudes of the trends, particularly at stations in close proximity. No significant trends were observed in R99p, with the majority of the stations recording constant amounts of precipitation of the 99^{th} percentile.

Vancouver Island recorded small decreasing trends in R95p at its three most easterly sites (Shawnigan Lake, Victoria International Airport, Victoria Gonzales), while a large decreasing trend was observed at Sooke Lake North. It should be noted however, that the trend at Sooke Lake North is not significant given the variability of the trend and the negligible trend at Shawnigan Lake, which possesses a longer record may be more accurate.

On the mainland, Surrey and eastern Metro Vancouver stations are again uniformly negative in their observed reductions of extreme precipitation, with declines of 25 mm/decade to 33 mm/decade. Elsewhere in the region the trends are more mixed, with similar but opposing trends at Grouse Mountain (-12mm/decade) and North Vancouver (+12mm/decade), positive and negative trends in Delta (+15 mm/decade and -5 mm/decade), and Vancouver (+40 mm/decade and -15 mm/decade).

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