CLIMATE PROJECTIONS FOR THE CITY OF VANCOUVER: HIGHLIGHTS REPORT

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PACIFIC CLIMATE IMPACTS CONSORTIUM

Title

Climate Projections for the City of Vancouver: Highlights Report
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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.

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Cover Image:

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1. Introduction

The Earth's climate system—atmosphere, land, ocean and the ecosystems they support—is changing in response to increasing concentrations of greenhouse gases and various pollutants in the atmosphere from ongoing industrial development. The increase in global mean temperature in recent decades has been unequivocally established and attributed to these anthropogenic drivers, and similar changes are being detected in key climate variables on continental scales.[1] Recent historical temperature change in British Columbia is also emerging from the noise of climate variability (see Figure 3 below), and future projections indicate this trend will continue without significant cuts in carbon emissions. The regional and local manifestations of global climate change need to be studied and monitored, in order to design appropriate responses and adaptations.

Like other major cities worldwide, the City of Vancouver requires up-to-date, science-based, spatially resolved information to enable effective planning and policy decisions. This short report summarizes the data produced by the Pacific Climate Impacts Consortium (PCIC) delivered as part of this project. We hope that it will be helpful as a stepping stone for the City as it develops plans and effective responses to these upcoming challenges.

[1] Gulev, S.K., et al., 2021: Changing State of the Climate System. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, doi: 10.1017/9781009157896.004.

2. Highlights

The City of Vancouver is situated on the Pacific coast, bordered by the North Shore mountains and Burrard Inlet to the north and the Fraser River to the south. The City spans an area of 115 km^2 with an average elevation of 16 m above sea level; see Figure 1. Air temperature observations collected since 1950 over the surrounding Lower Fraser Valley show a clearly increasing trend of magnitude 0.42 ± 0.07 °C per decade.[2] This may be expected to prompt responses in other climatic variables, and this study explores some of those changes using state of the art climate model projections for the area. The results of this study show that in the coming decades, Vancouver can expect:

- Warmer summer temperatures, with more extreme heat days and heatwaves;
- Warmer nights and a longer growing season;
- Warmer winter temperatures and less frequent frost;
- Less rain and more dry days in the summer months;
- More precipitation falling in fall, winter and spring;
- An increased fraction of precipitation falling as rain.

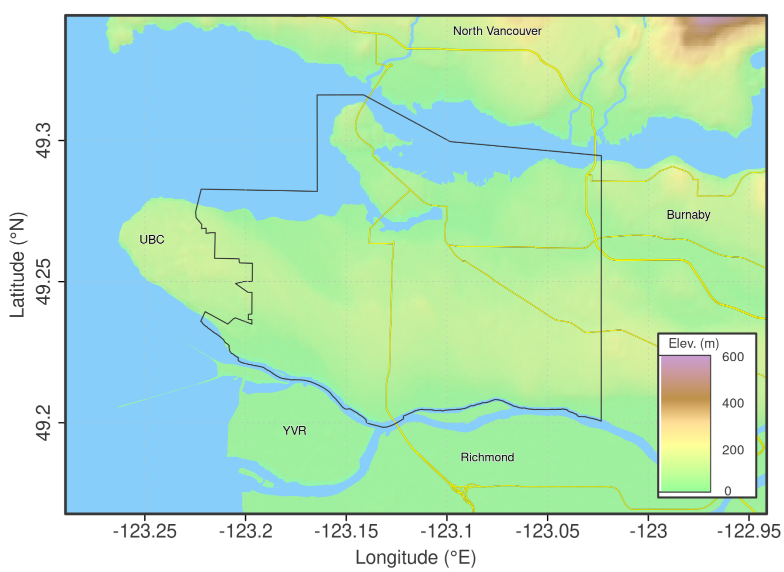


Figure 1. Domain of interest, the City of Vancouver, with the municipal boundary shown by the irregular black curve. Colours denote elevation, in metres above sea level.

[2] Results of an analysis conducted by PCIC for the annual "State of the Pacific Ocean" report; see Curry, C.L. and Lao, I., "Land temperature and hydrological conditions in 2022," pp 17-21. In: Boldt, J.L., Joyce, E., Tucker, S., and Gauthier, S. (Eds.), *State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2022*. Can. Tech. Rep. Fish. Aquat. Sci. 3542: viii + 312 p. (2023).

The following infographic provides a snapshot summary of the relevant results for the City, with an emphasis on changing climate extremes, which may be of special concern. These and other aspects of the projections are explored further in the remainder of the report.

	Impact Driver	1990s	High Emissions Scenario 2041-2070 ("2050s")		
		Median	Low	Median	High
EXTREME HEAT	Hottest summer day	29.7ºC	32.2ºC	32.9ºC	36ºC
EXTREME HEAT	Number of >30ºC days per year	1	6	9	29
EXTREME HEAT	Number of >16ºC nights per year	6	43	57	92
EXTREME HEAT	Longest annual heatwave (in days)	3	5	6	17
EXTREME HEAT	Number of heat wave days per year	1	9	16	46
DROUGHT	Total summer rainfall	144mm	113mm (-21%)	138mm (-4%)	143mm (-0%)
DROUGHT	Total annual snowfall	46mm	8mm (-84%)	19mm (-60%)	28mm (-45%)
FLOODING	Number of days with heavy rainfall (>95p)	9	10	11	12
FLOODING	Maximum 1-day precipitation	46mm	51mm (+8%)	53mm (+15%)	58mm (+28%)
FLOODING	Total rainfall on the 1-in-20 wettest day	72mm	80mm (+11%)	86mm (+19%)	97mm (35%)

Figure 2. Infographic summarizing model-simulated values of some key climate indices ("Impact Drivers") for the City of Vancouver. Definitions of all indices may be found in the Appendix. 'Low', 'Median' and 'High' values in the future projections columns refer to results from the 10th, 50th and 90th percentiles of the climate model ensemble. See *Section 3: Methods and Presentation* for further explanation.

3. Methods and Presentation

3.1 Climate Model Projections

The climate projections are based on an ensemble of 9 global climate models (GCMs) drawn from a larger collection of models developed during the Sixth Coupled Model Intercomparison Project (CMIP6), coordinated by the World Climate Research Programme. The climate projections presented here are based on a high greenhouse gas emissions scenario, known as the Shared Socioeconomic Pathway 5-8.5 (SSP585), which describes a trajectory of future emissions spurred by continued and expanded use of fossil-fuels worldwide. Two other scenarios are also presented in the data package accompanying this report: a medium-intensity emissions pathway, SSP245, and a low-intensity pathway, SSP126, which covers the possibility of a low-carbon technology transformation of worldwide energy systems.[3] Planning based on climate projections under SSP585 could be considered a "no regrets" strategy for adaptation. By the 2090s under SSP585, global mean surface air temperature reaches a level 4.3 °C higher than the 1850-1900 average. The evolution of air temperature and precipitation under the three SSPs, for British Columbia (BC) specifically, is shown in Figure 3.

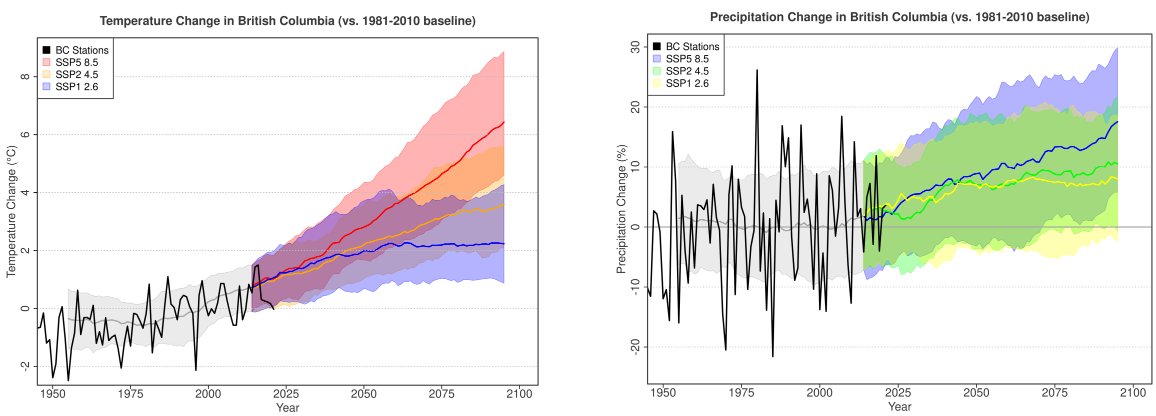


Figure 3. Changes in annual mean air temperature (*left*) and total precipitation (*right*) relative to their values in 1981-2010, averaged over all of BC. The black curves show historical values obtained from the station data in BC from 1948-2021, while the coloured curves show median GCM projections under the three development pathways (SSPs) from 2015-2100. The shaded areas show the 10^{th}-90^{th} percentile range in model-simulated results over the historical and future periods, for each SSP.

Each GCM represents the climate system using a global, horizontal grid with a limiting resolution between 100 km and 250 km, depending on the model. These coarse-grained data are first bias-

[3] An accessible description of the SSPs may be found at https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/.

corrected against available observations (spanning 1950-2012) and then statistically downscaled to 10 km resolution[4]. In a second downscaling step, the model data are further downscaled to a resolution of 800m using fine-scale climatological maps. It should be recognized, however, that while the latter account for fine-scale topography, important features of, and influences on, local daily climate are not represented in the dataset.[5]

Downscaled climate model results are presented for four 30-year periods: the historical reference period, 1981-2010 (referred to as the “Past” or “1990s” for short), the near future, 2021-2050 (the “2030s”) , mid-century, 2041-2070 (the “2050s”) and the end-of-century, 2071-2100 (the “2080s”). These 30-year periods are chosen both to smooth out year-to-year climate variability, and to provide a long enough period to characterize the behaviour of fairly rare events. The seasonal definitions used are “meteorological” seasons: i.e., winter (December 1 to February 28), spring (March 1 to May 31), summer (June 1 to August 31) and fall (September 1 to November 30). A range of indices are computed from daily temperature and precipitation to describe various aspects of the climate. For projections, median estimates from the climate model ensemble are typically emphasized, with the 10th to 90th percentile ranges over the ensemble also provided where appropriate.

It is important to recognize that not all projected changes emerging from the climate model ensemble are necessarily substantial. For a given variable, location, and emissions pathway, each model produces a projected future climate, resulting in a range of possible outcomes. Since no single model is “right,” the median value of the ensemble can be used as a practical best-guess projection, with the 10th to 90th percentile spread indicating the uncertainty amongst the models. *If the spread includes zero change, meaning that not all models agree on the sign of the change, then relatively low confidence should be placed in the median value.* In the relatively rare cases when less than half of the models agree on the sign of change, users are alerted to the reduced confidence via a printed message on the maps.

3.2 Climatic Indicators

The following indicators, derived from the model-simulated daily temperature and precipitation, represent a “highlight reel” of key results drawn from the much more extensive set of climate indices delivered for this project. In consultation with City staff, they were selected either because they have implications for a range of climate-related impacts, or because they feature particularly large changes from recent historical conditions. In the following section, a plain

[4] Details on the downscaling methods used at PCIC may be found on the Data Portal section of our website, pacificclimate.org.

[5] Examples of these being realistic day-to-day variability and co-variability between nearby locations, and fine-scale land cover type, for example. It should also be recognized that since the models are bias-corrected to daily observations spanning a specific time period, here 1950-2012, more recent observations will not be reflected in results displayed for the “Past.”

language definition is provided for each indicator, followed by a summary of its projected change for the 2030s, 2050s, and 2080s, under the high (SSP585) emissions scenario. Detailed definitions of all indicators are provided in the Appendix.

i. Temperature Indicators

Winter Temperatures

Seasonal Temperature Change and Variability

Growing Season Length

Heating Degree Days

Cooling Degree Days

Heatwave Indicators and Annual Hottest Day

1-in-20 Year Hottest Day

ii. Precipitation Indicators

Summer Rainfall

Dry Spells

Autumn Rainfall

Snowfall

Seasonal Precipitation Change and Variability

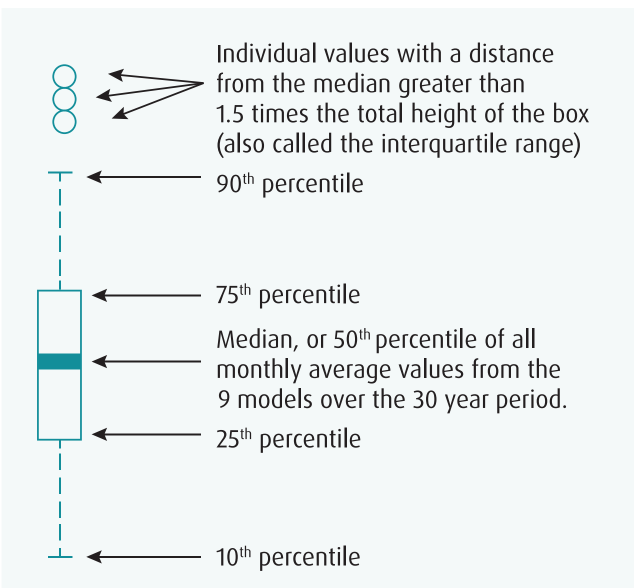
1-in-20 Year Wettest Day and Wettest 5 Consecutive Days

3.3 Interpreting Figures and Tables

The data deliverables for the project comprise: (i) maps of climate variables over the region in Past and Future periods, for each of the three scenarios; and (ii) tables (Excel spreadsheets) of area-averaged results for the same. Results for absolute or relative difference are also provided, where appropriate. References to the tables are occasionally made in the report. Most of the figures presented below are maps, showing the City of Vancouver and the surrounding area. Colour contours indicate values of the indicated variable, with a nominal limiting resolution of 800m. *Due to the limitations of the downscaling methodology mentioned above, along with the inherent uncertainty in future outcomes, the exact position of contours on the maps should not* *be taken literally*. On each map, the area average shown at bottom left is computed over the City of Vancouver only (area inside the black curve).

There are two types of maps: single period and future change. Single period maps, e.g., "Past: 1990s" or "Projection: 2050s," show actual values of a variable, e.g., temperature in °C. Future change maps, e.g., "Projected Change: 2050s - 1990s," show differences between historical and future-simulated periods, and may be in the units of the variable or in relative terms, e.g., percent change in precipitation. In the interest of concision, all future change maps shown in this summary report are for the 2050s under the high emissions (SSP585) pathway. For most indicators, the magnitude of these changes should be roughly comparable to that projected for the 2080s under the moderate emissions scenario (i.e., SSP245).

Other figures in the report use area-averages for the City while expressing the range of projected values over models and years for a certain variable. An example of this type of presentation, the "box-and-whisker" plot, is shown in Figures 5 and 13, and an aid to their interpretation is given below. Note that, in these figures, the range shown by the whiskers reflects both year-to-year and model-to-model variability.



Finally, note that when cited in the text, values from the spreadsheets are often rounded to indicate the likely precision of the quantity being discussed, given the known model uncertainties. For example, a temperature of 29.8°C would be cited as 30°C, while 2717 degree-days become 2715 degree-days. The tables contain median values with ranges given in parentheses (10^{th} – 90^{th} percentile of different model projections). Usually medians are cited in the text; but ranges encompass the range of possible behaviour, and should not be ignored, especially when the climate variable in question might enter into critical decision-making.

4. Temperature-based Indicators

4.1 Winter Temperatures

We begin by examining projected changes in temperature averaged over the winter season, i.e. December to February. The maps below show winter nighttime low temperature (Figure 4) and winter daytime high temperature (Figure 5), both averaged over 30-year periods.

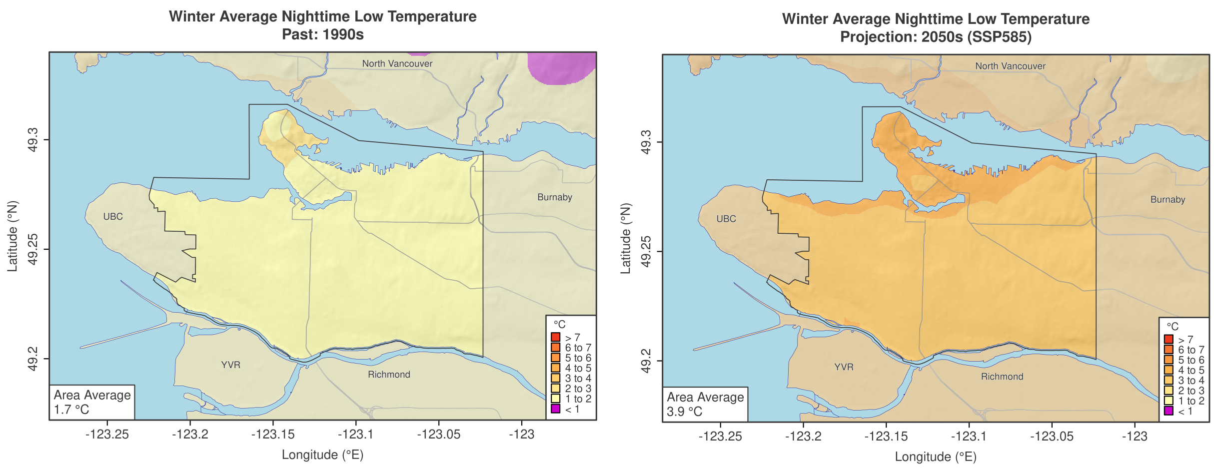


Figure 4. *Left:* Winter average nighttime low temperature (TN) in the Past (1981-2010). *Right:* Projected winter average TN in the 2050s (2041-2070).

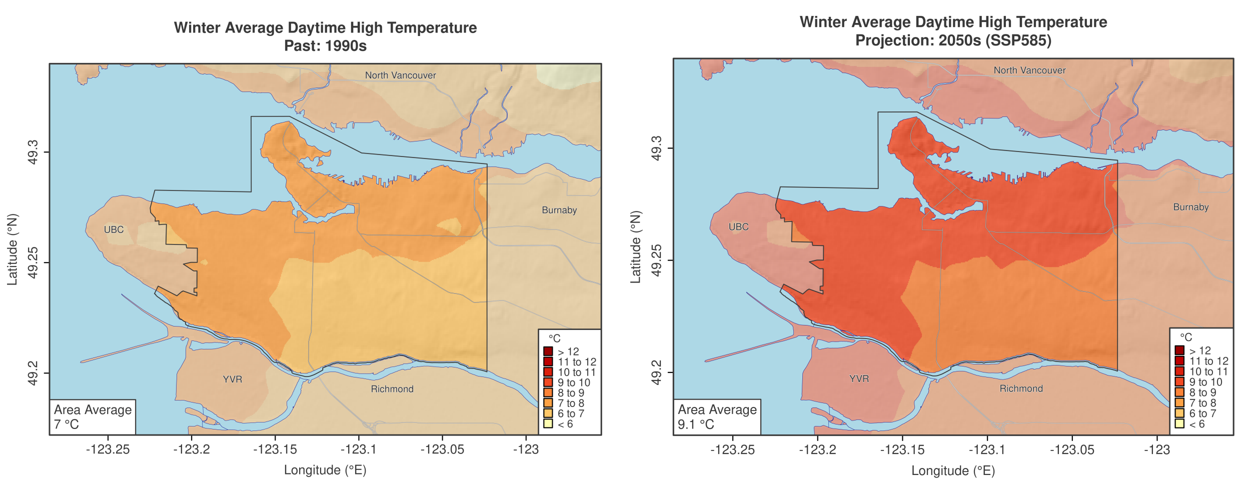


Figure 5. *Left:* Winter average daytime high temperature (TX) in the Past (1981-2010). *Right:* Projected winter average TX in the 2050s.

Projections

- In the **Past**, winter nighttime low temperatures (TN) in Vancouver averaged around 1.7°C.
- In the **Past**, winter daytime high temperatures (TX) in Vancouver averaged around 7°C.
- The median **Future-projected** TN increases to around 4°C by the 2050s and to 5.5°C by the 2080s.
- The median **Future-projected** TX increases to around 9°C by the 2050s and to 11°C by the 2080s.

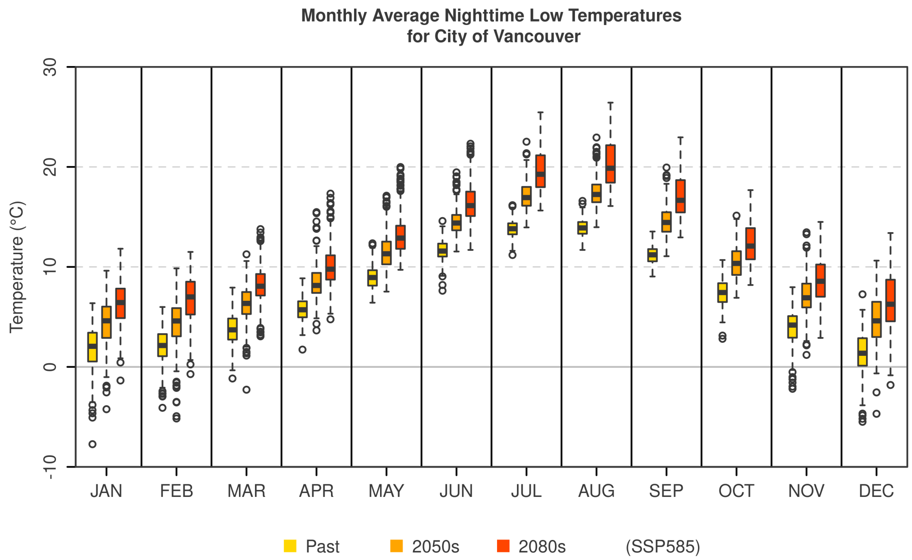
Context and Implications

- While freezing temperatures will still occur occasionally during winter (see variable 'TNN' in the SSP5-8.5 Projections Summary Table), the increase in future-projected TN will be noticeable as manifested in a longer growing season and lower heating demand, on average (see below).
- Warming winter temperatures will lead to an increased fraction of precipitation falling as rain instead of snow. Snow events, which typically occur a few times each winter in the City, will still occur, but less frequently.
- Although outside of the assessment domain and at higher elevation, Vancouver's water supply areas will display similar shifts in winter temperatures from Past values. Hence, snowpack variability in the headwaters of reservoir areas should be closely monitored.

4.2 Seasonal Temperature Change and Variability

The projected warming of winter temperatures mentioned above is, in fact, expected to occur year-round. Future-projected changes in temperature over the year are shown in the figure below for monthly mean nighttime low (TN) and daytime high (TX) temperatures under the SSP585 scenario. The box-and-whisker plots reflect both year-to-year and model-to-model variability in all 30 Januaries, Februaries, etc., over the Past and Future periods. Some features worth noting are:

- Freezing temperatures become increasingly rare in the Future.
- Spring (loosely defined as the beginning of the growing season, when daily mean temperature T_m consistently exceeds 5°C; see next subsection) begins earlier in the Future, while Fall (defined similarly as the end of the growing season) ends later, resulting in an effectively shorter winter season.
- The frequency of high extremes in summer increases notably, with July and August average daytime high temperatures exceeding 25°C in about three-quarters of models and years by the 2050s.



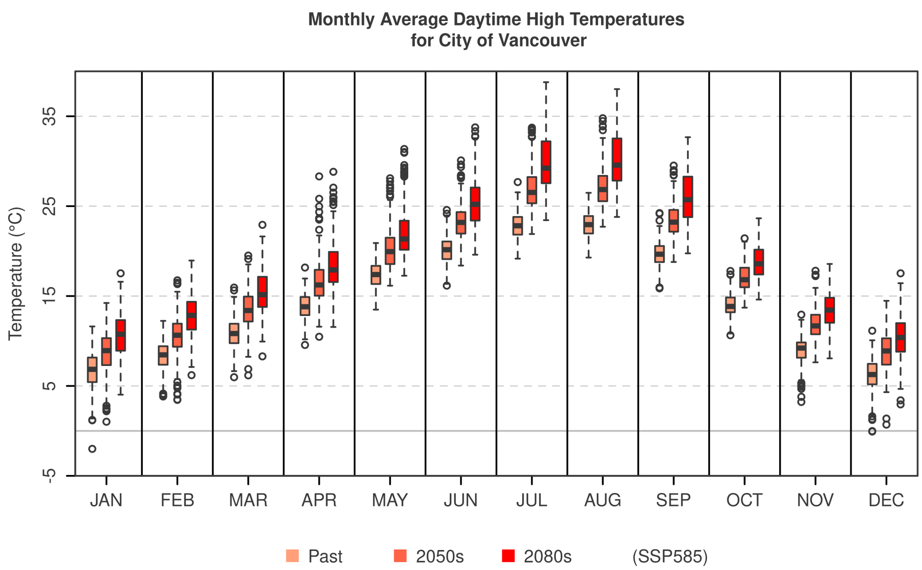


Figure 6. Annual cycle of monthly mean nighttime low temperature (TN; *upper*) and daytime high temperature (TX; *lower*) in the Past, 2050s and 2080s periods.

4.3 Growing Season Length

Growing season length (GSL) is an annual measure indicating the period when temperatures are high enough for most vegetation to grow. The GSL is the number of days between the first span of at least 6 consecutive days with daily average temperatures above 5°C, and the first span, after July 1, of 6 days with temperatures below 5°C. This measure helps to highlight how urban forests, agricultural and landscaped areas, grasses, weeds (and their pollens) may be affected by climate change.

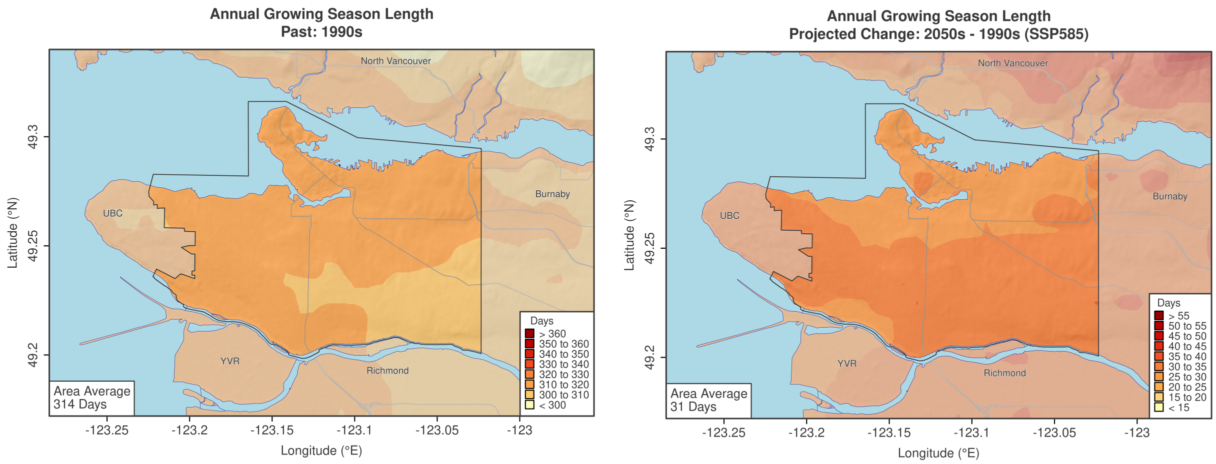


Figure 7. *Left:* Growing season length in the Past. *Right:* Projected increase in growing season length by the 2050s.

Projections

- In the **Past**, Vancouver's growing season lasted roughly 314 days.
- The median **Future-projected** growing season increases by 31 days to roughly 345 days by the 2050s and by 42 days to around 355 days by the 2080s.

Context and Implications

- Other things being equal, a longer GSL implies potentially more productive vegetation in the future.
- However, since GSL uses only a lower temperature threshold (and not an upper threshold for account for heat stress) and ignores changes in precipitation, it should be considered an upper limit for estimates of future productivity.
- A related measure to GSL is the length of the frost-free season, which uses a lower threshold of 0°C. In the Past, Vancouver had a frost-free season of 330-360 days, and will become effectively frost-free year-round by the 2080s.

4.4 Heating Degree Days

Heating degree days (HDD) are calculated by summing the number of degrees that the daily mean temperature falls below 18°C for every day in a year.[6] This measure is commonly used to estimate the heating demand for buildings in the cooler months.

[6] For example, if the daily mean temperature on January 1 is 10°C, followed by one day of 4°C, two days of −1°C and three days of 0°C, then HDD for that week are calculated as: (18−10) + (18−4) + 2 × (18−(−1)) + 3 × (18−0) = 114 degree-days. (Note that days with temperature equal to or greater than 18°C are not counted).

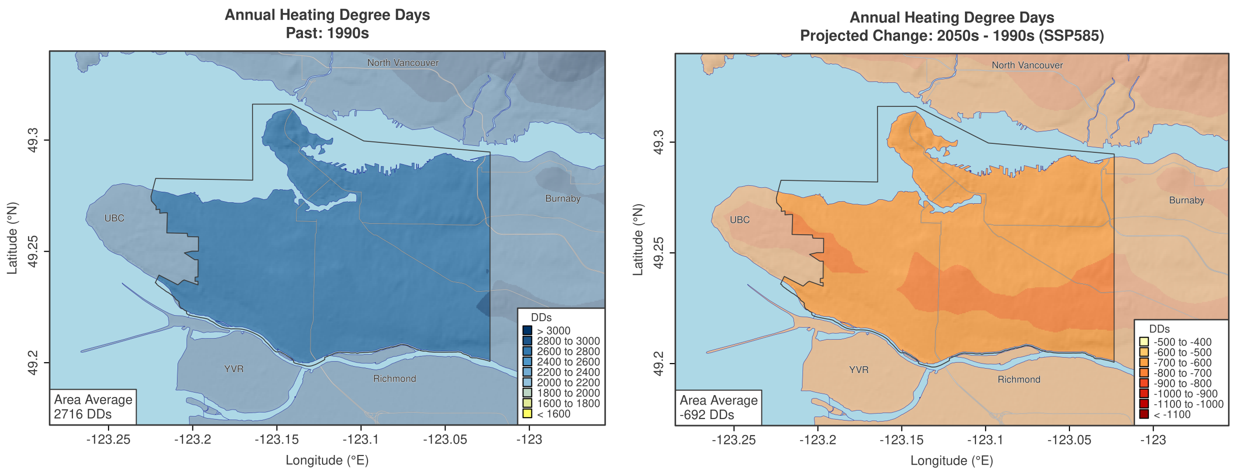


Figure 8. *Left:* Heating degree days (HDD) in the Past. *Right:* Projected decrease in HDD in the 2050s.

Projections

- In the **Past**, Vancouver had a median of roughly 2715 HDD.[7]
- The median **Future-projected** HDD decreases to 2025 (a 25% decrease) by the 2050s and to 1705 (a 37% decrease) by the 2080s.

Context and Implications

- Due to its cumulative nature, a reduction in HDD is amongst the clearest indicators of warming, both in recent historical observations and in model projections.
- While mean winter temperatures will warm throughout the coming decades, Vancouver's continued exposure to easterly polar outflows from Northwestern Canada suggests that the potential for multi-day cold snaps will persist in the future, though they should be less frequent.
- For this reason, building heating systems will still need to be responsive to occasional sub-zero winter temperatures.

[7] Someone consulting the tables for the National Building Code of Canada (NBCC, 2015) will see a different value of HDD listed for Vancouver than the one cited here. One reason for this is the larger area covered by our Core/Peninsula subregion. Another is the different methodology and period of observations used to calculate HDD in the NBCC. As our estimate depends to some extent on coarse-grained climate models, while the NBCC employs interpolated station data, the NBCC value would normally be considered more reliable in this subregion (which contains several meteorological stations). For users interested in future HDD estimates, the relative differences from Past values can be used for HDD projections, regardless of which baseline value is used. A helpful web-based tool that offers historical and projected values of HDD and 18 other design variables across Canada is PCIC's *Design Value Explorer* tool at https://services.pacificclimate.org/design-value-explorer/.

4.5 Cooling Degree Days

The opposite of HDD, cooling degree days are calculated by summing the number of degrees that the daily mean temperature exceeds 18°C for every day in a year.[8] This measure is commonly used to estimate the demand for mechanical cooling (i.e., air conditioning) in buildings in the warmer months.

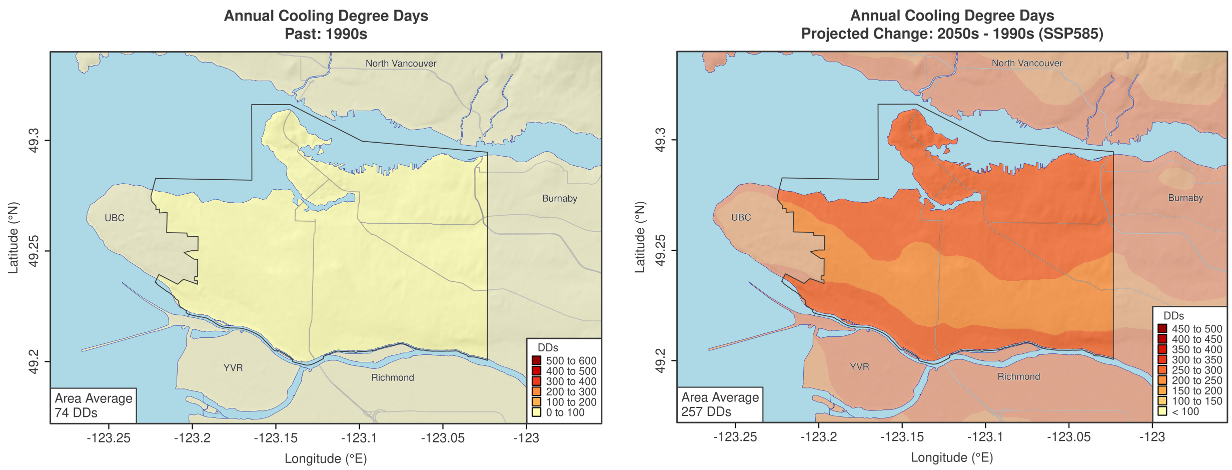


Figure 9. *Left:* Cooling degree days in the Past. *Right:* Projected increase in cooling degree days in the 2050s.

Projections

- In the **Past**, Vancouver had a median of roughly 75 cooling degree days, with the vast majority of such days occurring in summer.
- The median **Future-projected** cooling degree days increase to about 345 (a factor of 4.6 increase) by the 2050s and to nearly 600 (an eight-fold increase) by the 2080s. While most such days will continue to occur in summer, they will increasingly occur during late spring and early fall.

Context and Implications

- Like the projected decrease in HDD, an increase in cooling degree days is among the clearest indicators of warming, both in recent historical observations and model projections.
- New buildings may need to be designed differently to meet this large projected increase in cooling demand. Existing buildings may need to be retrofitted, where possible.

[8] For example, if the daily mean temperature on July 1 is 20°C, followed by three days of 21°C, one day of 25°C and two days of 16°C, then the cooling degree days for that week are calculated as: (20−18) + 3 × (21−18) + (25−18) = 18 degree-days. (Note that days with temperature equal to or less than 18°C are not counted).

Updates to the Building Code to account for overheating specifically are provided in the BC Energy Step Code (i.e., Step 3 for Part 9 buildings and Step 2 for Part 3 buildings).

4.6 Heatwaves, Hot Summer Days, and Annual Hottest Day

These indicators highlight the most extreme temperatures occurring during the year. Episodes of multi-day extreme heat, which were rare in the Past, are captured by several heatwave (HW) indicators, defined in the Appendix. These are partly based on threshold temperatures for emergency health alerts used specifically in BC[9]. Since spatial variations in these indices across the City are quite small[10], the area-averaged results are summarized in a table rather than as maps. For reference, two single-day extreme heat measures are also included: the temperature of the single hottest day of the year—not necessarily occurring during a HW—and the number of days with TX > 30°C. All indices describe a typical year within the indicated 30-year period.

Projections

- In the **Past**, there was usually one heatwave per year, lasting up to 3 days and having a peak daily temperature of 31°C.
- The median **Future-projected** number of HWs increases to roughly 4 per year by the 2050s and 6 per year by the 2080s.
- HWs are also projected to increase in length in the future (approaching 12 consecutive days or more by the 2080s) and will feature both warmer daytime and nighttime temperatures.

Context and Implications

- The public will need to adapt to more frequent, longer, and intense HWs in future.
- Public information campaigns linked to meteorological forecasts will be essential.
- Health care and emergency services will need to be properly resourced to handle increased incidence of heat-related illness, stress and anxiety.

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[9] See the report, *BC Provincial Heat Alert and Response System (BC HARS): 2023*, May 2023. Available at: http://www.bccdc.ca/health-professionals/professional-resources/heat-event-response-planning. The lower threshold temperatures used in our HW definition, which is intended for use throughout BC, are TX = 28°C and TN = 13°C. In addition, a HW must: 1) last at least 2 full days; and 2) have TX and TN exceeding their 95th percentile values in the Past.
[10] One reason for this is that fine-scale land surface type is not included in our modelling chain, so that the urban heat island effect, e.g., is not reflected.

Table 1. Measures of extreme heat in the Past and Future-projected periods. Upper values in each table cell are the ensemble median, with values in parentheses giving the 10th to 90th percentile range over the model ensemble.

City of Vancouver: Heatwave Indices, Hot Summer Days and Warm Nights					
Index	Description	Past	2030s	2050s	2080s
HWD	HW days (days)	1	6 (*4 to 18*)	16 (*9 to 46*)	36 (*29 to 94*)
HWXL	HW maximum length (days)	3[11]	4 (*3 to 7*)	6 (*5 to 17*)	12 (*9 to 62*)
HWN	Annual number of HWs	1	2 (*2 to 5*)	4 (*3 to 7*)	6 (*5 to 8*)
TXHX	Avg. TX in most extreme annual HW (°C)	31	31 (*30 to 32*)	32 (*31 to 33*)	33 (*32 to 34*)
TNHX	Avg. TN in most extreme annual HW (°C)	18	18 (*18 to 19*)	19 (*19 to 20*)	21 (*20 to 23*)
TXX	TX on hottest day of year (°C)	30	32 (*31 to 34*)	33 (*32 to 36*)	35 (*34 to 40*)
SU30	Number of days reaching TX > 30°C	1	5 (*3 to 12*)	9 (*6 to 29*)	21 (*17 to 73*)
TR16C	Number of nights reaching TN > 16°C	7	36 (*3 to 12*)	57 (*6 to 29*)	93 (*17 to 73*)

4.7 The 1-in-20-Year Annual Hottest Day

This indicator describes *extreme* temperatures so high, they are expected to occur only once every 20 years in the historical climate. In other words, the 1-in-20 Year Hottest Day presently has a 5% chance of occurring in any given year. The figure below shows the projected changes in this type of event in two ways: first, in terms of how frequently an event *of the same TX value* occurs in the future; and second, in terms of how much TX increases for an event occurring *with the same frequency* (or annual probability) in the future.

[11] It may seem strange that HWD < HWXL in the Past, but this is an artifact of small number statistics. Some years in the Past contained no HWs, leading to a mean annual value of 0.7 for HWD (rounded to 1 in the table). Nevertheless, one or more years had HW lengths of 2 or 3 days, leading to the mean HWL = 2.8 days (rounded to 3) over the 30-year period. As the number of HWs increases in future years of the simulations, the expected behaviour HWD > HWXL emerges.

For example, in the Past, a daily maximum temperature of 33°C or higher occurred once every 20 years or so in Vancouver. In the projections for the 2050s, this temperature is exceeded a median of 9 times (with a model range of 5 to 18 times) in a 20-year period, or almost once every other year. Alternatively, one can say based on the same projections that in the 2050s, a 1-in-20 year event has a magnitude of around 37°C (with a model range of 36°C to 41°C; see the 'Return Levels' tab in the SSP585 Summary Table).

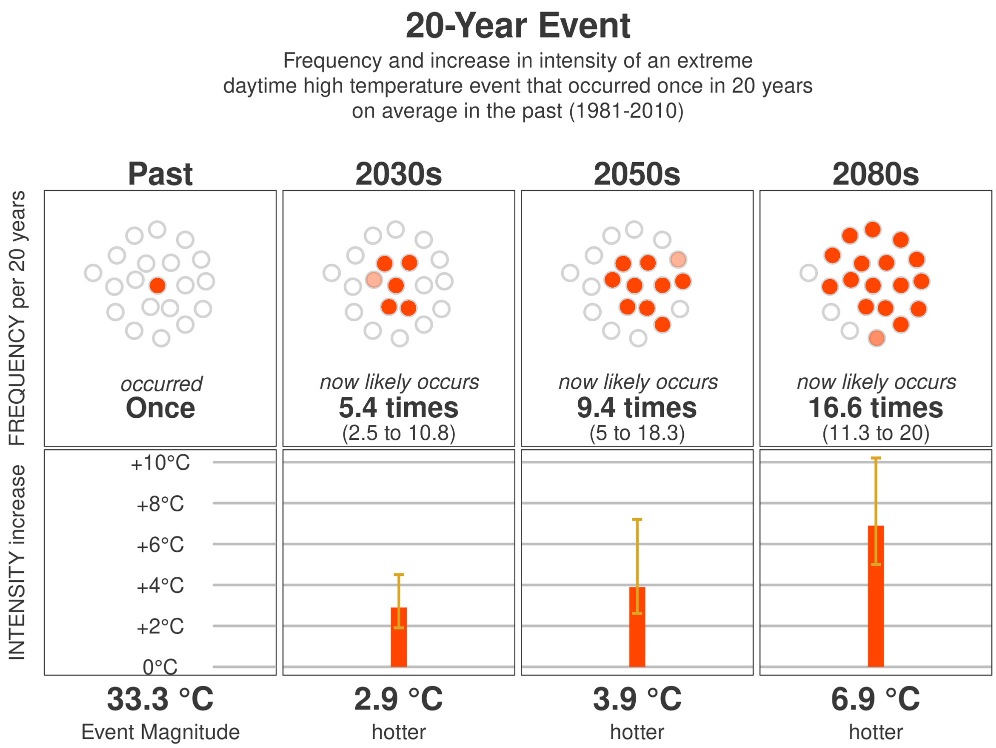

Figure 10. *Upper panels:* Frequency of a 1-in-20 year daily maximum temperature event (TX) in the Past and projected frequency of the same magnitude event (i.e. TX = 33°C) in the three future periods. *Lower panels*: Increase in magnitude of a 1-in-20 year TX event from the Past to Future periods. Figure design is taken from similar infographics in the IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3-32, doi:10.1017/9781009157896.001.

5. Precipitation-based Indicators

5.1 Summer Rainfall

We begin this section with an examination of dry season rainfall in Vancouver—specifically, the 30-year mean of summer (June-July-August) total rainfall.

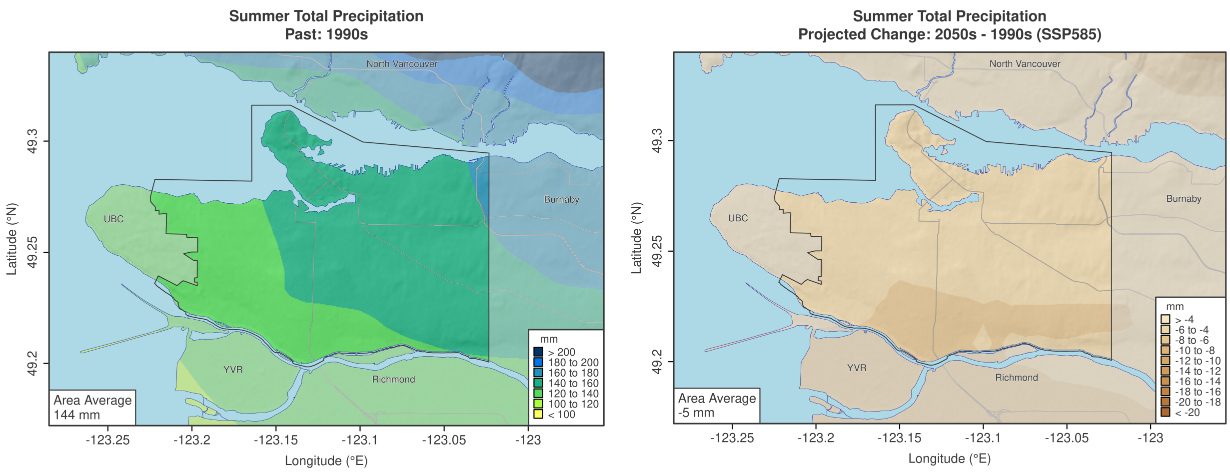

Figure 11. *Left:* Summer total rainfall in the Past. *Right:* Projected decrease in rainfall in the 2050s.

Projections

- In the **Past**, the median total summer rainfall in Vancouver was roughly 145 mm.
- The median **Future** summer rainfall is projected to decrease by −4% to about 140 mm by the 2050s and by −16% to roughly 130 mm by the 2080s.

Context and Implications

- The projected decrease in summer rainfall is opposite to that in the cool seasons (see below).
- In tandem with the higher summer temperatures mentioned above—which increase potential evaporation—reduced summer rainfall increases the probability of drought conditions.
- Additional efforts to conserve water and protect urban water supply may be needed.

5.2 Dry spells

This indicator tracks the annual maximum length of consecutive dry days, where "dry" days are those with less than 1 mm of precipitation.

Projections

- In the **Past**, the median dry spell length in Vancouver was 23 days.
- The median **Future-projected** dry spell length increases by 17% to 27 days (range 22 - 33 days) by the 2050s and by the same median amount but with a larger model range (24 - 41 days) by the 2080s.

Context and Implications

- The increase in dry spell length is consistent with the higher summer temperatures and reduced summer rainfall highlighted above.
- Additional efforts to conserve water and protect urban water supply may be needed.

5.3 Autumn Rainfall

Moving now to an examination of precipitation during the wetter months, we present results for the 30-year mean of autumn (September-October-November) total rainfall.

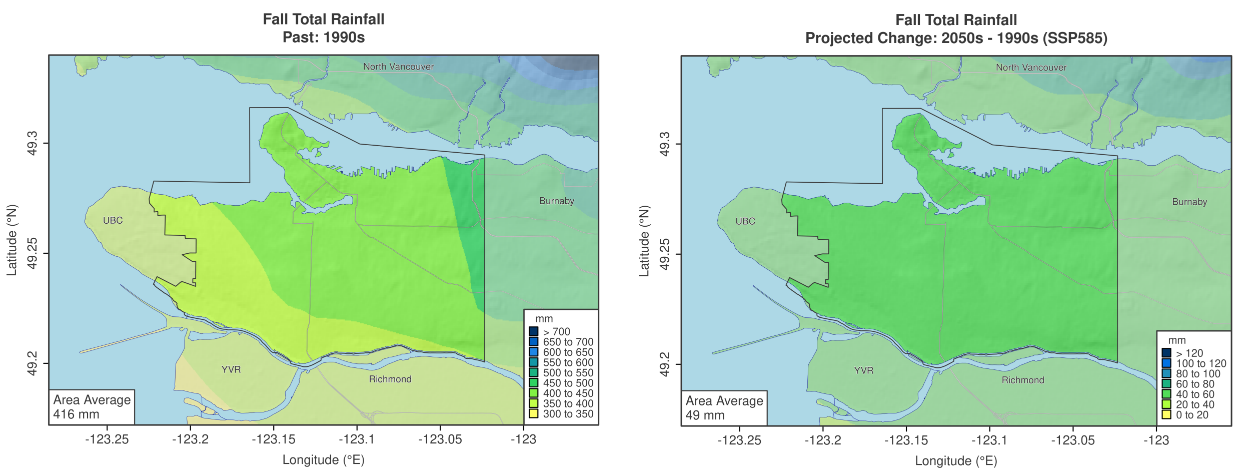

Figure 12. *Left:* Total autumn rainfall in the Past. *Right:* Projected increase in rainfall in the 2050s.

Projections

- In the **Past**, the median autumn rainfall in Vancouver was roughly 415 mm.
- The median **Future-projected** autumn rainfall increases by 12% to 465 mm by the 2050s and by 21% to 505 mm by the 2080s.

Context and Implications (for all wet season months)

- Throughout the century, overall increases in precipitation are expected, except in summer (see above).
- While winter is historically the rainiest season in Vancouver, followed by autumn, the projected relative increase in autumn rainfall is larger than for winter rainfall.
- By the end of the century, some years may have more rain in autumn than in winter.

5.4 Snowfall

Snowfall is inferred from the downscaled total daily precipitation and temperature, using a widely validated empirical relationship.[12]

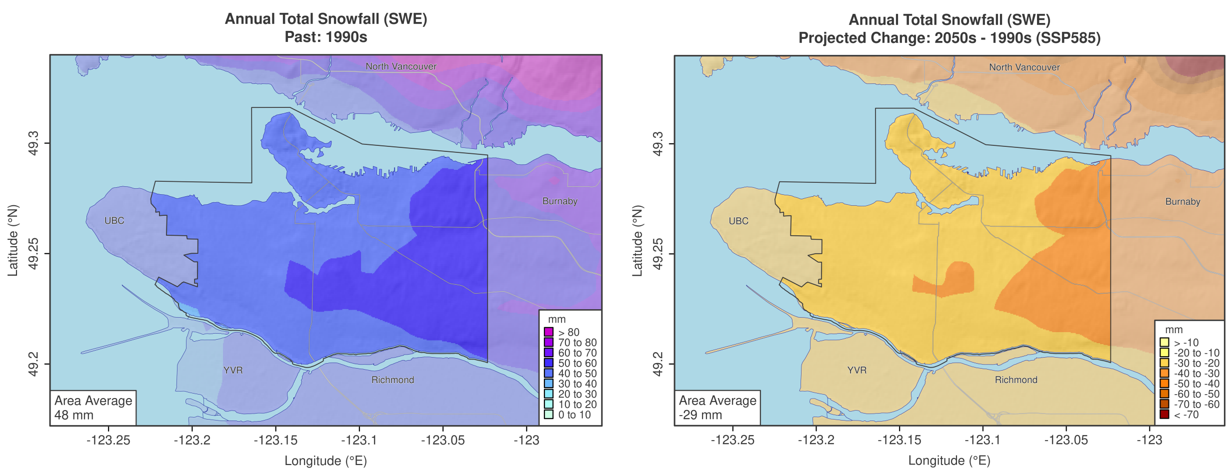

Figure 13. *Left:* Total annual snowfall in the Past. *Right:* Projected decrease in snowfall in the 2050s.

Projections

- In the **Past**, the median annual snowfall in Vancouver was nearly 50 mm (snow water equivalent, or SWE).
- The median **Future-projected** snowfall decreases by 60% to around 20 mm (range 8 to 28 mm) by the 2050s and by nearly 90% to just 6 mm (range 1 to 12 mm) by the 2080s.

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[12]Dai, A. (2008). "Temperature and pressure dependence of the rain-snow phase transition over land and ocean," *Geophysical Research Letters*, 35(12). Snowfall projections should be taken with special caution, for two reasons. First, the amount of total precipitation that falls as snow is a sensitive function of local temperature, so whatever temperature biases remain after the downscaling procedure result in uncertainty in snowfall. Over time, however, as local temperatures exceed 0℃ more often in winter, this uncertainty decreases.

Context and Implications

- Due to the robust projection of an increase in cold season temperature (see above), the expectation of a smaller fraction of precipitation falling as snow in future decades is reasonable, even if its magnitude is somewhat uncertain.
- Of more concern is the very limited model ability to simulate the unique conditions that lead to the rare, but sometimes heavy, snowfalls in Southwest BC. The CMIP6 models used in this study are probably not able to capture this behaviour very well, meaning that the change in frequency of winter storms resulting in heavy snowfall is largely unknown.
- For this reason, it would likely be premature to make changes to municipal snow removal plans, for example, until at least mid-century.

5.5 Seasonal Precipitation Change and Variability

While precipitation in Vancouver exhibits a notable seasonality, with far larger amounts in the colder months, this occurs against the background of high year-to-year variability. As a result, a climate change signal is more difficult to distinguish in precipitation than in temperature. One exception is the projected decline in snowfall summarized above. Combined with an increase in annual total precipitation of +5%, the resulting median projection in annual total rainfall is +8%. The figure below shows model estimates of monthly total rainfall in the Past and both Future periods. While median values increase in the colder months throughout the century, what is more striking are the changes in variability (occurring across both individual models and years, as done for temperature above). For example, we note the occurrence of higher extreme monthly rainfall amounts in future periods, especially during the autumn months; some November rainfall totals exceed 600 mm in future, compared to around 450 mm in the Past.

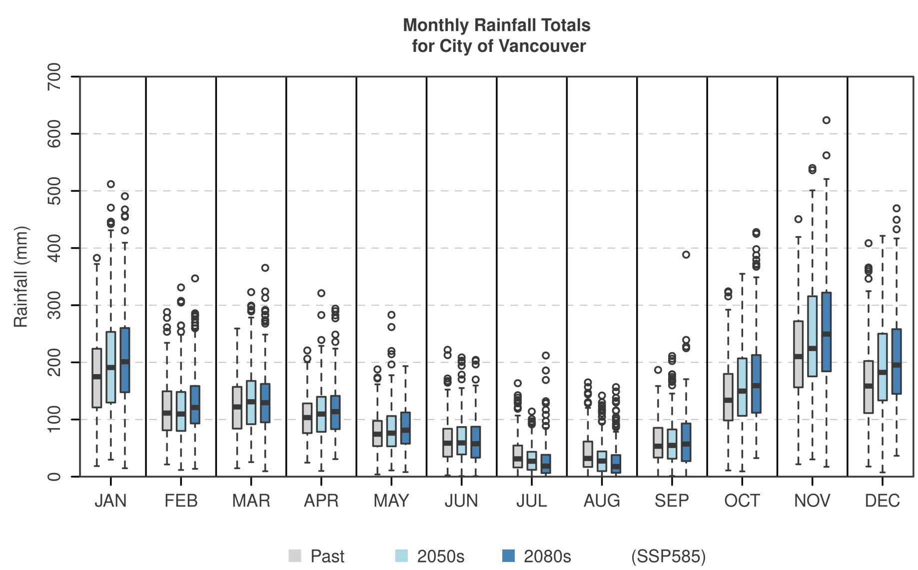

Figure 14. Annual cycle of total monthly rainfall in the Past, 2050s and 2080s periods.

5.6 The 1-in-20 Year Wettest Day and 1-in-20 Year Wettest 5-Day Period

These indicators describe *extreme* rainfall events so intense, they are expected to occur only once every 20 years in the Past climate. Put differently, the 1-in-20 Year Wettest Day and Wettest 5 Days have a 5% chance of occurring in any given year in the Past.

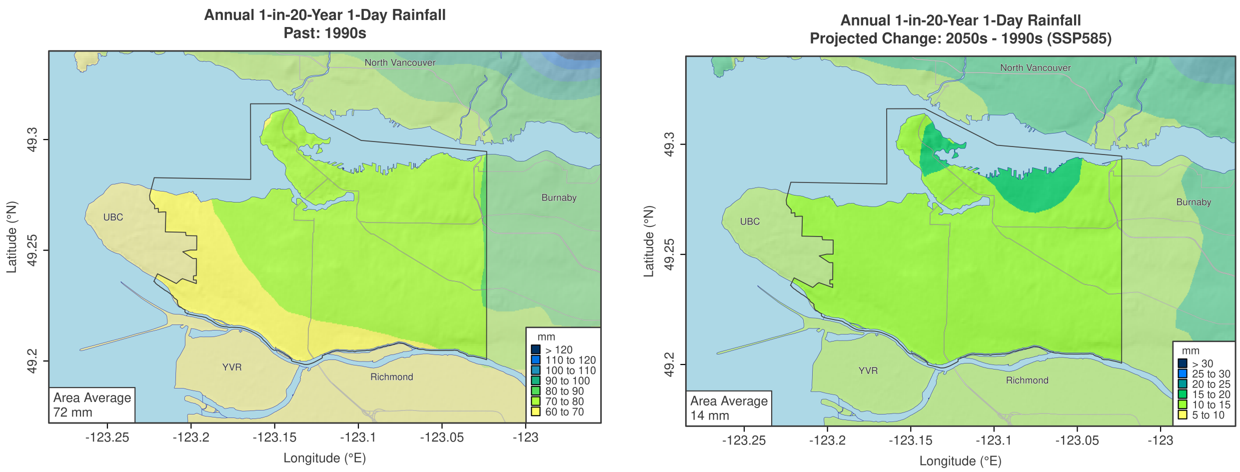

Figure 15. *Left:* 1-in-20 year, single-day maximum rainfall in the Past. *Right:* Projected change in single-day maximum rainfall in the 2050s.

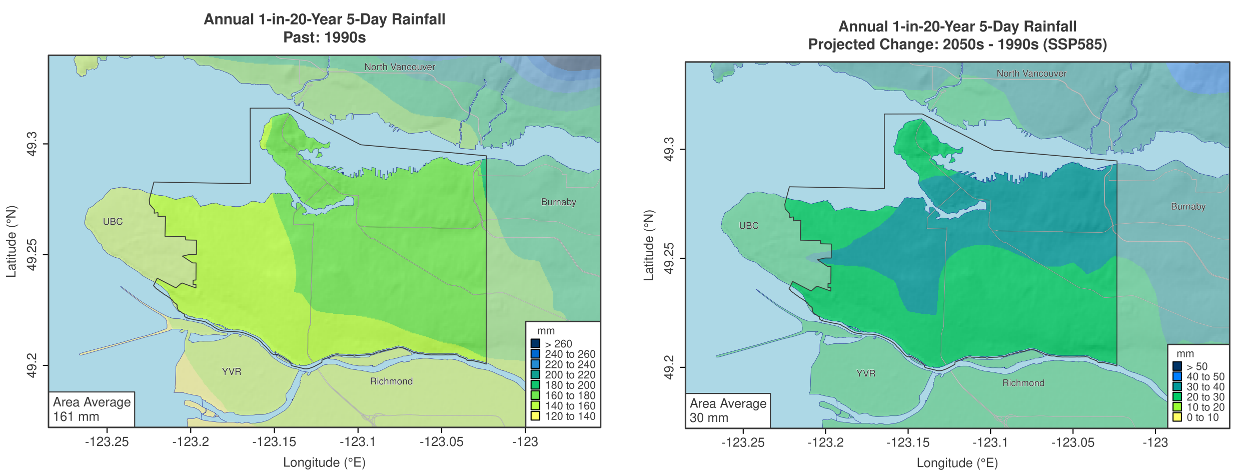

Figure 16. Same as above, but for 5-day accumulated maximum rainfall.

Projections

- In the **Past**, the median 1-in-20 Year, single-day rainfall in Vancouver was around 70 mm, while the median 1-in-20, 5-day rainfall was about 160 mm.
- The median **Future-projected** 1-in-20 Year, single-day rainfall increases by 20% to around 85 mm by the 2050s and by 30% to about 95 mm by the 2080s.

- The median **Future-projected** 1-in-20 Year, 5-day rainfall increases by 20% to around 190 mm by the 2050s and by 25% to about 200 mm by the 2080s.

As in the case of rare temperature events, one may express these changes in extreme rainfall in a more visually intuitive way, as in the diagram below.

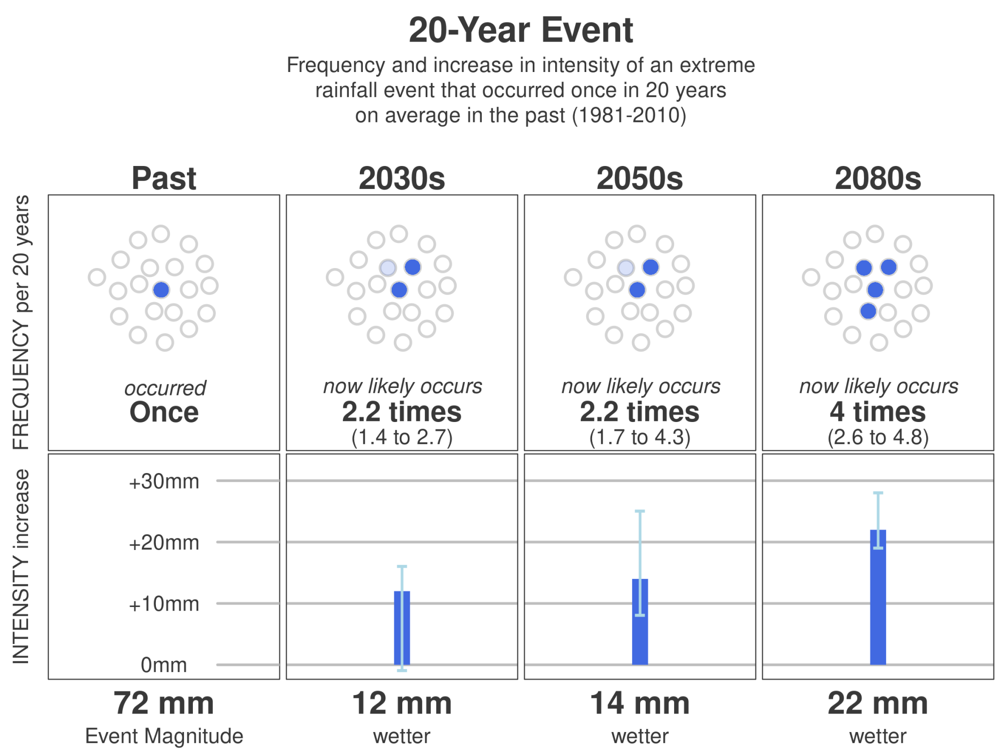

Figure 17. *Upper panels:* Frequency of a 1-in-20 year daily maximum rainfall event in the Past and projected frequency of the same magnitude event (i.e. 72 mm) in the three future periods. *Lower panels*: Increase in magnitude of a 1-in-20 year single-day rainfall event from the Past to Future periods. Figure design is taken from similar infographics in the IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3-32, doi:10.1017/9781009157896.001.

Context and Implications

- The larger relative changes in these measures of intense rainfall than for seasonal or annual mean rainfall occurs due to different mechanisms that control how extreme precipitation and average precipitation respond to warming.
- Designers of urban drainage systems will need to plan for higher single- and multi-day rainfall amounts, with appropriate changes to culverts, storm drains, and other infrastructure elements.

6. Conclusions

Over the past decade, manifestations of climate change are being experienced in towns and cities across the country. There are indications that the projected changes outlined in this report are already underway: increasing mean temperatures, seasonal shifts and longer growing seasons, unprecedented summer temperatures, and exceptional rainfall events are some that come to mind. Municipal services and infrastructure increasingly report being affected by these events, and the need to plan for a changing climate is growing in urgency.

The results presented in this short summary report, and the extensive data supporting it, should be helpful for designing climate adaptation strategies. However, readers should bear in mind some caveats. First, the area of study is only a small part of an interconnected region that is highly influenced by oceanic modes of variability (e.g., the El Nino-Southern Oscillation and the Pacific Decadal Oscillation) and the interaction of dynamic, large-scale atmospheric flows with highly complex terrain that borders the City and determines much of its weather and seasonal climate. A comprehensive climate assessment would consider a much larger region (in this case, Greater Vancouver including the North Shore mountains and the Fraser Valley) in order to give a complete picture of how, for example, drier summers are connected with changes in winter snowpack and the spring freshet. Second, despite the value added from statistical downscaling of coarse-grained GCMs to fine scales approaching that of several city blocks, the downscaled results are ultimately limited by processes that are lacking in the parent GCMs. For example, detailed land cover data and projected land use change are known to influence climate and climate change on small scales. Finally, while the results have been expressed mainly as medians of the model ensemble, it is important to consider the full range of GCM projections when planning, to allow for a “no regrets” approach to decision-making.

In conclusion, the climate projections presented in this report suggest specific areas of focus for considering the impacts of climate change on the City of Vancouver. In combination with more comprehensive studies that introduce fine-scale information about important elements not covered here—for example, the location of critical infrastructure, population density, etc.—this work should support conversations about adaptation, planning, and other actions to increase the City’s resilience in the coming years.

Appendix: List of Climate Indices and Definitions

SHORT NAME	VARIABLE	DEFINITION	UNITS
Standard			
PR	Precipitation	Annual/seasonal precipitation totals	mm
RAIN	Rainfall	Annual/seasonal rainfall portion of precipitation using temperature-based rain-snow partitioning	mm
SNOW	Snowfall	Annual/seasonal snowfall (snow water equivalent) portion of precipitation	mm (H_2Oeq)
TM	Daily Average Temperature	Annual/seasonal daily average temperature	°C
TX	Daily MaximumTemperature	Annual/seasonal average daily maximum temperature	°C
TN	Daily Minimum Temperature (usually overnight)	Annual/seasonal average daily minimum temperature	°C
Climdex: Temperature-based			
TXX	Maximum TX	Annual/seasonal maximum of TX	°C
TNN	Minimum TN	Annual/seasonal minimum of TN	°C
TXN	Minimum TX	Annual/seasonal minimum of TX	°C
TNX	Maximum TN	Annual/seasonal maximum of TN	°C
TX90P	Hot Days	Annual percentage of days with TX > 90th historical percentile	%
TX10P	Cool Days	Annual percentage of days with TX < 10th historical percentile	%
TN90P	Warm Nights	Annual percentage of days with TN > 90th historical percentile	%
TN10P	Cold Nights	Annual percentage of days with TN < 10th historical percentile	%
DTR	Diurnal Temperature Range	Annual/seasonal diurnal temperature range, TX − TN	°C
SU	Summer Days	Annual number of days with TX > 25 °C	days
SU30	Hot Summer Days	Annual number of days with TX > 30 °C	days
TR	Tropical Nights	Annual number of days with TN > 20 °C	days
TR16C	Temperate Nights	Annual number of days with TN > 16 °C	days
ID	Ice Days	Annual number of days with TX < 0 °C	days
FD	Frost Days	Annual number of days with TN < 0 °C	days
CSDI	Cold Spells	Annual count of days with at least 6 consecutive days when TN < 10th historical percentile	days
WSDI	Warm Spells	Annual count of days with at least 6 consecutive days when TX > 90th historical percentile	days

GSL	Growing Season Length	Growing season length (number of days between first span of at least 6 days with TM > 5 °C and first span after July 1st of 6 days with TM < 5 °C)	days
Climdex: Precipitation-based			
CDD	Consecutive Dry Days	Annual maximum length of consecutive dry days (PR < 1 mm)	days
CWD	Consecutive Wet Days	Annual maximum length of consecutive wet days (PR ≥ 1 mm)	days
SDII	Simple Daily Precipitation Intensity Index	Annual average PR on days with PR ≥ 1mm	mm
R1MM	Precipitation ≥ 1mm	Annual count of days with PR ≥ 1mm	days
R10MM	Precipitation ≥ 10mm	Annual count of days with PR ≥ 10mm	days
R20MM	Precipitation ≥ 20mm	Annual count of days with PR ≥ 20mm	days
RX1DAY	Maximum 1-Day PR	Annual/seasonal maximum 1-day PR	mm
RX2DAY	Maximum 2-Day PR	Annual/seasonal maximum 2-day PR	mm
RX5DAY	Maximum 5-Day PR	Annual/seasonal maximum 5-day PR	mm
RN1DAY	Maximum 1-Day RAIN	Annual/seasonal maximum 1-day rainfall	mm
RN2DAY	Maximum 2-Day RAIN	Annual/seasonal maximum 2-day rainfall	mm
RN5DAY	Maximum 5-Day RAIN	Annual/seasonal maximum 5-day rainfall	mm
R95P	Very Wet Day PR	Annual total PR when PR > 95th percentile of daily PR in historical period	mm
R95DAYS	Very Wet Days	Annual number of days when PR > 95th percentile of daily PR in historical period	days
R99P	Extreme Wet Day PR	Annual total PR when PR > 99th percentile of daily PR in historical period	mm
R99DAYS	Extreme Wet Days	Annual number of days when PR > 99th percentile of daily PR in historical period	days
Degree Days			
CDDcold18C	Cooling Degree Days	Annual, cumulative TM difference above 18 °C	°C-days
GDDgrow5C	Growing Degree Days	Annual, cumulative TM difference above 5 °C	°C-days
HDDheat18C	Heating Degree Days	Annual, cumulative TM difference below 18 °C	°C-days
FDDfreeze0C	Freezing Degree Days	Annual, cumulative TM difference below 0 °C	°C-days
Heatwave Indices			
HWD	Heatwave (HW) days	Annual count of HW days, where a HW is defined as both TX and TN exceeding: 1) their 95th percentiles (historical),	days

		AND; 2) BC HARS thresholds* for at least 2 consecutive days.	
HWN	HW number	Annual number of distinct HWs	#
HWXL	HW duration	Annual maximum HW length	days
TNH	HW intensity (night)	Average TN over all HWs in a year	°C
TXH	HW intensity (day)	Average TX over all HWs in a year	°C
TNHX	Maximum TNH	Average TN during most extreme HW in a year	°C
TXHX	Minimum TNH	Average TX during most extreme HW in a year	°C
HWDD	HW degree days	Annual, cumulative TM difference above HW threshold	°C-days
Return Levels			
TX_RP5	5-Year return level of TX	5-Year return level of TX	°C
TX_RP10	10-Year return level of TX	10-Year return level of TX	°C
TX_RP20	20-Year return level of TX	20-Year return level of TX	°C
TX_RP25	25-Year return level of TX	25-Year return level of TX	°C
TX_RP30	30-Year return level of TX	30-Year return level of TX	°C
TN_RP5	5-Year return level of TN	5-Year return level of TN	°C
TN_RP10	10-Year return level of TN	10-Year return level of TN	°C
TN_RP20	20-Year return level of TN	20-Year return level of TN	°C
TN_RP25	25-Year return level of TN	25-Year return level of TN	°C
TN_RP30	30-Year return level of TN	30-Year return level of TN	°C
RN1_RP5	5-Year return level of RN1DAY	5-Year return level of RN1DAY	mm
RN1_RP10	10-Year return level of RN1DAY	10-Year return level of RN1DAY	mm
RN1_RP20	20-Year return level of RN1DAY	20-Year return level of RN1DAY	mm
RN1_RP30	30-Year return level of RN1DAY	30-Year return level of RN1DAY	mm
RN1_RP50	50-Year return level of RN1DAY	50-Year return level of RN1DAY	mm
RN2_RP5	5-Year return level of RN2DAY	5-Year return level of RN2DAY	mm
RN2_RP10	10-Year return level of RN2DAY	10-Year return level of RN2DAY	mm
RN2_RP20	20-Year return level of RN2DAY	20-Year return level of RN2DAY	mm
RN2_RP30	30-Year return level of RN2DAY	30-Year return level of RN2DAY	mm
RN2_RP50	50-Year return level of RN2DAY	50-Year return level of RN2DAY	mm
RN5_RP5	5-Year return level of RN5DAY	5-Year return level of RN5DAY	mm
RN5_RP10	10-Year return level of RN5DAY	10-Year return level of RN5DAY	mm
RN5_RP20	20-Year return level of RN5DAY	20-Year return level of RN5DAY	mm
RN5_RP30	30-Year return level of RN5DAY	30-Year return level of RN5DAY	mm
RN5_RP50	50-Year return level of RN5DAY	50-Year return level of RN5DAY	mm