January 31, 2018

Supplemental Climate Information: Lake Louise (Banff), Yoho and Kootenay National Parks

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Contents

Preface

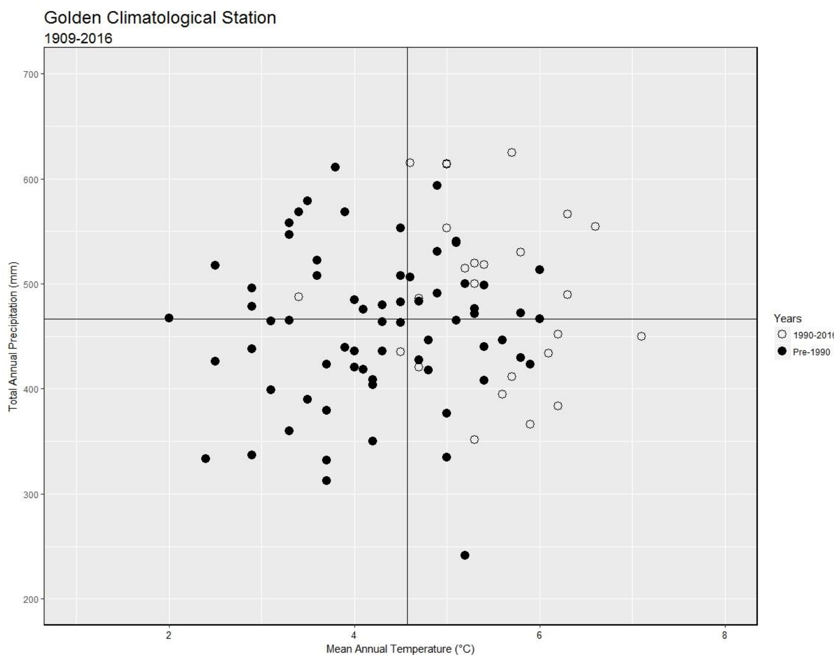
This document is a detailed supplement to the "Let's Talks about Climate Change: Mountain Region" report (Parker, 2017) and is intended to provide reference material to support climate change adaptation discussions in Lake Louise (Banff), Yoho and Kootenay National Parks.

The climate in the region varies considerably in space and time and is influenced by factors such as latitude, topography and elevation. To better understand regional climate patterns see Janz and Storr (1977). While there are several meteorological stations in the region, most only have relatively short or seasonal datasets and for reporting longer term trends only those stations available in the AHCCD database (ECCC, 2017) were used (e.g., Banff, Golden). Interpolated data or data from other meteorological stations (e.g., Peyto Moraine, Bow Hut, etc…) could be considered in future analysis if required.

Future climate projections are modelled with several greenhouse gas concentration trajectories, called **Representative Concentration Pathways (RCP)** (Vuuren *et al.*, 2011). They describe possible climate futures and are named after respective radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6, +4.5 and +8.5 watts/m^2). **RCP 2.6** assumes we take action and greenhouse gas emissions peak in 2010-2020 and decline thereafter. **RCP 4.5** assumes emissions peak around 2040 and then decline. **RCP 8.5** assumes we take no action and emissions continue to rise throughout the 21st century.

Highlights

- Mean annual air temperature for the region has increased by 1.5-2.2 ˚C since 1950. The greatest warming generally being observed in winter months and nighttime periods.
- The warming trend is projected to continue and model results indicate a further increase of 2-8 ˚C by 2100 depending on the location and RCP scenario used.
- Total annual precipitation is variable, while no clear trend is observed for Banff, Golden has shown a slight increase, particularly in rain amounts in the spring.
- Today's "one in 100 year" rainfall event (22-48 mm/hr) is projected to become a "one in 25-50 year" event and the future "one in 100 year" event is projected to increase by an additional 6-9 mm/hr.
- The growing season has already increased by 16 days since 1900 and will continue to increase by as much as 80 days by 2100 under RCP 8.5.
- Wildfire season length is expected to increase.
- The alpine treeline is projected to continue to move upslope.
- Climate effects on stream flow are complex and influenced by factors such as glacial loss, decreased snow pack and rain on snow events. While declines in peak flows have been reported, large flood events still occur.
- Glacial loss is evident and projected to continue.



From this plot for Golden, mean annual temperatures appear to have increased in the past few decades while precipitation remains variable.

Disclaimer

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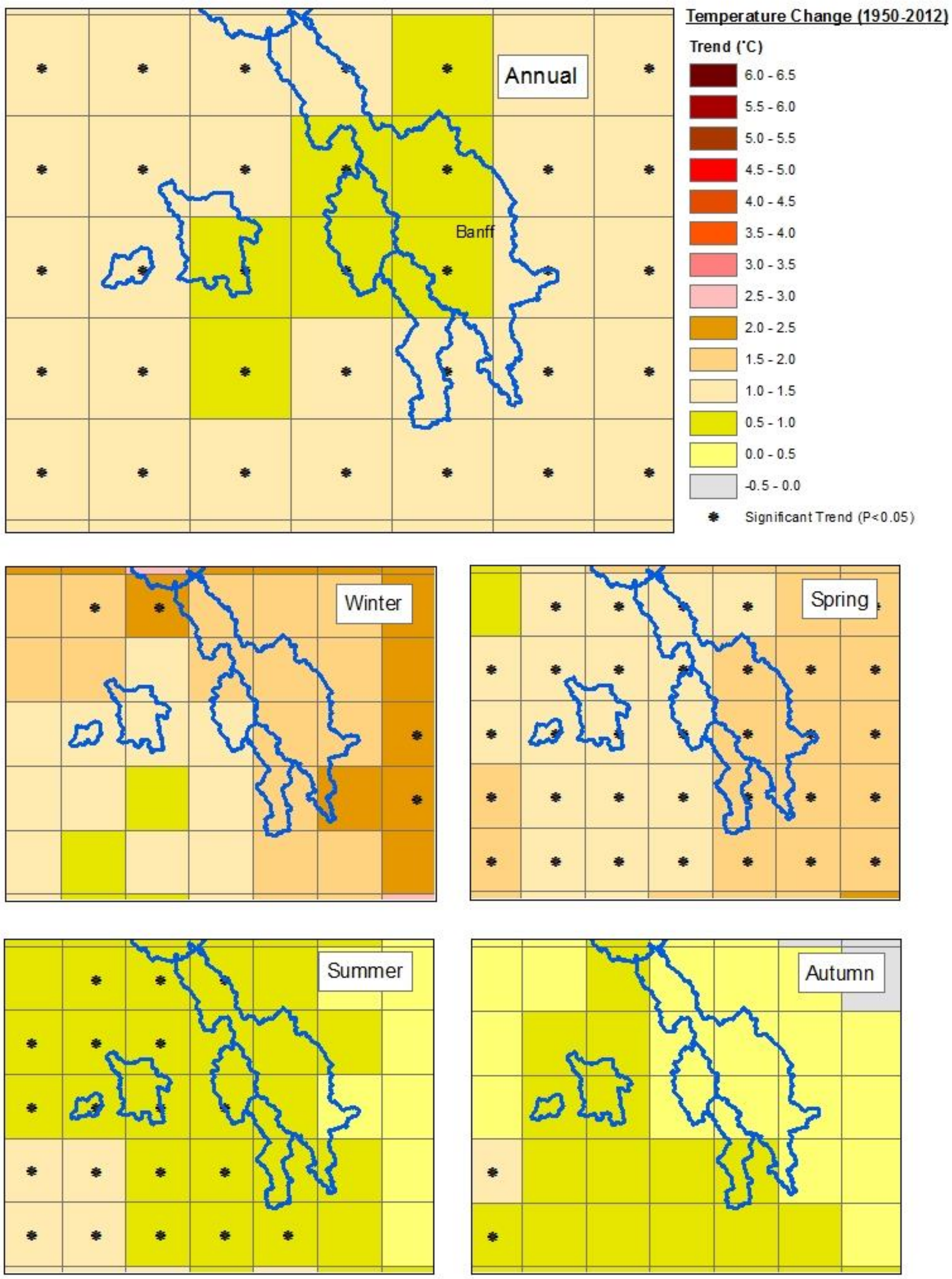
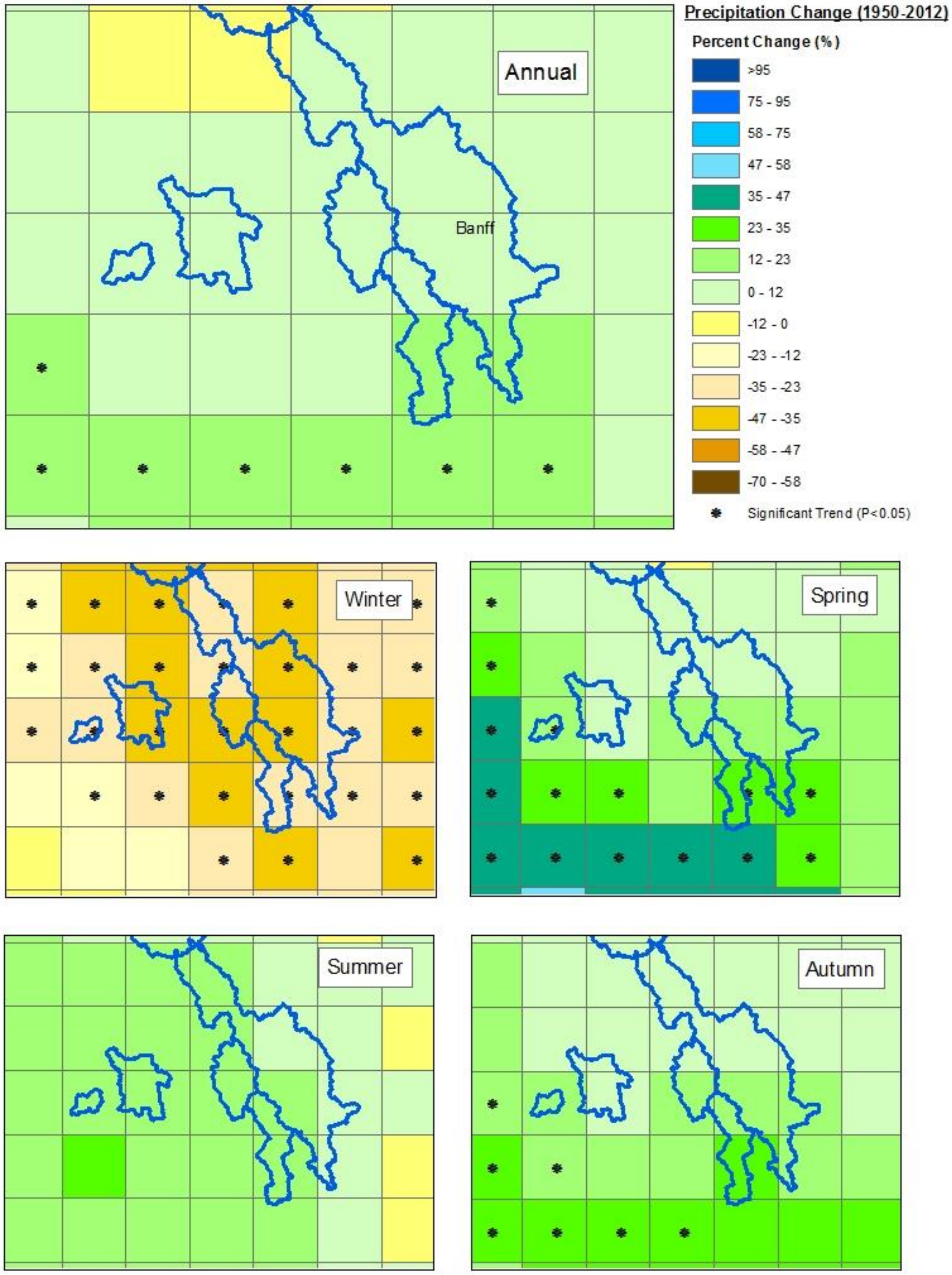
1. Observed Climate Trends

DeBeer *et al.* (2016) analyzed annual and seasonal temperature and precipitation CANGRD (http://open.canada.ca/data/en/dataset/3d4b68a5-13bc-48bb-ad10-801128aa6604) data for the period 1950–2012 and derived trends following Zhang *et al*. (2000).



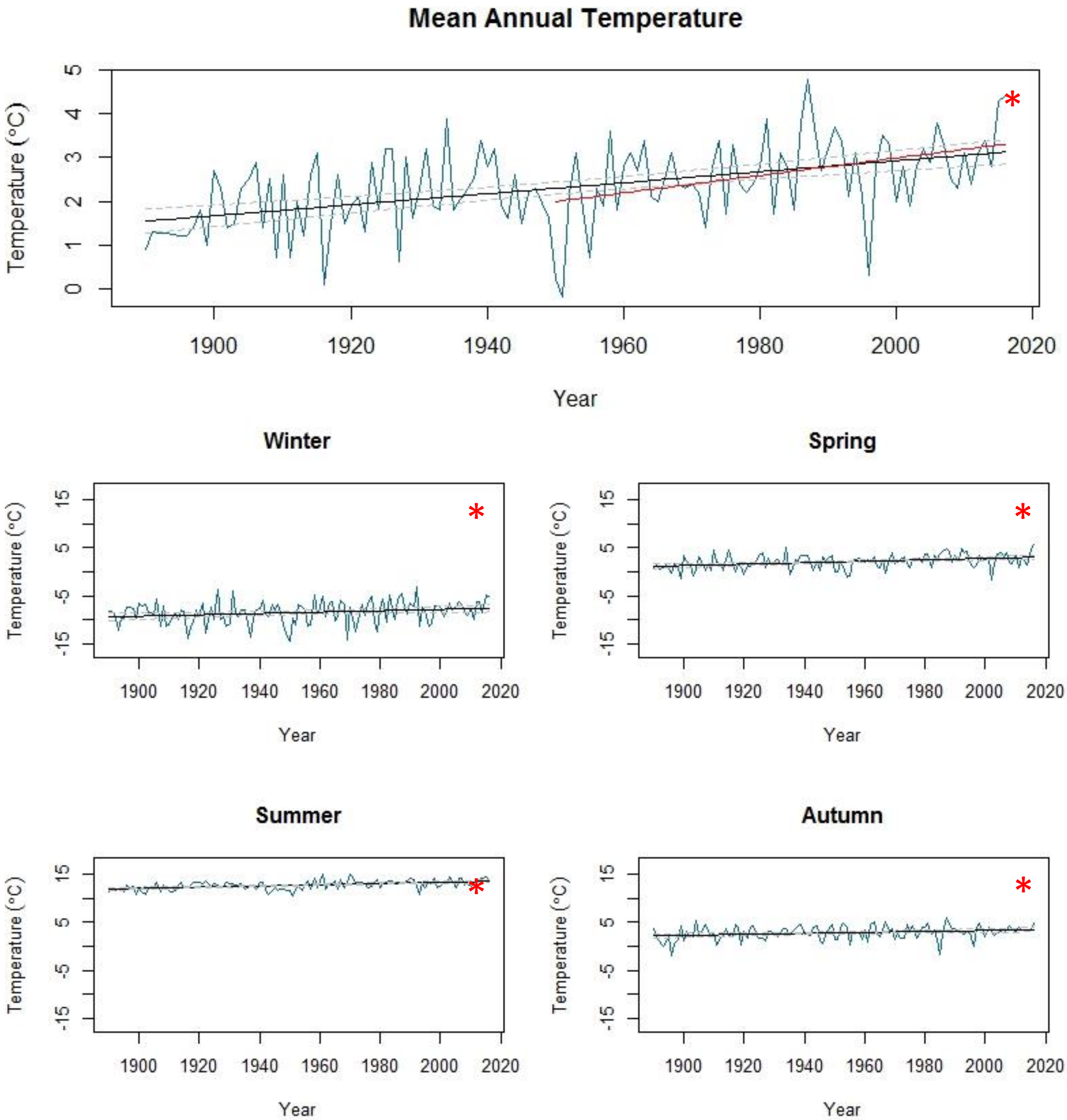
Mean annual and seasonal temperature trends (˚C per 63 years) from 1950-2012 based on DeBeer *et al.'s* (2016) analysis of CANGRD temperature data (grateful to Dr. Chris DeBeer for providing key data and Jeff Truscott for helping with GIS analysis). Statistically significant (P<0.05) trend for a given grid cell = *.



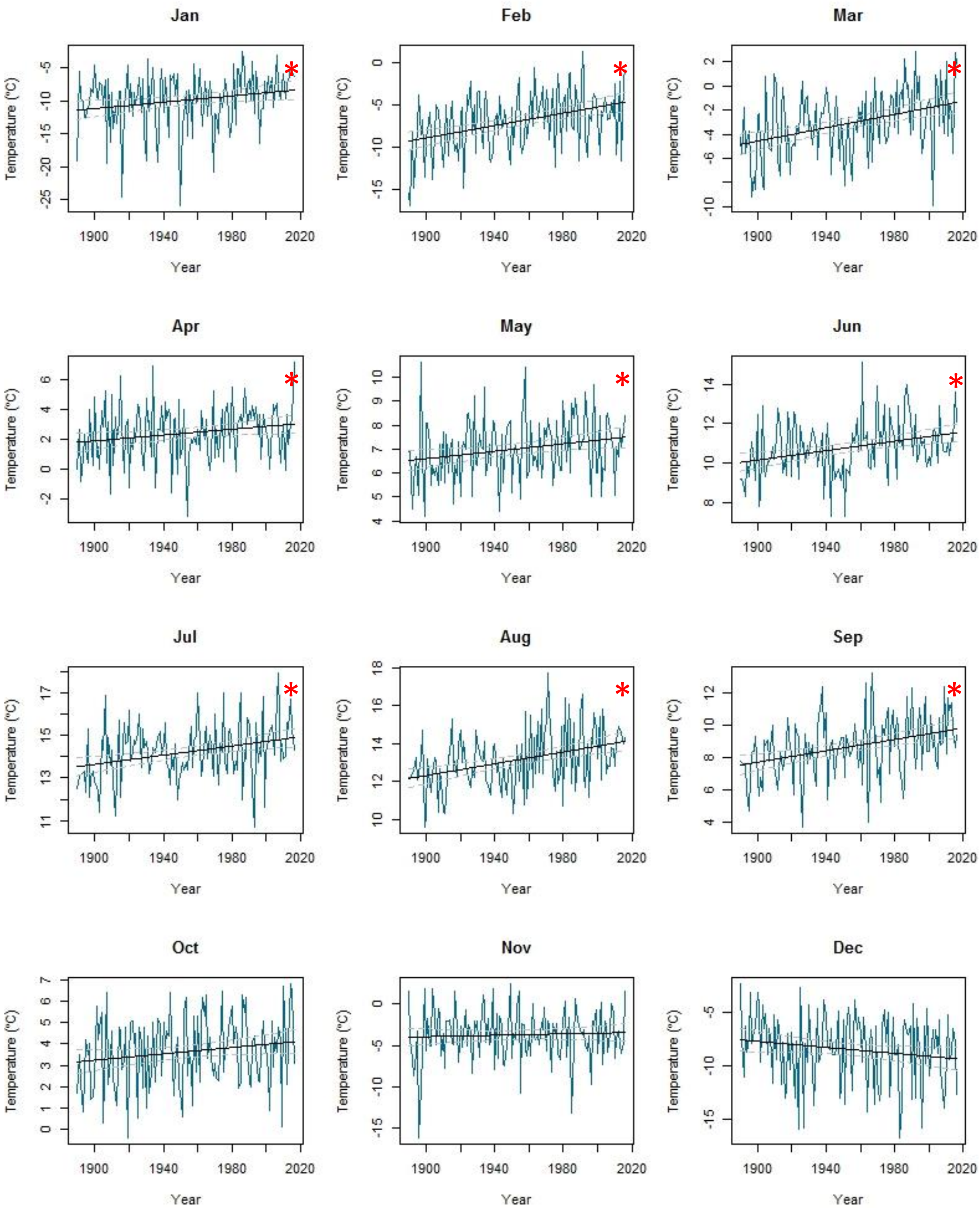
Percent change in annual and seasonal totals of precipitation (% per 63 years) from 1950-2012 based on DeBeer *et al.'s* (2016) analysis of CANGRD precipitation data (grateful to Dr. Chris DeBeer for providing key data and Jeff Truscott for helping with GIS analysis). Statistically significant (P<0.05) trend for a given grid cell = *.

1.1 Banff Temperature

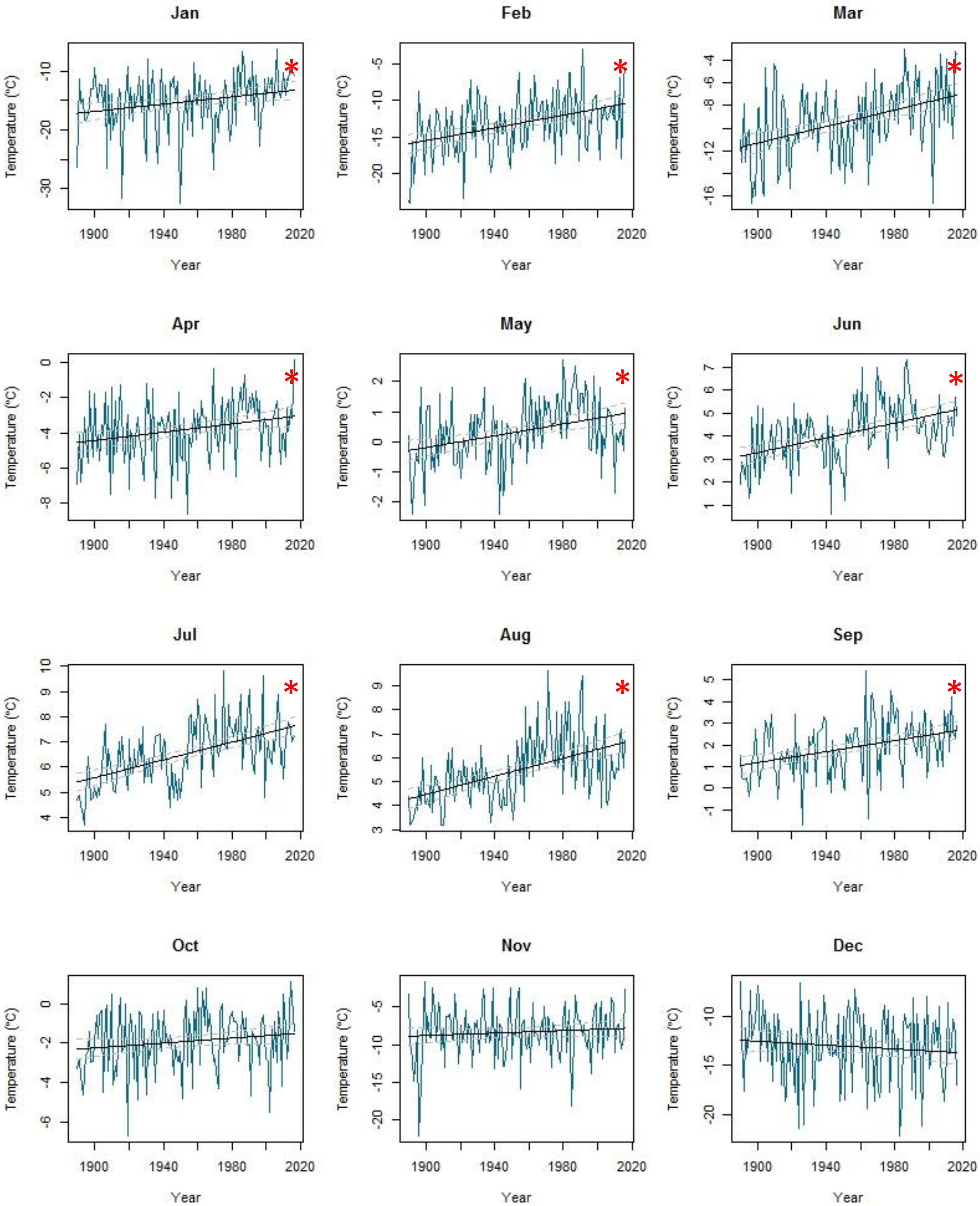
Mean annual, seasonal and monthly temperature at the Banff climatological station (3050519) from 1890 to 2016 (ECCC, 2017). Trend determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. The annual plot also includes the trend since 1950 (red line). "*" = statistically significant trend ($P<0.05$).



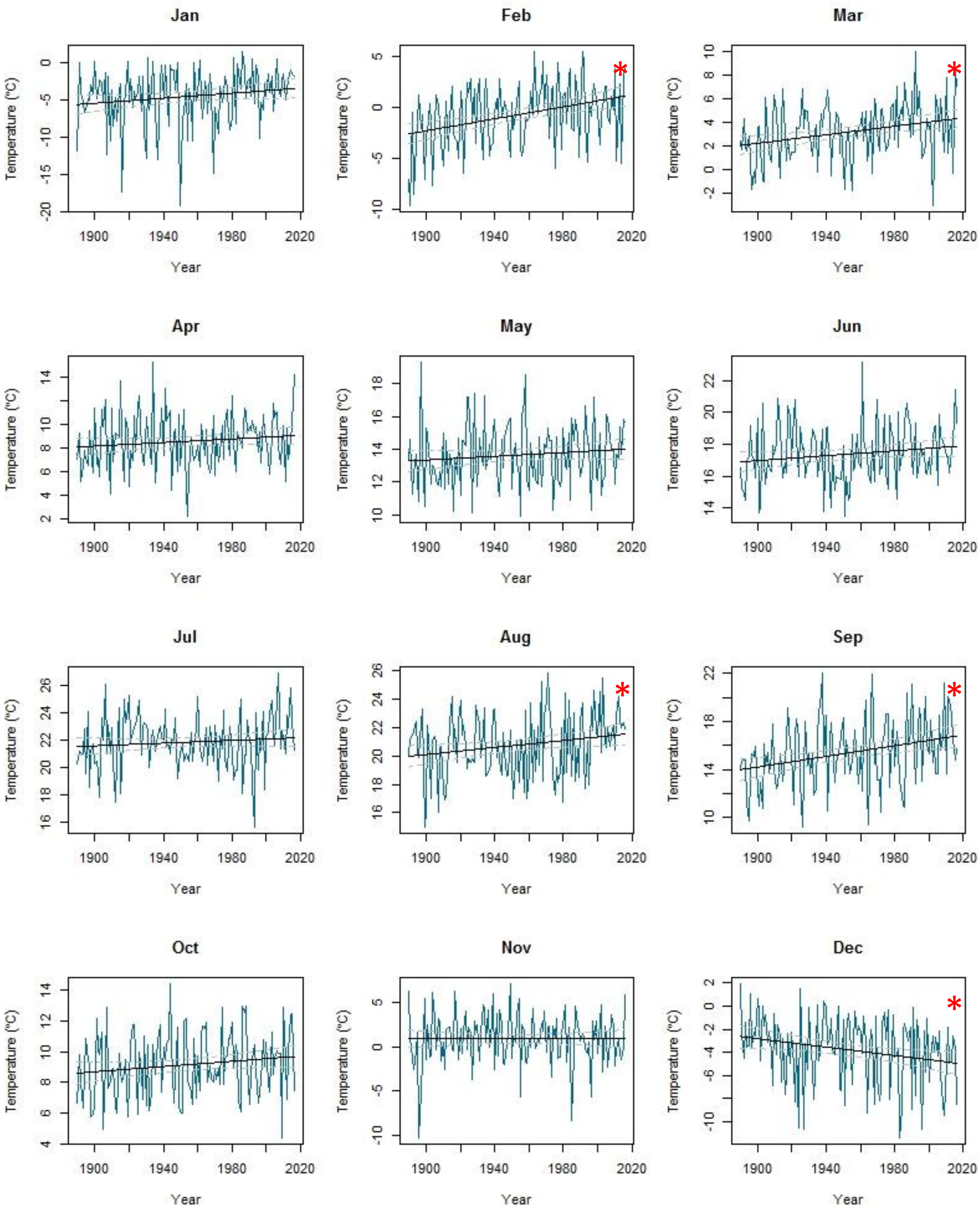
Banff mean annual and seasonal temperature. A statistically significant ($P<0.05$) increase observed in mean annual temperature, ~1.4°C since 1890 and ~2.2°C since 1950. A statistically significant ($P<0.05$) increase observed in mean seasonal temperature for all seasons. The greatest increase was observed for winter (Dec, Jan, Feb) and spring (Mar, Apr, May), ~1.5°C since 1890.



Banff mean monthly temperature. All months, except Oct, Nov and Dec, showed a statistically significant (P<0.05) increase. The greatest increase was observed for Feb, ~4°C since 1890. Dec is the only month which appears to show a slight decreasing trend in mean monthly temperature.



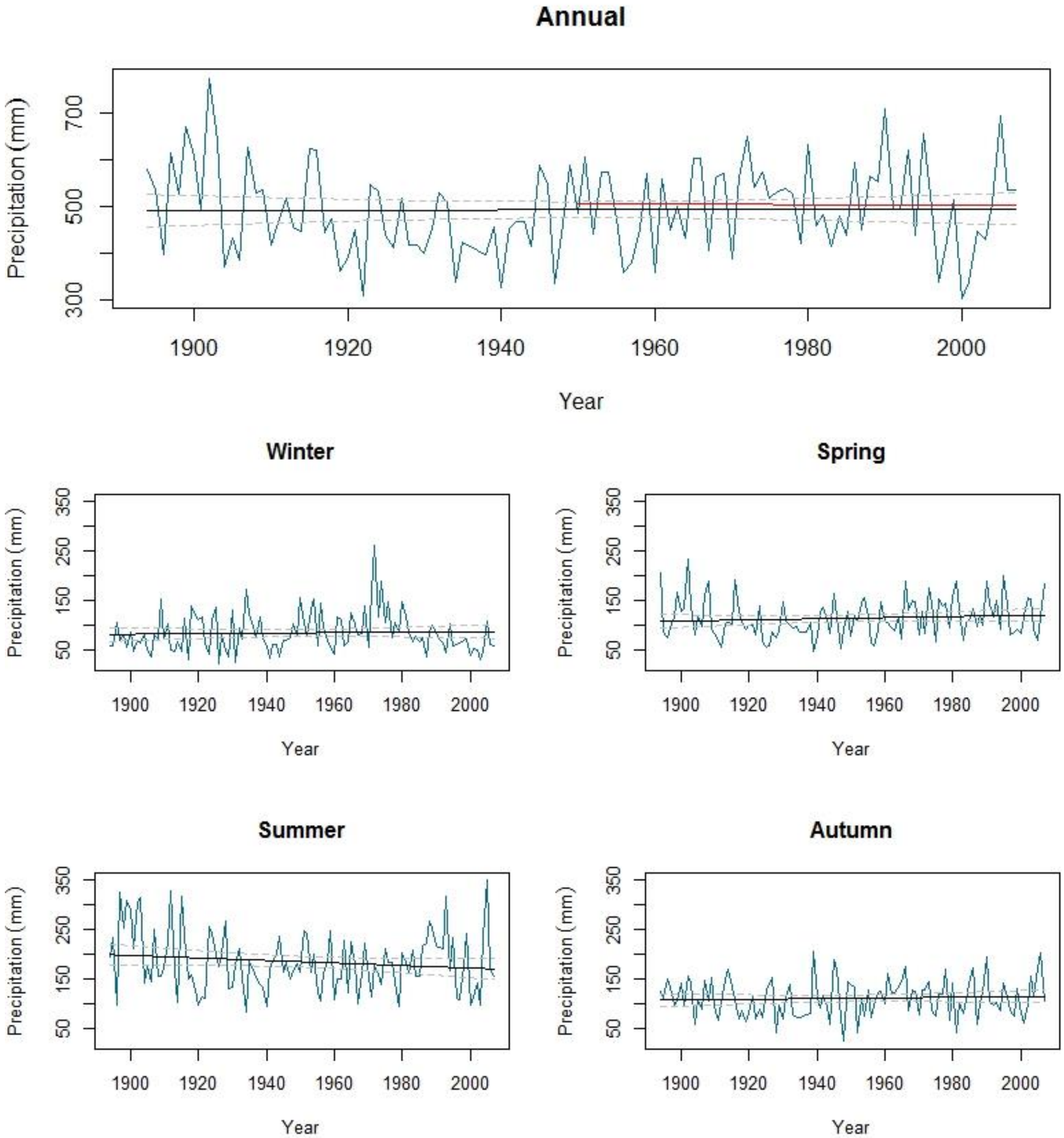
Banff mean monthly <u>minimum</u> temperature. All months, except Oct, Nov and Dec, showed a statistically significant ($P<0.05$) increase in mean monthly minimum temperature (i.e., nighttime). The greatest increase was observed for Feb, ~4.7°C since 1890. Dec is the only month which appears to show a slight decrease in mean monthly temperature.



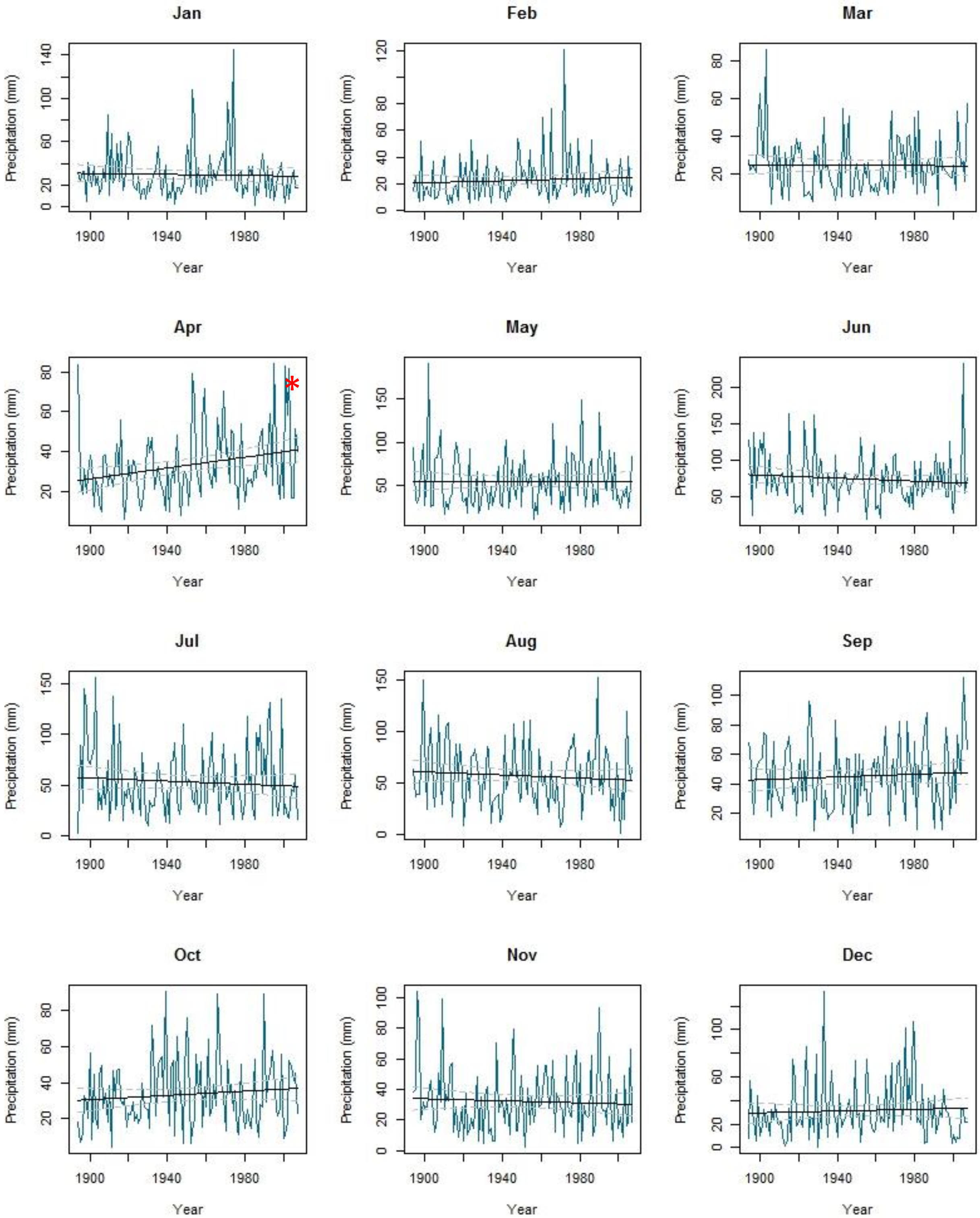
Banff mean monthly <u>maximum</u> temperature. Feb, Mar, Aug, Sep and Dec all demonstrated a statistically significant (P<0.05) trend in mean monthly maximum temperature (i.e., daytime). The greatest increase was observed for Feb, ~3.2°C since 1890. Dec was the only month to show a decrease, ~2°C since 1890.

1.2 Banff Precipitation

Total annual, seasonal and monthly precipitation at the Banff climatological station (3050519) from 1894 to 2007 (ECCC, 2017). Trend determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).

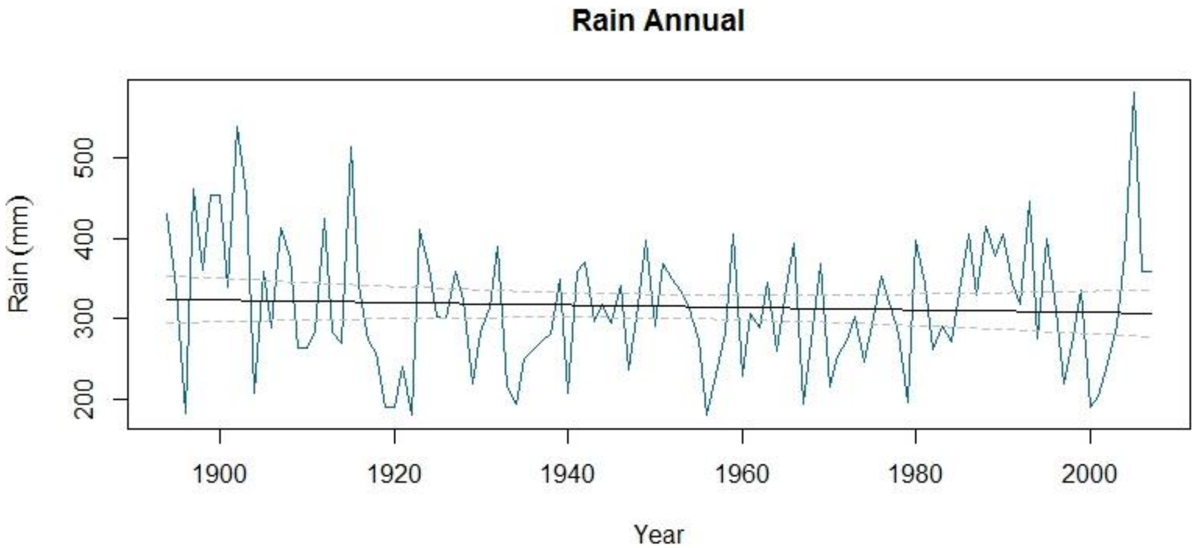


Banff total annual and seasonal precipitation. No statistically significant (P<0.05) trend is observed between 1894 and 2007. However, a slight decreasing trend is noted for the summer season (Jun, Jul, Aug).



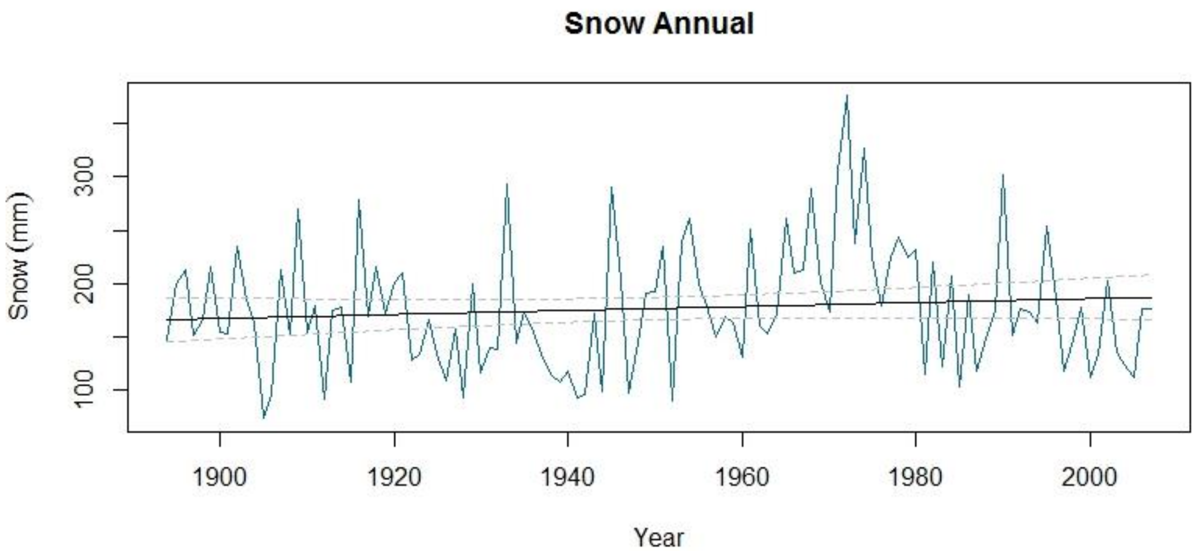
Banff total monthly precipitation. Apr has shown a statistically significant (P<0.05) increase since 1894, ~14.6 mm (53%). No other month shows a statistically significant (P<0.05) increase or decrease in total monthly precipitation, but slight trends may be noted.

Total Annual Rain



Total annual rain does not show a statistically significant (P<0.05) trend since 1894. Data is quite variable.

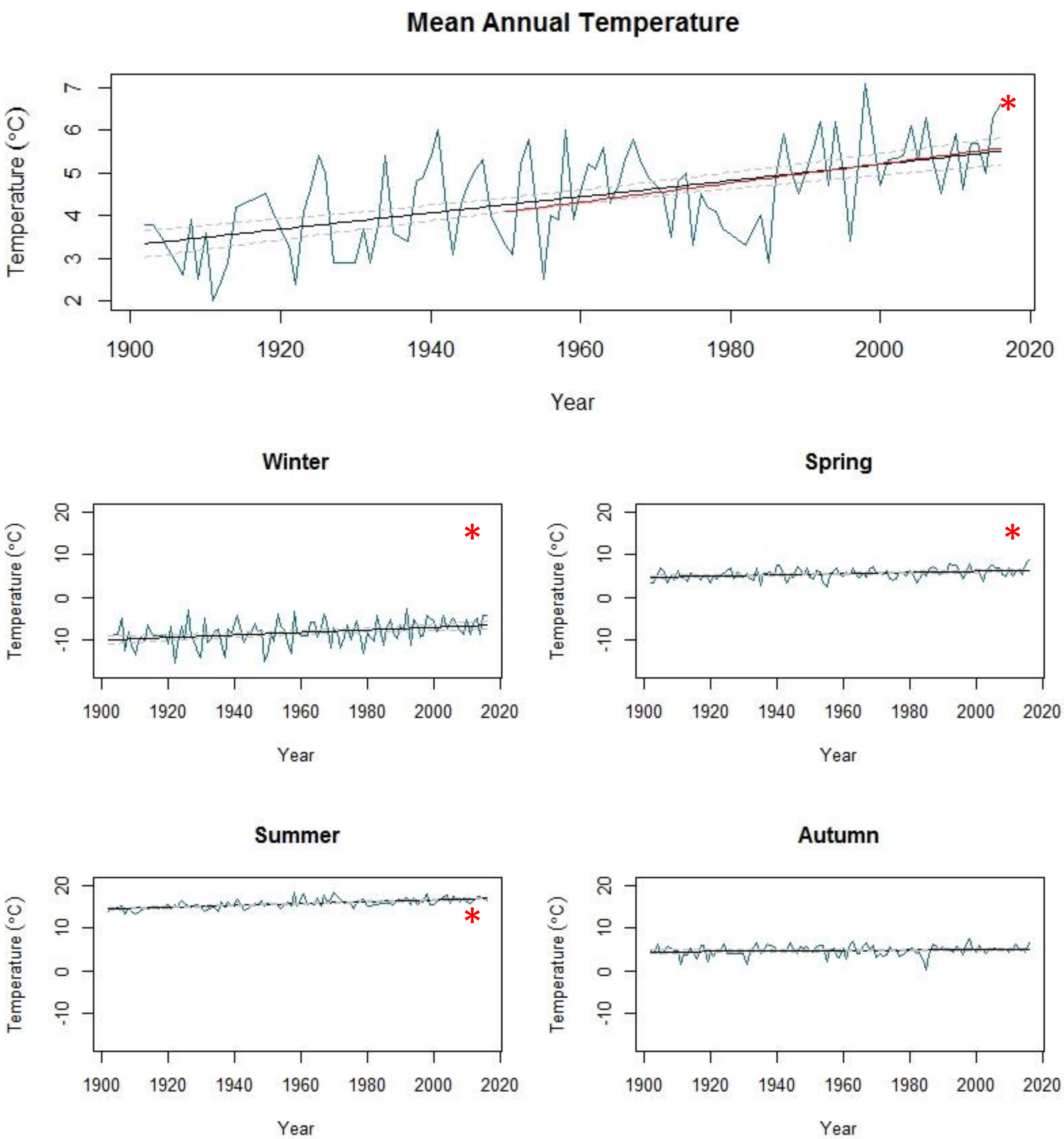
Total Annual Snow



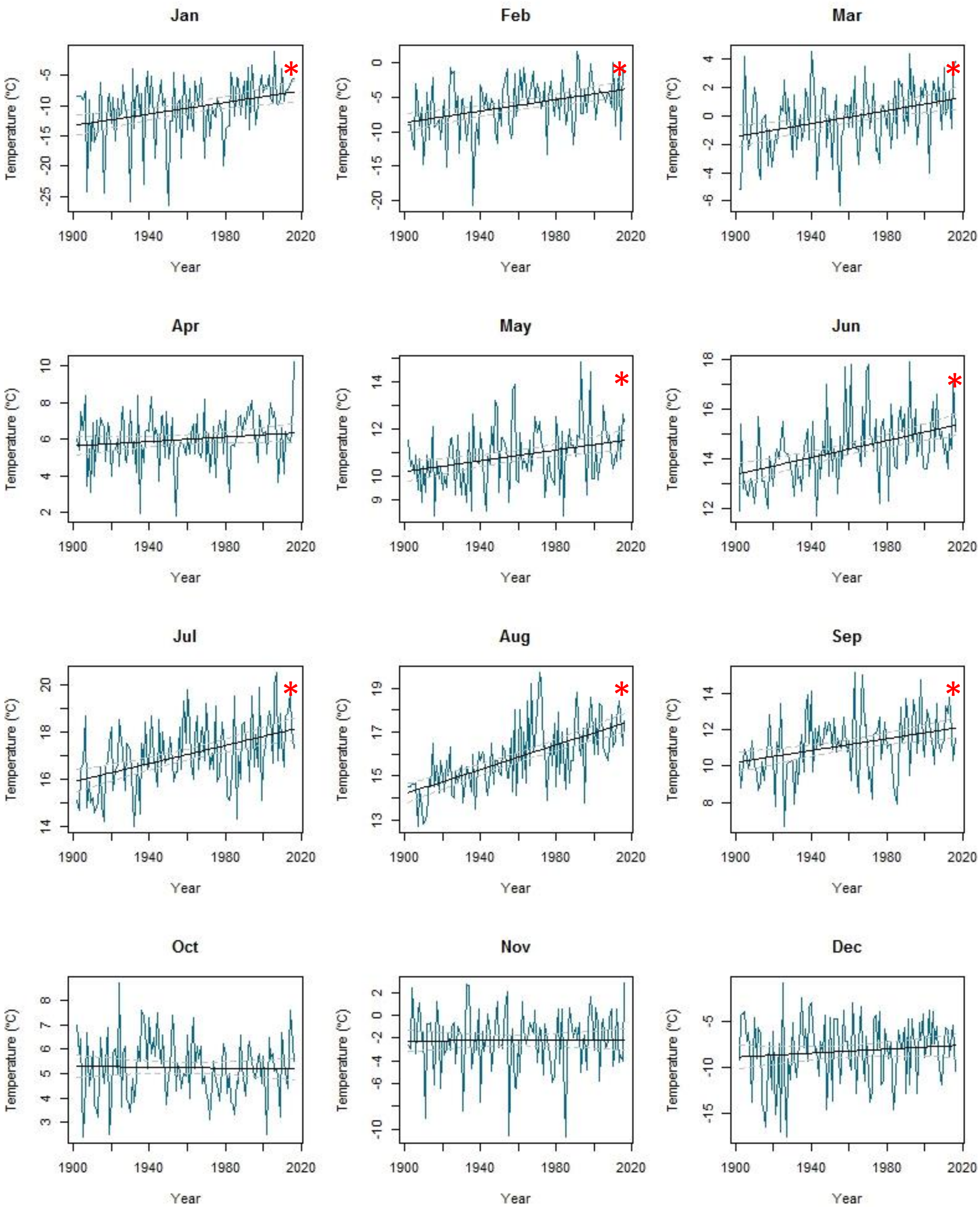
Total annual snow does not show a statistically significant (P<0.05) trend since 1894. Data is quite variable.

1.3 Golden Temperature

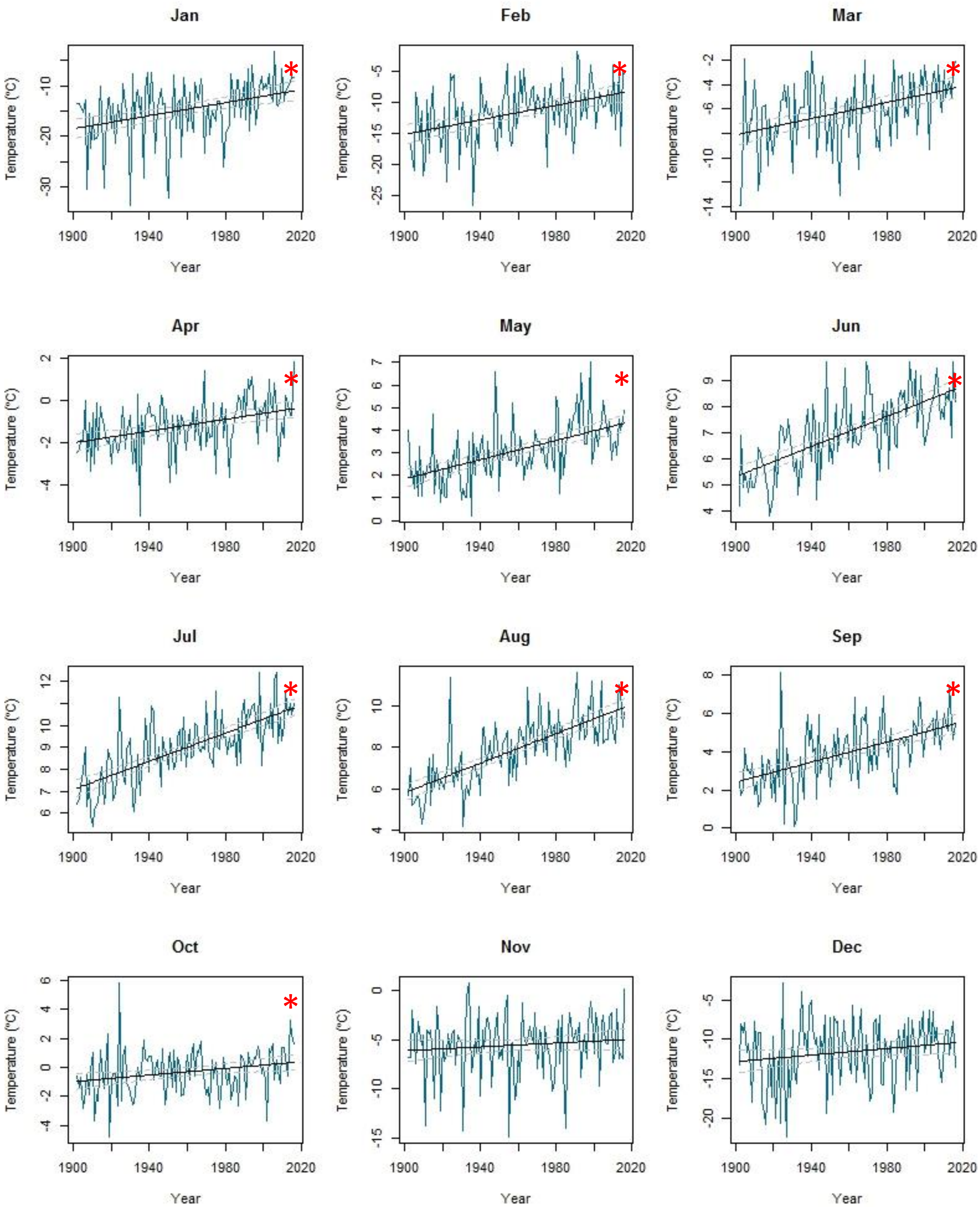
Mean annual, seasonal and monthly temperature at the Golden climatological station (1173210) from 1902 to 2016 (ECCC, 2017). Trend determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. The annual plot also includes the trend since 1950 (red line). "*" = statistically significant trend (P<0.05).



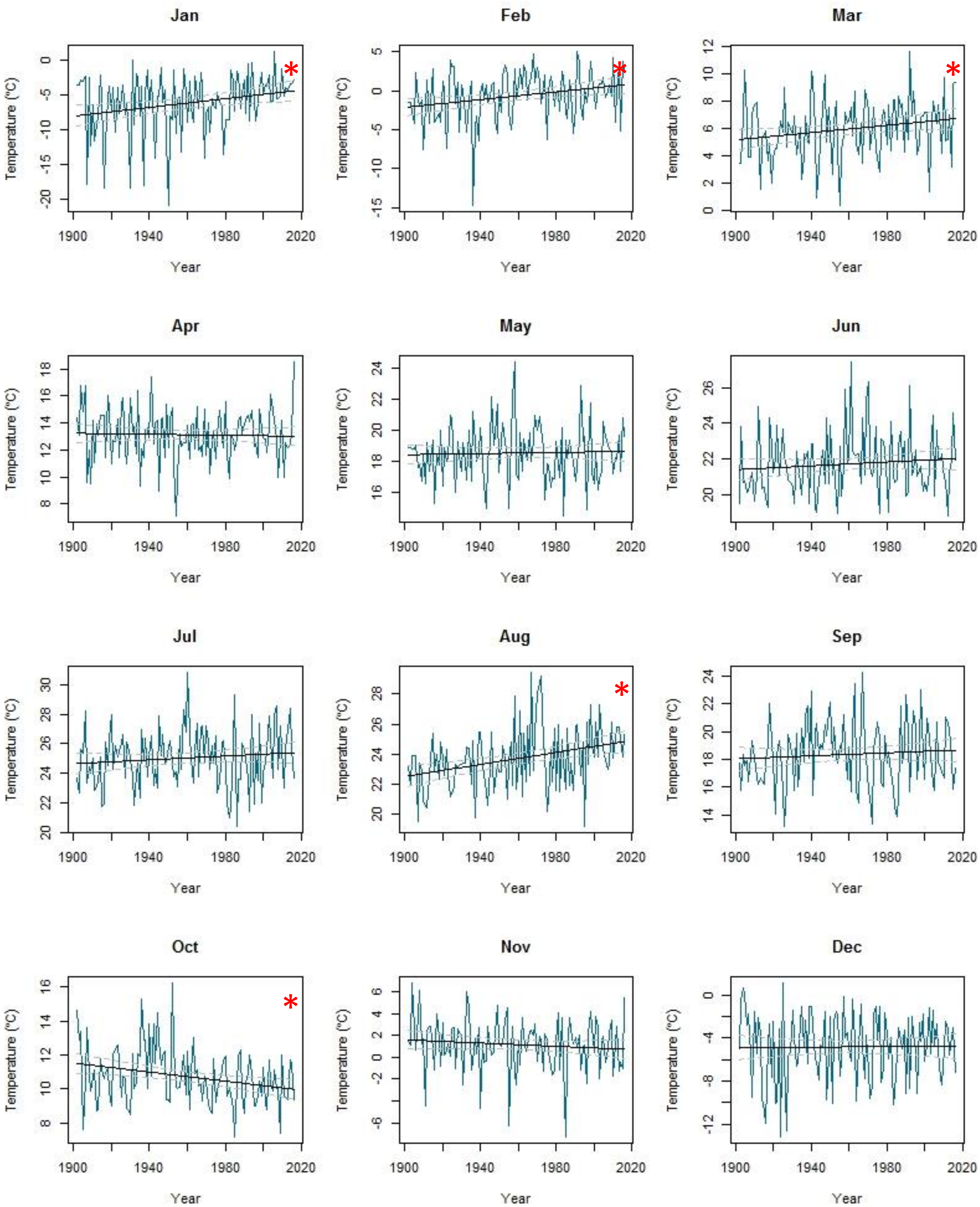
Golden mean annual and seasonal temperature. A statistically significant (P<0.05) increase is observed in mean annual temperature, ~2.2°C since 1902 and ~1.5°C since 1950. A statistically significant (P<0.05) increase in mean seasonal temperature observed for all seasons, except for autumn (Sep, Oct, Nov). The greatest increase was observed for winter (Dec, Jan, Feb), ~3.4°C since 1902.



Golden mean monthly temperature. All months except Apr, Oct, Nov and Dec have demonstrated a statistically significant (P<0.05) increase. The greatest increase was observed for Jan, ~4.4°C since 1902.



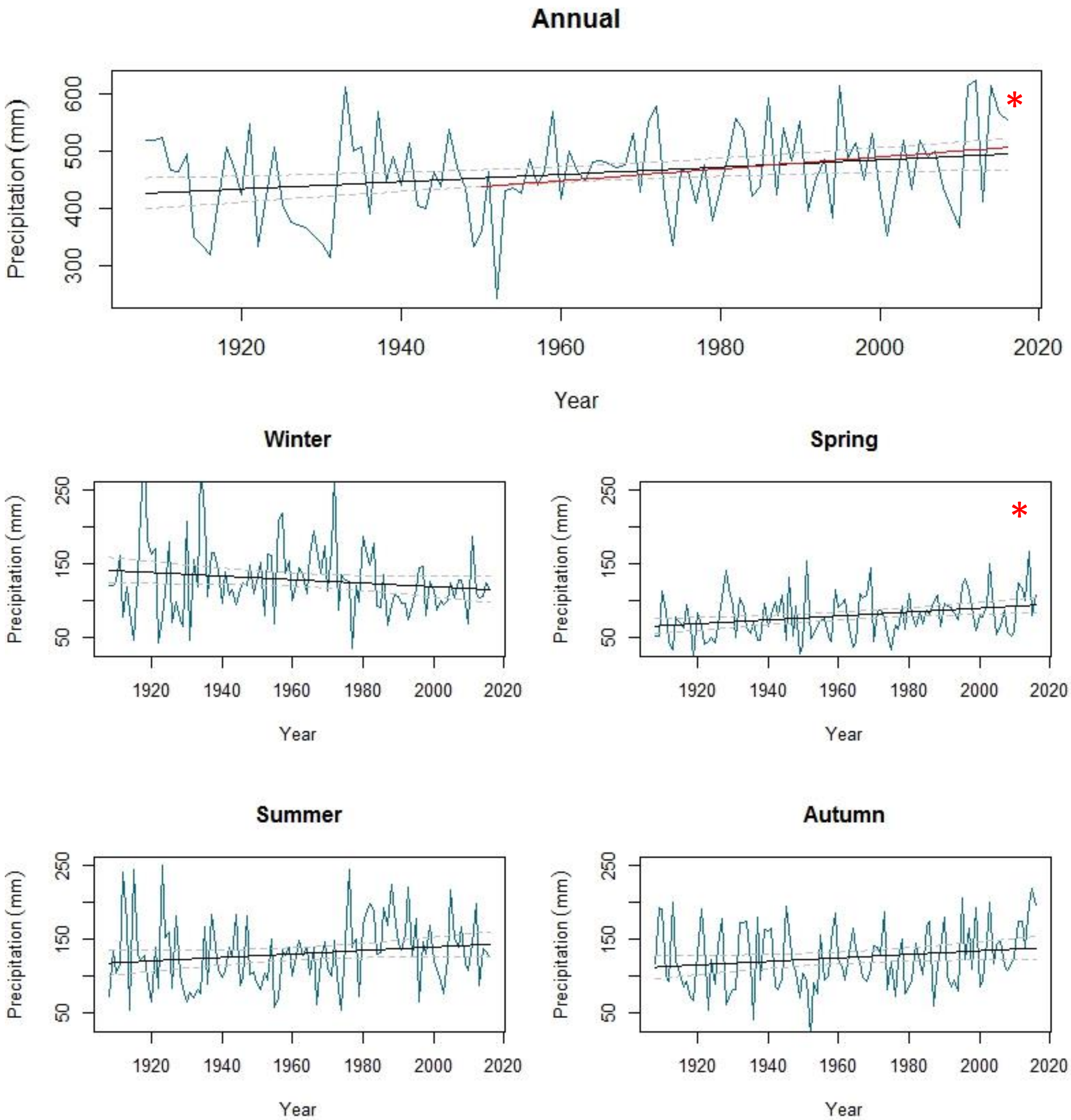
Golden mean monthly <u>minimum</u> temperature. All months except Nov and Dec have demonstrated a statistically significant ($P<0.05$) increase in mean monthly minimum temperature (i.e., nighttime). For example, the monthly mean for Jan has increased by ~7.1°C and Aug by ~4.1°C since 1902.



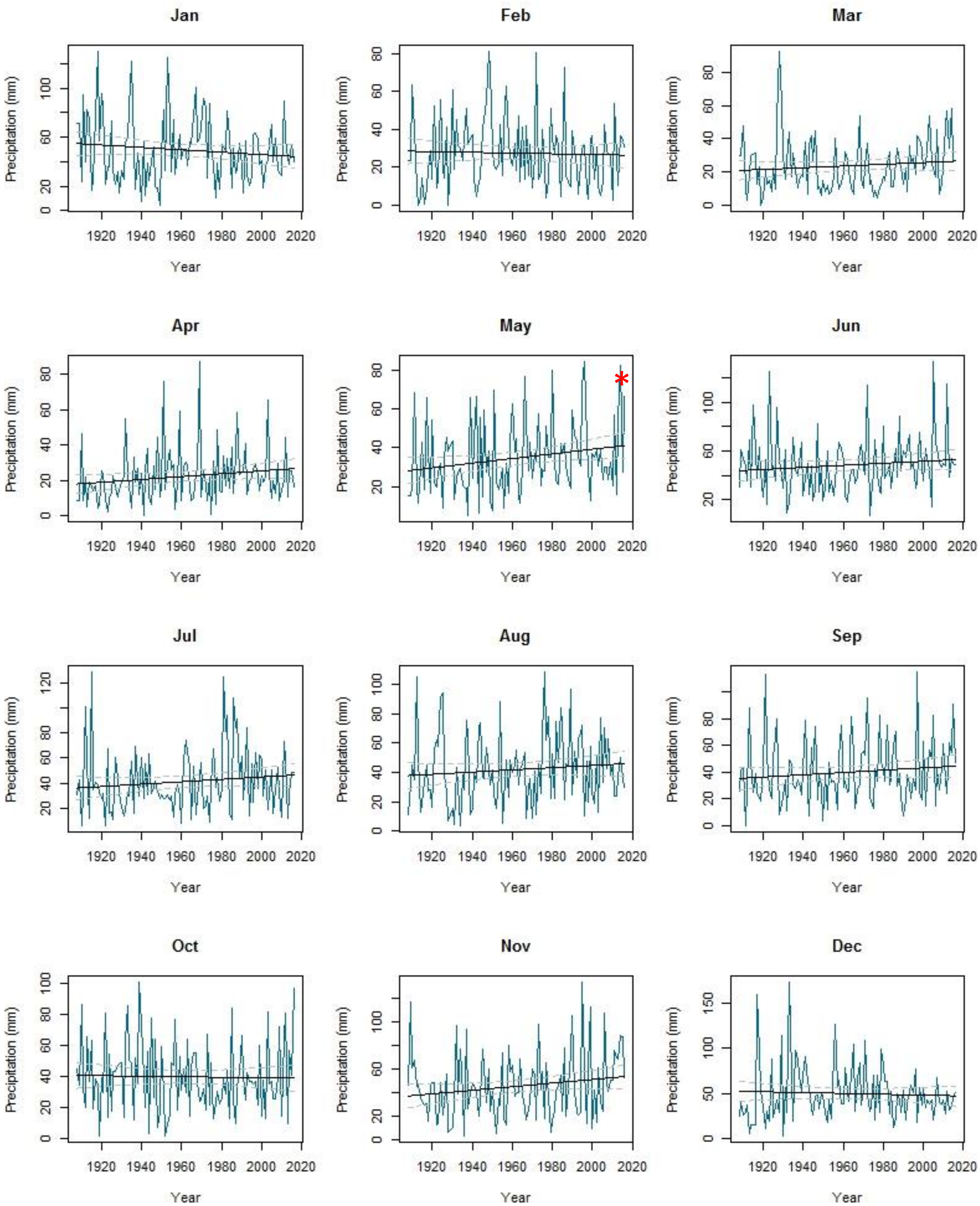
Golden mean monthly <u>maximum</u> temperature. Jan, Feb, Mar, Aug and Oct have all demonstrated a statistically significant ($P<0.05$) increase in mean monthly maximum temperature (i.e., daytime). The greatest increase was observed for Jan, ~3.5°C since 1902.

1.4 Golden Precipitation

Total annual, seasonal and monthly precipitation at the Golden climatological station (1173210) from 1908 to 2016 (ECCC, 2017). Trend determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).

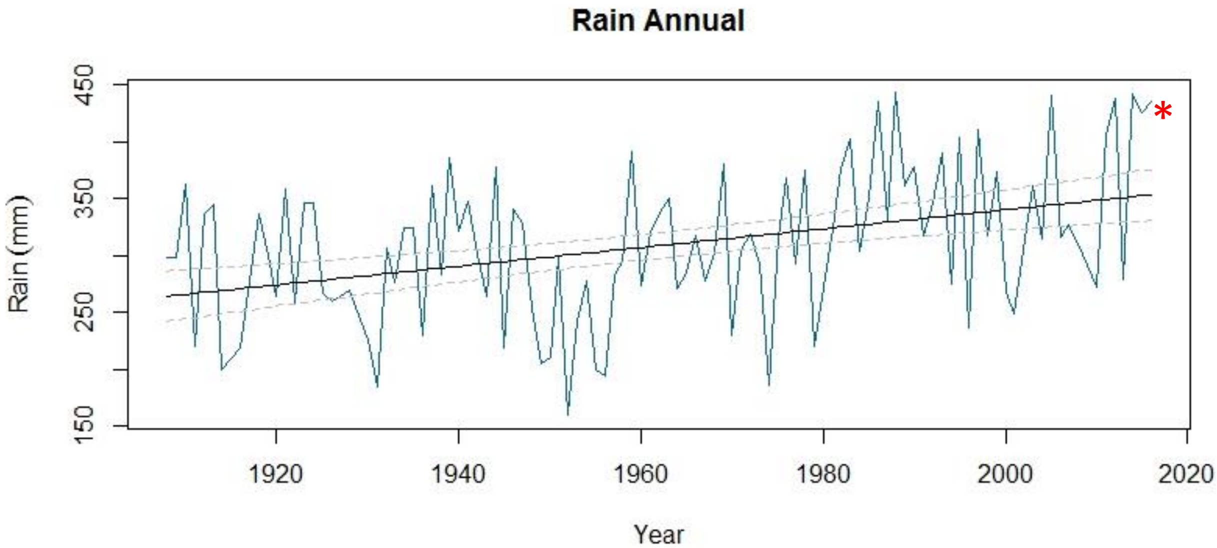


Golden total annual and seasonal precipitation. A statistically significant (P<0.05) increase by ~69 mm (16%) is observed since 1908. Of all the seasons, only spring (Mar, Apr, May) has shown a statistically significant (P<0.05) trend, increasing ~28.5 mm (43%) since 1908.



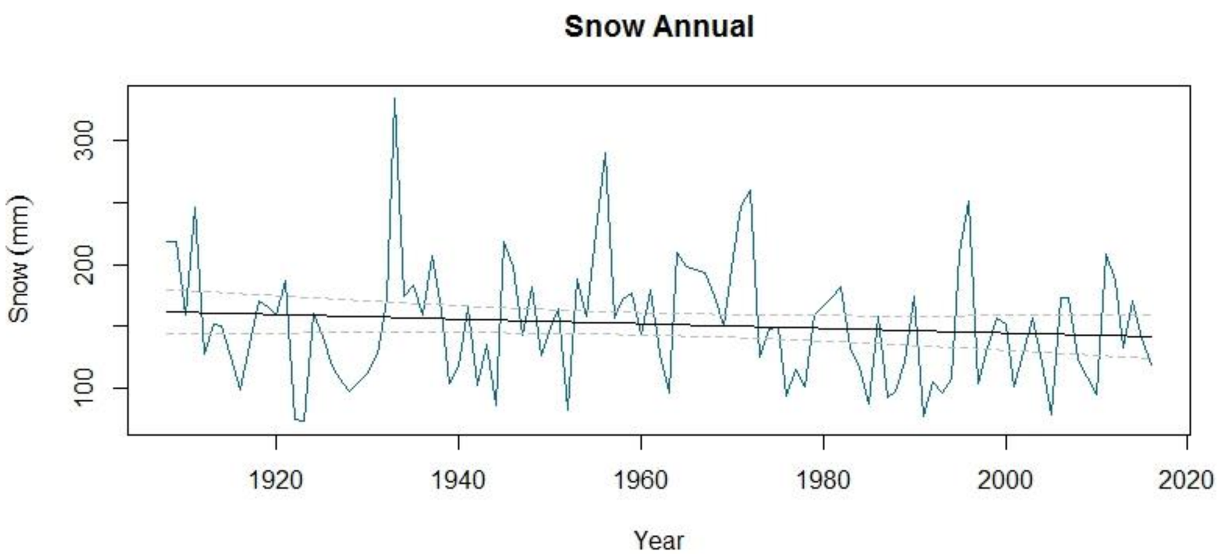
Golden total monthly precipitation. May is the only month to show a statistically significant ($P<0.05$) trend in total precipitation since 1908, ~13 mm (46%) increase.

Total Annual Rain



Total annual rain has shown a statistically significant (P<0.05) increase since 1908, ~89 mm (34%).

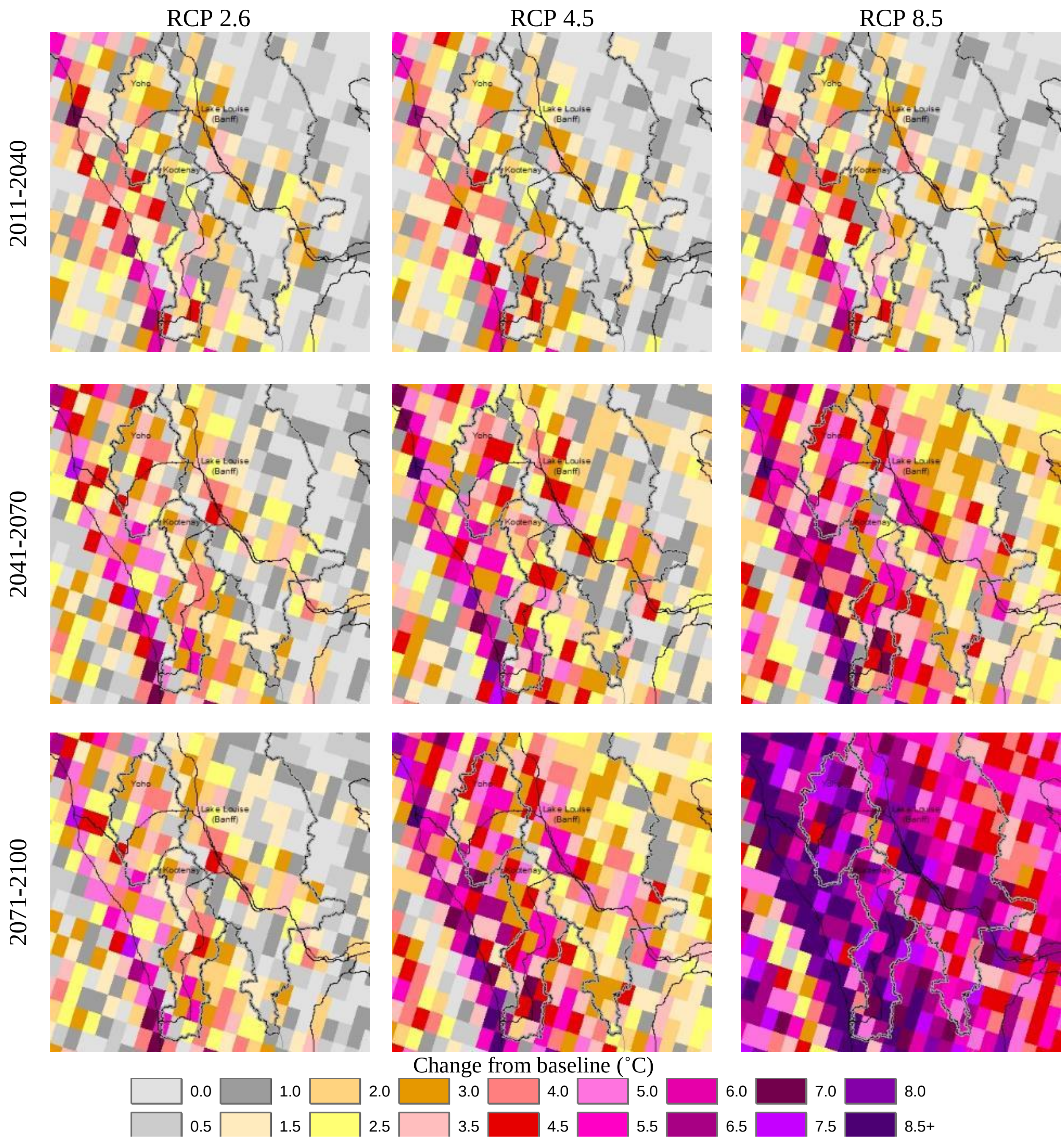
Total Annual Snow



Total annual snow has not shown a statistically significant (P<0.05) trend since 1908, however, a slight decreasing trend is observable.

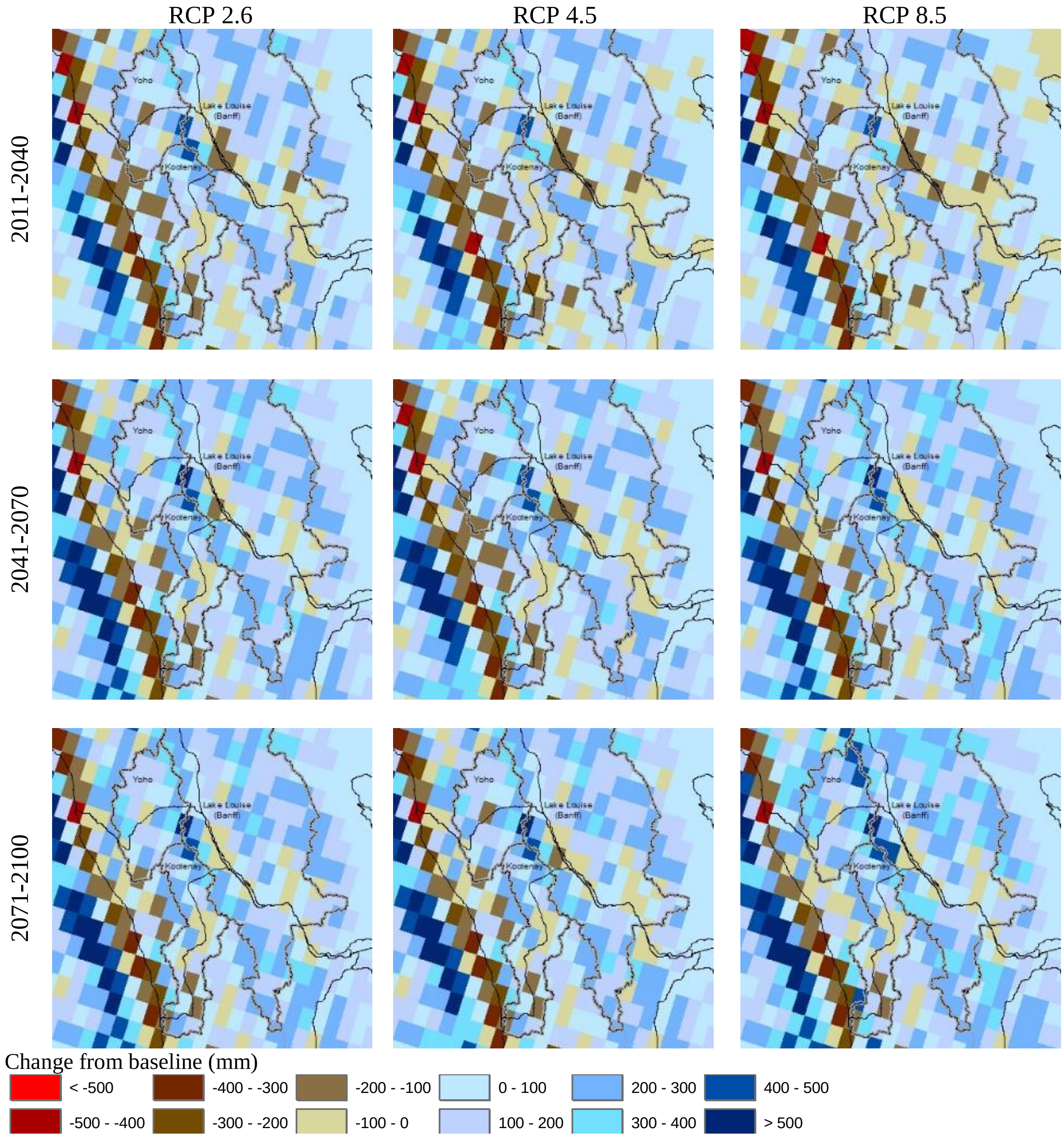
2. Projected Climate Trends

2.1 Temperature



Projected mean annual temperature increase for LLYK from a 1980-2010 baseline. Composite projection of CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011).

2.2 Precipitation

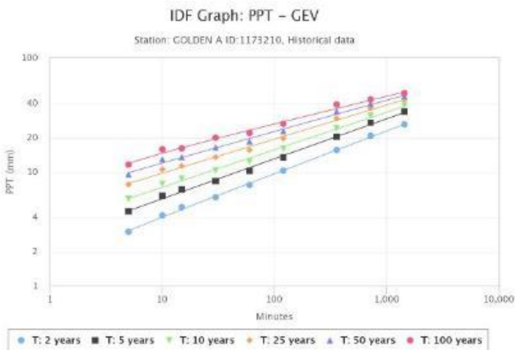


Projected total annual precipitation change for LLYK from a 1980-2010 baseline. Composite projection of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Data source Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011).

2.3 Rainfall Intensity, Duration and Frequency (IDF)

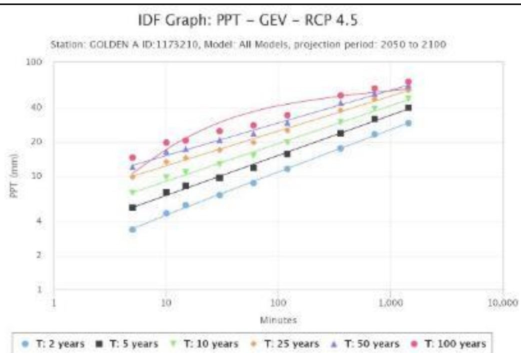
Extreme rainfalls calculated with Generalized Extreme Values (GEV) and an ensemble of climate models within IDF_CC Tool 2.0 (http://beta.idf-cc-uwo.ca/; see Simonovic *et al.* (2017)). Engineering datasets are also available at: http://climate.weather.gc.ca/prods_servs/engineering_e.html.

A. Golden Climatological Station (1173210)



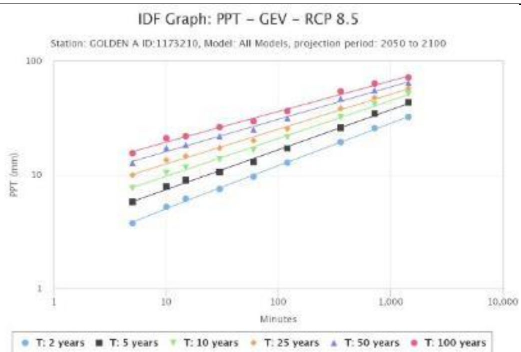
Baseline total precipitation amounts (mm) for Golden from 1973-2012 for different return periods (T).

T (years)	2	5	10	25	50	100
5 min	2.99	4.52	5.79	7.76	9.54	11.62
10 min	4.16	6.19	7.88	10.54	12.95	15.80
15 min	4.91	7.04	8.74	11.29	13.53	16.10
30 min	6.01	8.33	10.31	13.48	16.42	19.95
1 h	7.69	10.22	12.32	15.58	18.54	22.03
2 h	10.24	13.44	15.95	19.65	22.84	26.43
6 h	15.58	20.39	24.10	29.47	34.01	39.05
12 h	20.79	27.07	31.12	36.11	39.72	43.24
24 h	26.12	33.90	38.31	43.15	46.28	49.05



Projected (2050-2100) precipitation (mm) for Golden using an ensemble of models and **RCP 4.5**.

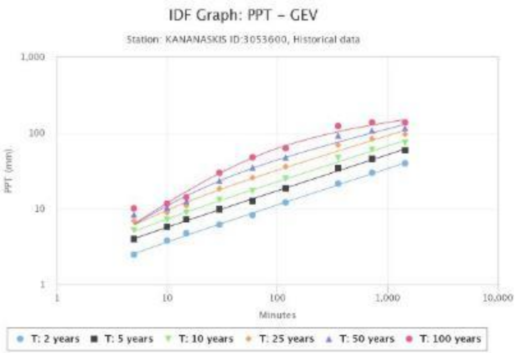
T (years)	2	5	10	25	50	100
5 min	3.37	5.27	7.11	9.83	12.09	14.54
10 min	4.69	7.20	9.67	13.32	16.40	19.70
15 min	5.53	8.19	10.76	14.41	17.34	20.54
30 min	6.78	9.64	12.58	16.94	20.75	24.78
1 h	8.68	11.83	15.06	19.71	23.63	27.86
2 h	11.53	15.62	19.64	25.14	29.47	34.25
6 h	17.53	23.71	29.72	37.81	44.04	50.97
12 h	23.28	31.72	38.86	47.30	53.09	58.95
24 h	29.20	39.95	47.86	56.79	62.83	67.32



Projected (2050-2100) precipitation (mm) for Golden using an ensemble of models and **RCP 8.5**.

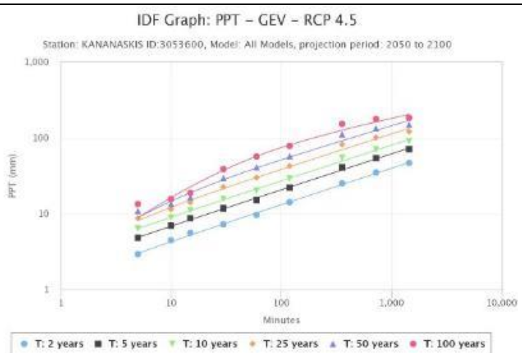
T (years)	2	5	10	25	50	100
5 min	3.76	5.80	7.67	9.99	12.79	15.55
10 min	5.24	7.93	10.45	13.54	17.33	21.05
15 min	6.18	9.00	11.63	14.63	18.42	21.95
30 min	7.55	10.63	13.74	17.25	21.91	26.38
1 h	9.65	13.02	16.49	20.07	25.06	29.61
2 h	12.83	17.14	21.41	25.55	31.44	36.48
6 h	19.49	26.00	32.35	38.41	46.95	54.34
12 h	25.87	34.58	41.89	47.86	55.66	63.67
24 h	32.44	43.43	51.63	57.80	64.56	71.92

B. Kanasaskis Climatological Station (3053600)



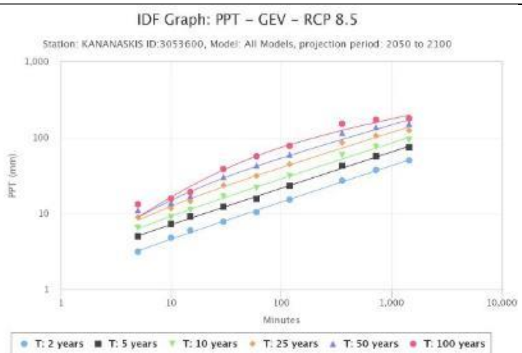
Baseline total precipitation amounts (mm) for Kanasaskis from 1973-2012 for different return periods (T).

T (years)	2	5	10	25	50	100
5 min	2.50	4.01	5.20	6.95	8.46	10.15
10 min	3.83	5.82	7.18	8.97	10.34	11.74
15 min	4.78	7.27	8.93	11.05	12.63	14.20
30 min	6.19	9.88	13.15	18.51	23.63	29.94
1 h	8.30	12.73	17.26	25.84	35.19	48.11
2 h	12.17	18.68	24.97	36.24	47.90	63.29
6 h	21.54	34.56	47.17	69.76	93.17	124.12
12 h	29.97	45.76	60.12	84.38	108.17	138.13
24 h	40.02	59.21	74.37	96.85	116.33	138.40



Projected (2050-2100) precipitation (mm) for Kanasaskis using an ensemble of models and **RCP 4.5**.

T (years)	2	5	10	25	50	100
5 min	2.94	4.83	6.43	8.79	10.95	13.50
10 min	4.51	7.02	8.97	11.50	13.54	15.74
15 min	5.63	8.78	11.16	14.18	16.53	19.00
30 min	7.28	11.86	15.76	22.69	29.81	38.95
1 h	9.73	15.20	20.40	30.20	41.32	57.18
2 h	14.27	22.24	29.24	42.77	57.81	78.93
6 h	25.31	41.13	55.30	82.47	112.49	154.41
12 h	35.18	54.35	70.93	101.70	134.69	178.18
24 h	47.04	71.57	90.90	121.80	151.00	184.98



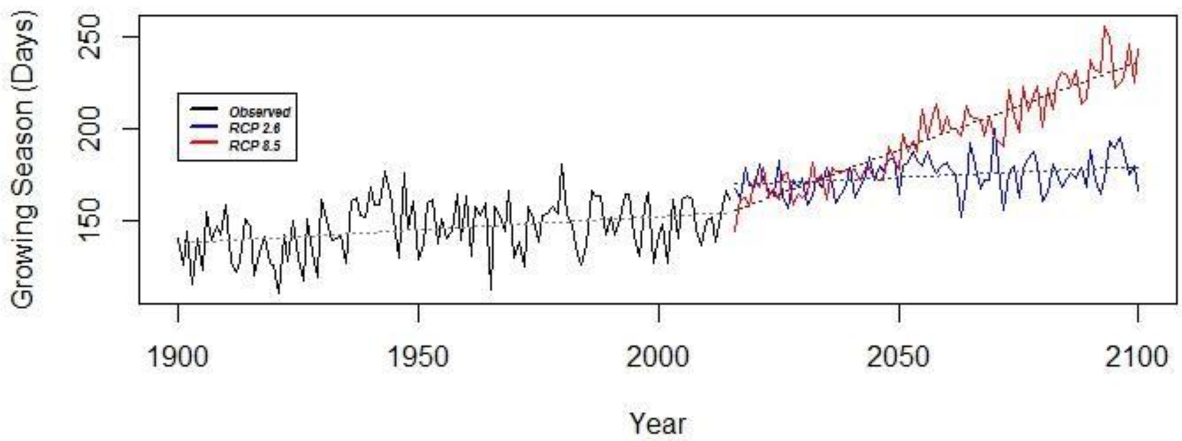
Projected (2050-2100) precipitation (mm) for Kanasaskis using an ensemble of models and **RCP 8.5**.

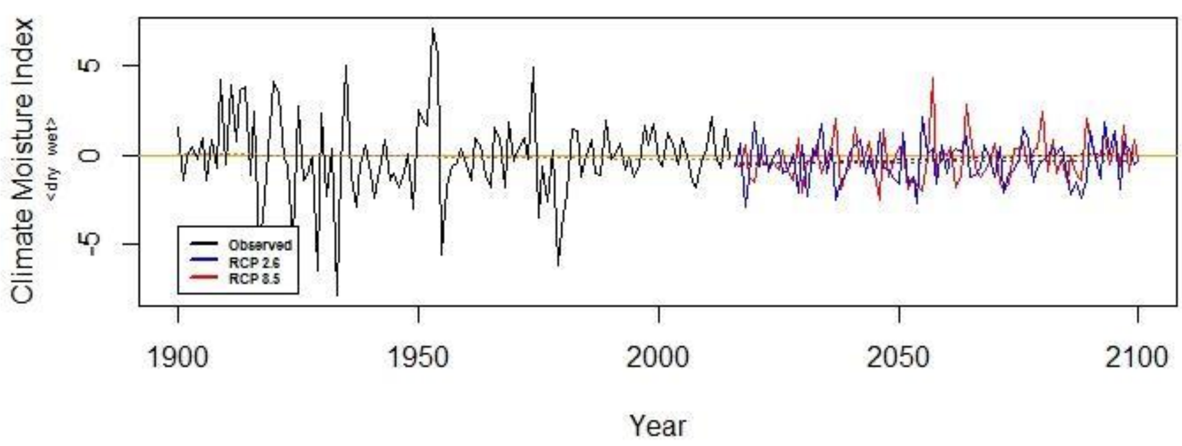
T (years)	2	5	10	25	50	100
5 min	3.15	5.05	6.52	8.96	11.13	13.31
10 min	4.83	7.34	9.01	11.78	13.88	15.84
15 min	6.03	9.17	11.20	14.55	17.03	19.29
30 min	7.83	12.39	16.72	23.68	30.36	38.77
1 h	10.49	15.68	21.79	31.59	43.27	57.09
2 h	15.36	23.24	31.36	44.86	60.01	78.50
6 h	27.27	42.92	59.25	86.34	116.31	153.33
12 h	37.83	57.34	76.18	106.68	137.79	172.15
24 h	50.48	74.79	93.67	124.64	152.63	179.98

One way to interpret this data, is to note that today's "one in 100 year" rainfall event (e.g., 22.03 mm/hr for Golden and 48.11 mm/hr for Kanasaskis) is projected to become a "one in 25 – 50 year" event in 2050-2100 and the future "one in 100 year" rainfall event is also projected to increase in amount (e.g., 27.86 - 29.81 mm/hr for Golden and 57.18 – 57.09 mm/hr for Kanasaskis).

2.4 Growing Season and Climate Moisture Index

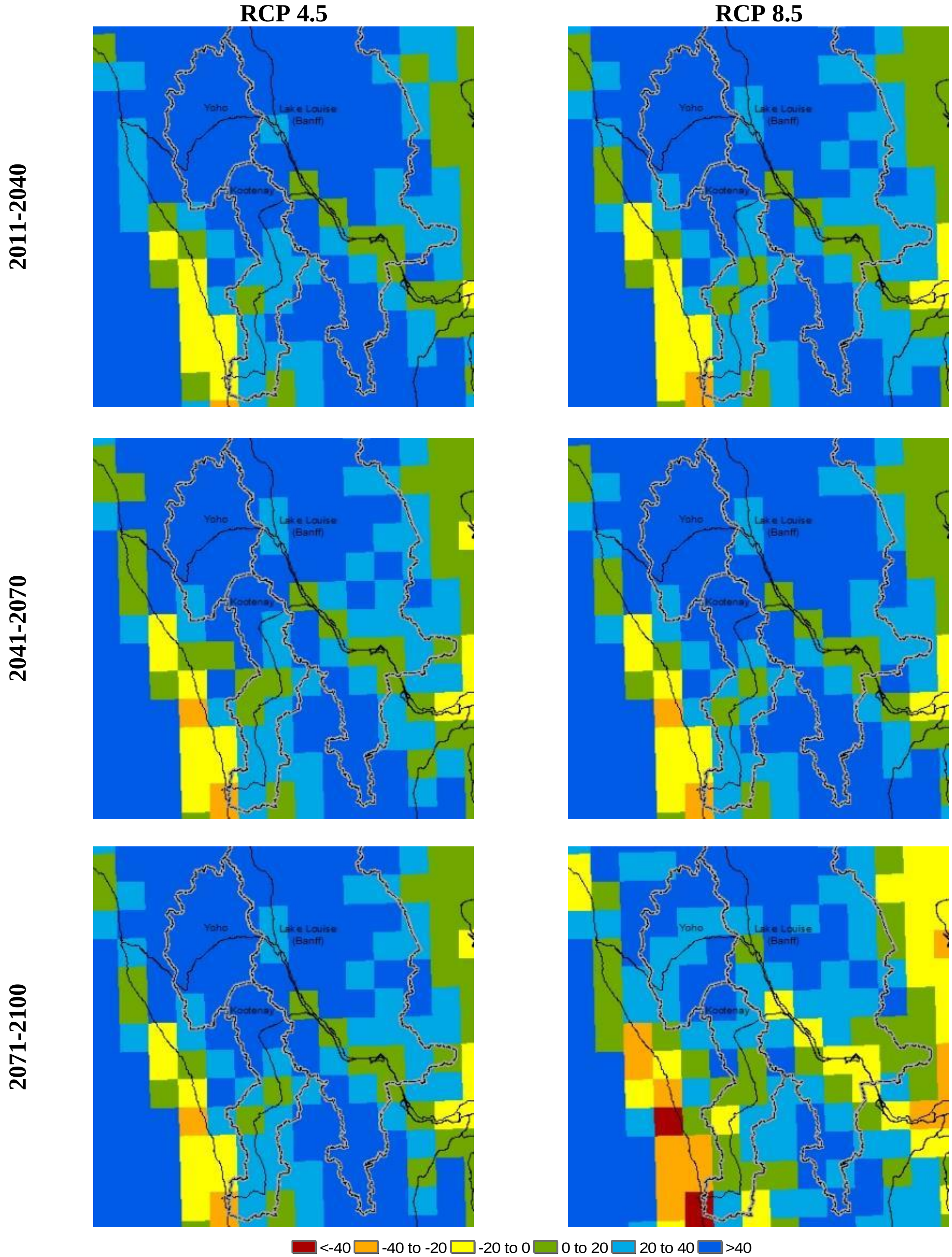
Growing Season is calculated as the number of days between the last occurrence of 0°C in spring and the first occurrence of 0°C in autumn. The metric is a widely used indicator of plant photosynthetic activity (http://www.nrcan.gc.ca/forests/climate-change/forest-change/18470). The **Climate Moisture Index** (CMI) is calculated as the difference between annual precipitation and potential evapotranspiration. A positive CMI value indicates wet conditions and a negative value indicates dry conditions (http://www.nrcan.gc.ca/forests/climate-change/forest-change/17772). Data courtesy of Dan McKenney and John Pedlar, Canadian Forest Service. Generalized linear model and plots developed in R (R Core Team, 2014).





Banff (51.2 N, 115.55 W), trend in **growing season length** for the historic period has shown a statistically significant ($P<0.05$) trend, increasing by ~16 days since 1900. Future trend under RCP 8.5 is projected to be a statistically significant trend ($P<0.05$) and increase by an additional 80 days by 2100. No statistically significant ($P<0.05$) trend is observed for **Climate Moisture Index** (CMI) values over the historic period or future RCP scenarios. Future CMI values are variable with no discernable trend and there is no statistically significant difference ($P<0.05$) between the historic and either RCP time periods, future projections are estimated to be negative (dry) 60% of time, an increase from 56% for the historic period.

Climate Moisture Index



Projected change in Climate Moisture Index for LLYK area from reference period (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. A positive value = wetter conditions, while a negative value = drier conditions. Data: Natural Resources Canada, http://www.nrcan.gc.ca/forests/climate-change/forest-change/17772.

3. Climate Impacts

3.1 Wildfire Regimes

- The frequency, seasonality, extent and severity of wildfires is closely tied to climatic conditions (e.g., Westerling *et al.*, 2006).
- Wildfire season length and frequency of extreme fire weather are expected to increase (e.g., affected by warmer springs and summers, less summer moisture and reduced snowpack) (Jain *et al.*, 2017; Kirchmeier-Young *et al.*, 2017; Wang *et al.*, 2015). Mori and Johnson (2013) project that the probability of large-scale fires in this region will increase with time.
- A key uncertainty is how climate change will affect precipitation, which directly impacts wildfire activity (e.g., fuel moisture). Flannigan *et al*. (2016) demonstrate that seasonal precipitation must increase 15% to offset every 1˚C rise in temperature. Although variable, a quick scan of the data presented for Banff and Golden, suggests that precipitation does not offset temperature.
- Temperature has a positive correlation with lightening.
- Wotton *et al.* (2017) project a future (for 2030 and 2090) increase in the number of days where crown fires are likely to occur as well as an increase in the number of days when fire intensities (e.g., head fire intensity above 10,000 kW/m) could exceed the capabilities of suppression resources (doubling in some end of century scenarios). Their maps are national in scale, but the LLYK study area is evident. Similarly, Wang *et al.* (2017) project an increase in the number of active burning days (i.e., spread days as related to daily fire weather).
- The suppression of forest fires (White, 1985), exclusion of Indigenous people (Binnema and Niemi, 2006) and climate change have all contributed to landscape change over the past century, including the large expansion of coniferous forests (Luckman, 1998; Nelson and Byrne, 1966). As such there is an associated concern to infrastructure and communities (e.g., Banff, Lake Louise, Field), if a fire were to start in these dense stand valleys (pers. comm. Elyse Mathieu).

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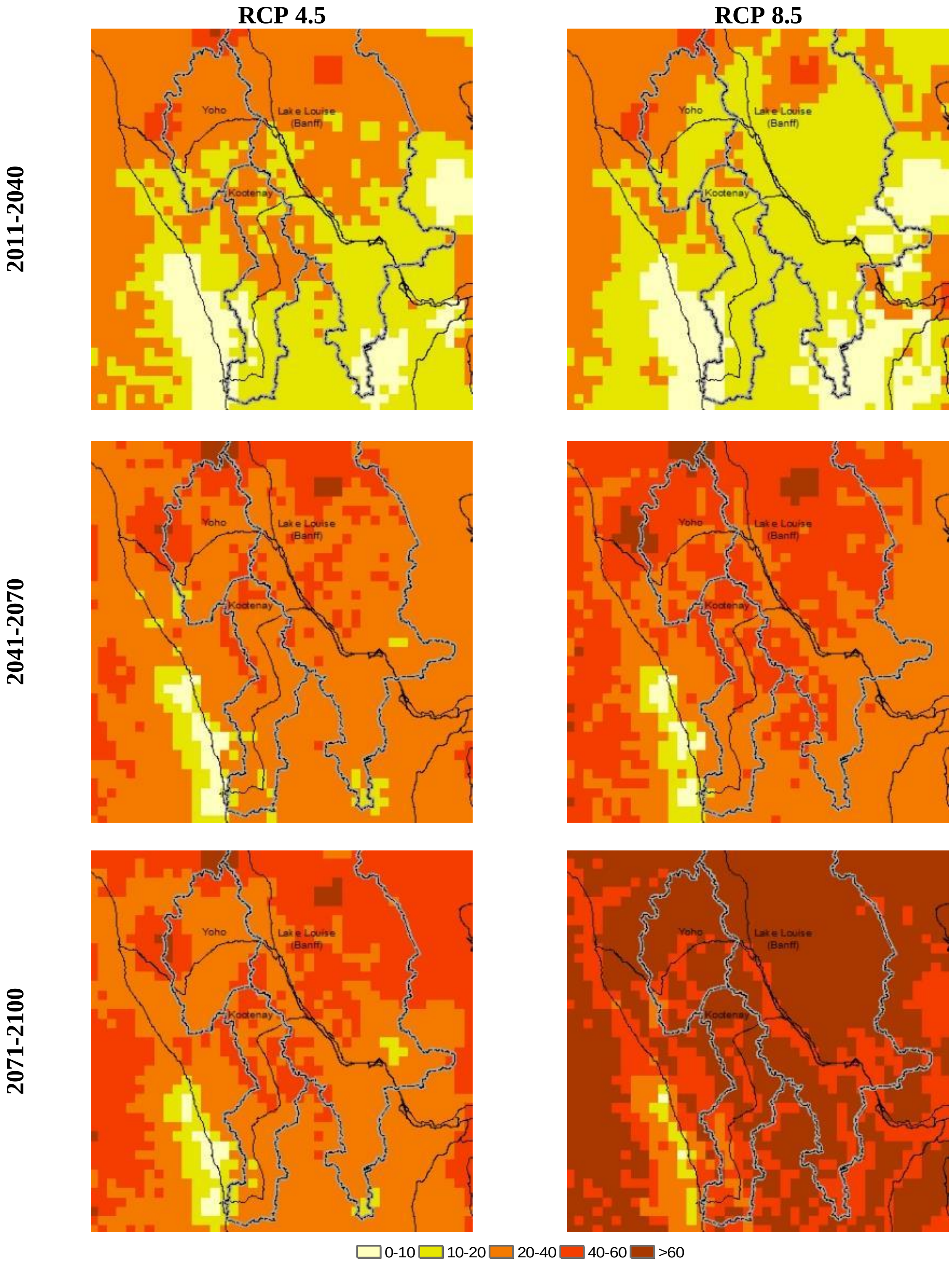
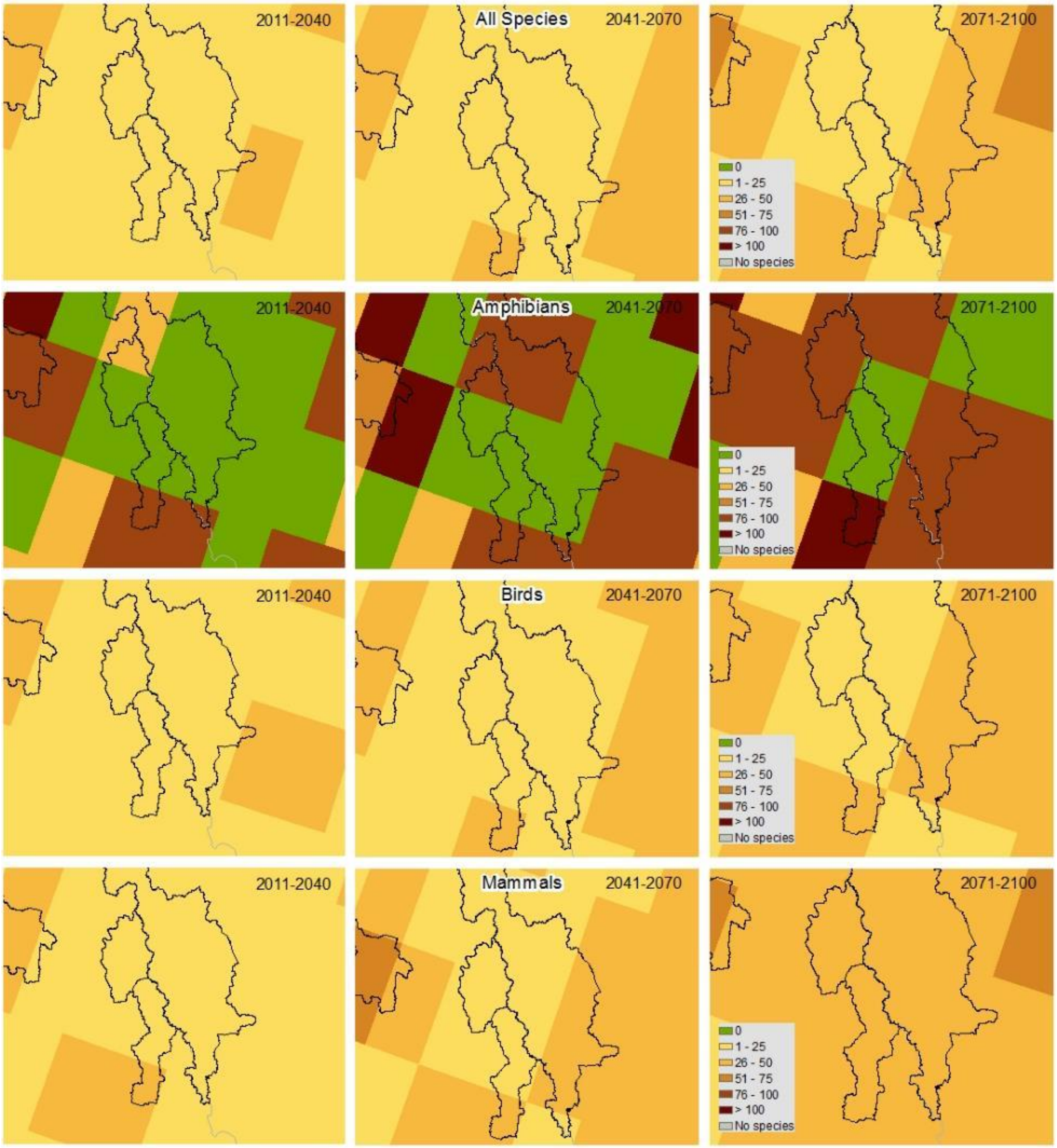


Projected increase in wildfire season for LLYK area. Increased length in days from baseline (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. Data: Natural Resources Canada, http://cfs.nrcan.gc.ca/fc-data-catalogue.

3.2 Biodiversity



Percent species turnover (50 km x 50 km grid) relative to current species occurrence, assuming full dispersal (i.e., species can move into new areas) using ten coupled atmosphere-ocean general circulations models (AOGCMS) as in Lawler et al. (2009) and the A2 emission scenario. **Species turnover** is calculated as a composite measure of **species loss** (i.e., % of species currently in a cell whose projected future range does not include the cell) and **species gain** (i.e., % increase in species due to range expansion). Data and analysis discussed further in Lindsay et al. (2016).

- Jones *et al*. (2017) studied stream temperatures in the Crown of the Continent and have reported warming trends and seasonal shifts.
- Messner *et al.* (2013) report on impacts of warming waters, introduced brook trout and an increase in zooplankton diversity in the region.
- Predicted reduction of floodplain forests is some reaches due to declining summer flows (Rood *et al.*, 2008).
- Roberts *et al.* (2014) report on a change in grizzly bear habitat due to climate change, including a general uphill migration on food resources.
- The upslope migration of the alpine treeline is occurring (treeline is at ~2300m). Brown (2013) reported rates between 0.23 and 1.8 m/yr in the Kanasaskis study area and Roush (2004) reported 2.2 m/yr in Kootenay NP. However, it is important to note that species migration is a variable and complex process, influenced by factors such as dispersal mechanisms, soil suitability, solar radiation, permafrost, moisture regimes, etc… (e.g., Luckman and Kavanagh, 2000)
- A subsequent reduction or loss of alpine tundra and meadow ecosystems may be a concern in some areas (e.g., Illerbrun and Roland, 2011).
- A change in the composition and structure of high elevation forests is suggested due to warming and a reduction in post-fire tree seedling establishment. A compensatory increase is expected from montane species moving upslope (e.g., alpine larch, Douglas fir, trembling aspen) and upper treeline species whitebark pine (Harvey *et al.*, 2016). However, whitebark pine colonization may be compromised by blister rust (*Cronartium ribicola*) (Tomback *et al.*, 2014).
- Pika (*Ochotona princeps*), water vole (*Microtus richardsoni*), and least chipmunk (*Tamias minimus oreocetes*) could be threatened as a result of disappearing tundra habitat (e.g., Otto *et al.*, 2015). Mountain sheep, goats and elk all move upslope to graze in alpine tundra during summer and could be affected by a loss of habitat and foraging resources.
- Climate change is cited as a potential factor contributing to caribou decline (COSEWIC, 2014; Festa-Bianchet *et al.*, 2011).
- Climate change is expected to facilitate the expansion of invasive species, for example, conditions in this region may become suitable for plant species African rue and brown knotweed (Chai *et al.*, 2016).

Additional Reading

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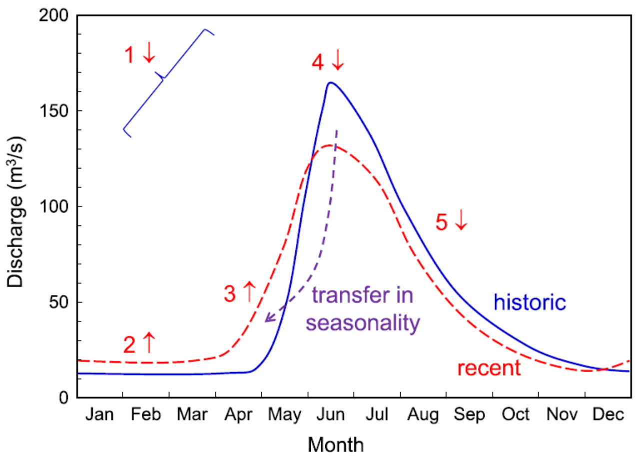
3.3 Hydrological Regimes



Source: Rood et al., (2016)

Hydrological change on the Bow River at Banff. The numbers represent the relevant changes: (1) declining overall annual flows over the past century; (2) with winter warming there is an increase in the proportion of rain versus snow and this increases winter river flows and decreases snow packs; (3) with spring warming there is an advancement in the period of snowmelt, (4) the timing of peak flows is relatively unchanged and there is consequently a longer interval after snowmelt commences. These (3 & 4) reduce the snowmelt contribution to the peak and also reduce the extent of watershed saturation, decreasing runoff from rain. The consequence of (1) through (4) is the reduction in annual peak flows and there is also the subsequent decline in summer flows (5).

- Rood et al., (2016) reported a statistically significant (P<0.05) decline in peak flows in the Bow River at the Banff gauge (05BB001) (similar to: Burn and Whitfield, 2016; Whitfield and Pomeroy, 2017), no statistically significant (P<0.05) trend reported in the Kootenay River at the Kootenay Crossing gauge (08NF001) or the Columbia River at the Nicholson gauge (08NA002).
- A correspondence with the Pacific Decadal Oscillation (PDO) and snowmelt duration was reported (Rood *et al.*, 2016; Whitfield and Pomeroy, 2016), e.g., negative phase of PDO is frequently associated with cooler and wetter conditions, a time of larger magnitude and duration floods.
- Large rain on snow events are rare (occurring <8% of years) but generate streamflows of great consequence, including the 2013 flood (Whitfield and Pomeroy, 2016). Winter/spring warming increases rain versus snow proportions, thus increasing winter flows and declining snow packs.
- Glacier ice melt is equivalent to 3% of annual discharge in Calgary, and as much as 8-20% in August (Bash and Marshall, 2014).
- Groundwater flow provides roughly half of annual water input to Lake O'Hara and groundwater reservoirs stores roughly 100 mm of snowmelt and rain water during the warm season and release during the cold season (CCRN, 2017; Hood and Hayashi, 2015).
- Debris in flood events is a concern (Shelley Humphries, pers. comm.).
- Insufficient water from the Pipestone River for snow making at Lake Louise was reported this autumn (Shelley Humphries, pers. comm.).
- Stream flow records and station information is available through ECDataExplorer (https://ec.gc.ca/rhc-wsc/default.asp?lang=En&n=0A47D72F-1).

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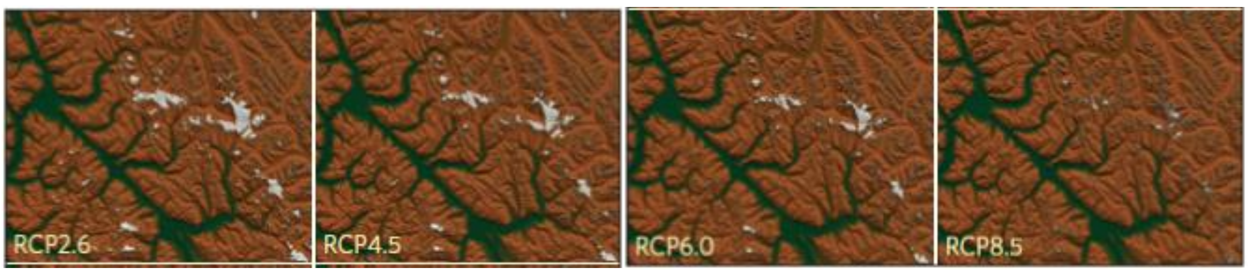
3.4 Glaciers

- Glaciers in the region have undergone considerable loss in the past 50+ years (i.e., negative mass balance, down wasting and terminal retreat). For instance, between 1952 and 2014 the Peyto Glacier has retreated 1.6 km and drought and warmer conditions in 2015 resulted in record negative mass balance (-2500mm) and streamflow discharge was almost double the long term average in early summer (CCRN, 2017).
- Real-time access to the glacial meteorological stations in Banff National Park can be found here: http://giws.usask.ca/telemetry/.
- A regionally relevant explanation of glacier fluctuations under the influence of climate is provided by Demuth and Ednie (2016).
- The effects of climate warming on mountain permafrost and ecosystem interactions in this region is largely unknown.
- Clarke *et al.* (2015) project that by 2100, the volume of glacier ice in western Canada will shrink by 70 ± 10% relative to 2005. The maximum rate of ice volume loss, corresponding to peak input of deglacial meltwater to streams and rivers, is projected to occur around 2020–2040. Garry Clarke has also developed and made available deglaciation animations based on this work, including a series of animations for Bow Glacier and Lake Louise/Yoho areas (http://couplet.unbc.ca/data/RGM_archive/RGM_movie_archive/).



Projected glacial loss for the Columbia Reach drainage basin by 2100 under various RCP scenarios (Clarke *et al.*, 2015).

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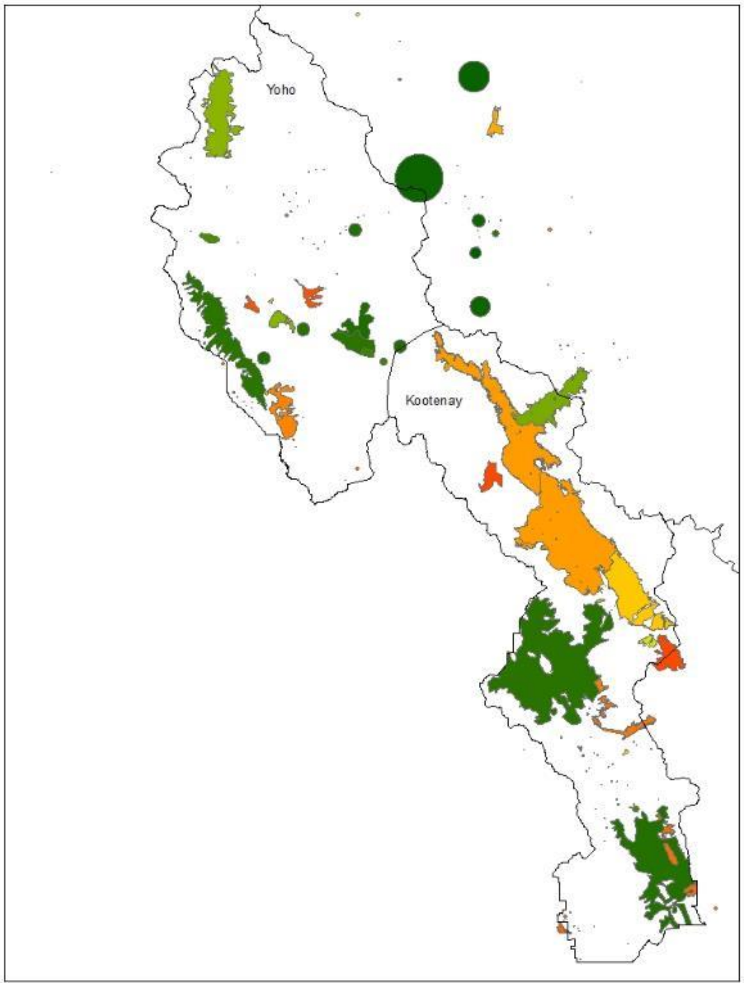
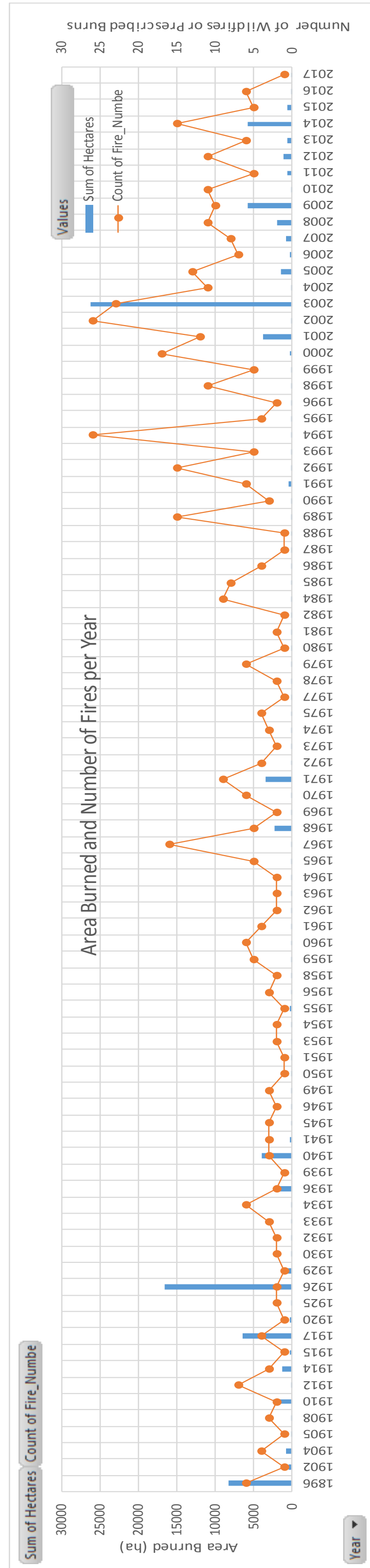
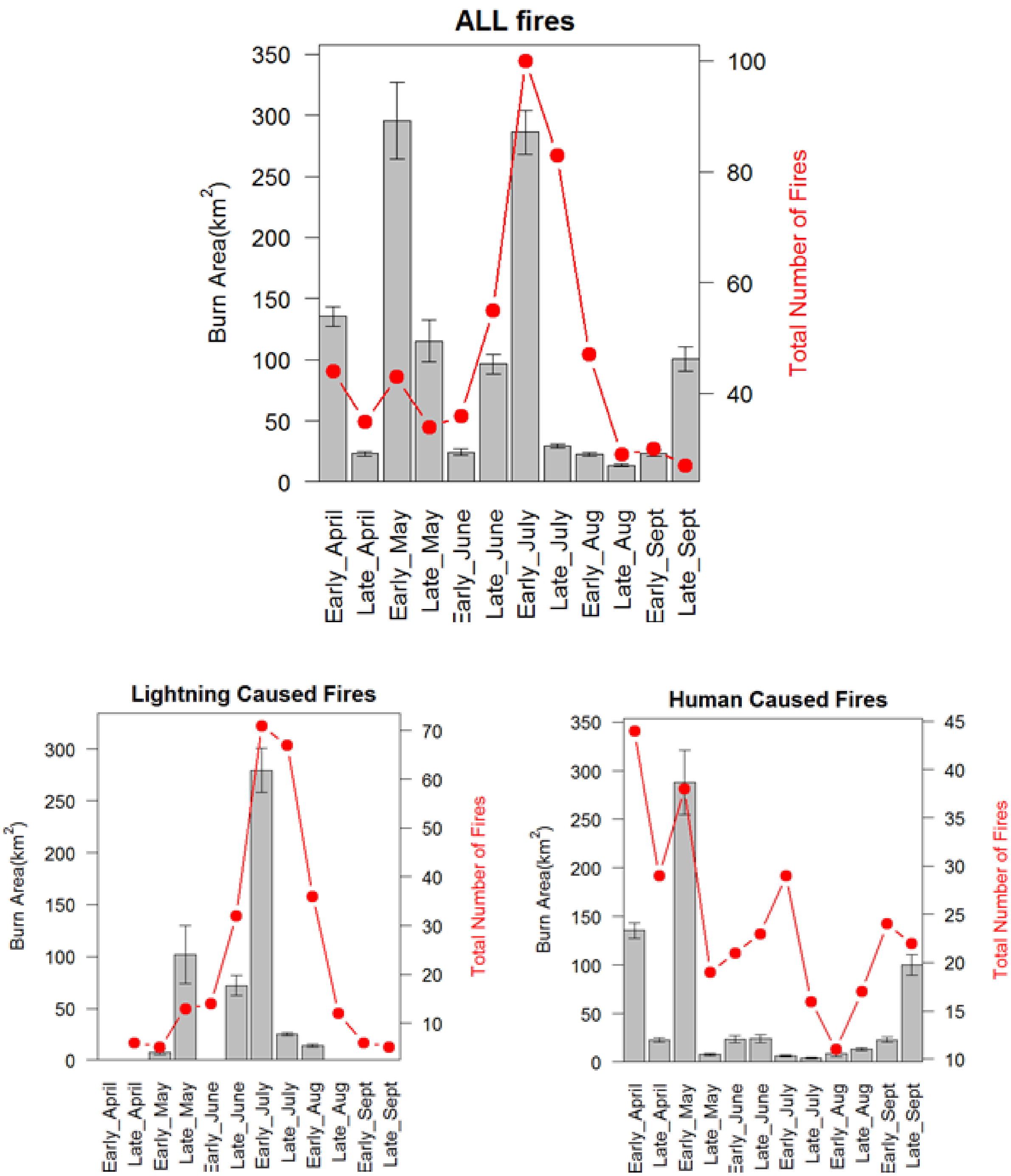
Appendix 1. Wildfire and Forest Insect

Wildfires and prescribed burns since 1896 in Kooteney and Yoho NPs

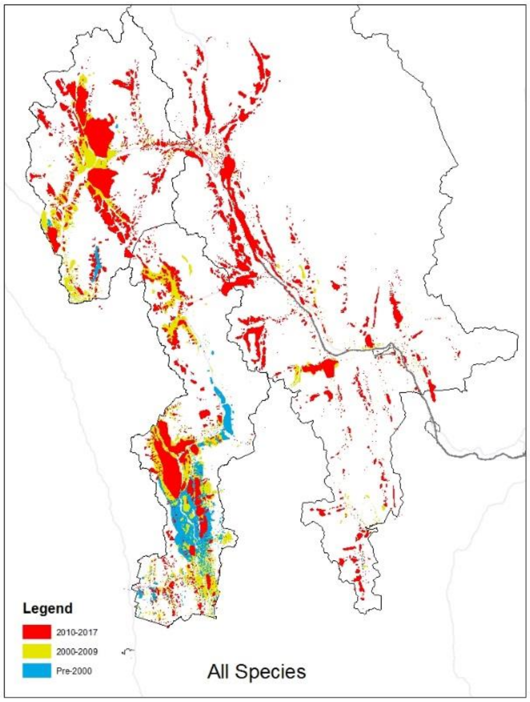


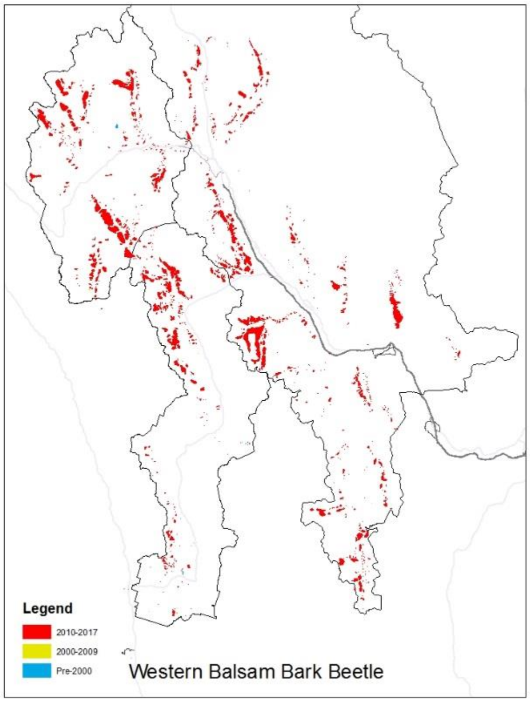
Data source: Tara Sharma and Darrel Zell, Parks Canada



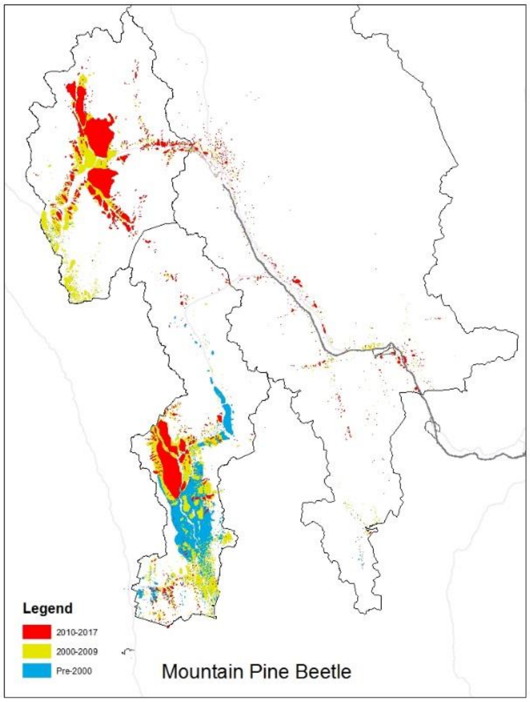


Bi-weekly sums of the area burned (km^2) and total number of fires (1919-2016) within Banff, Jasper and LLYK NPs including the distribution of Lightning and Human caused fires. Courtesy of Elyse Mathieu, Fire Research Analyst, CFS.





Primary Pest	Ha
Mountain pine beetle	124548
Western balsam bark beetle	38292
Two-year Spruce Budworm	18123
Northern lodgepole pine nee	17754
Aspen Leaf Miner	8474
Lodgepole pine dwarf mistlet	5516
Lophodermella needle cast	4119
Douglas-fir beetle	2764
Red belt	2071
Western false hemlock loope	1424
Bruce spanworm	1096
Spruce beetle	613
WPBR	435
Blow down damage	363
Larch needle cast	314
Larch budmoth	274
Drought damage	226
Large-spored spruce-labrador	144
Flood damage	43
Whitebark Pine decline	22
Avalanche damage	22
Mammal Damage	19
Armillaria Root Disease	10
Herbicide	4
Larch sawfly	4



Forest insect disease and select damage since 1934 to 2017 for Kootenay, Yoho and Lake Louise (Banff) area. Data courtesy Roger Brett, Canadian Forest Service. In addition, see report Brett (2016).