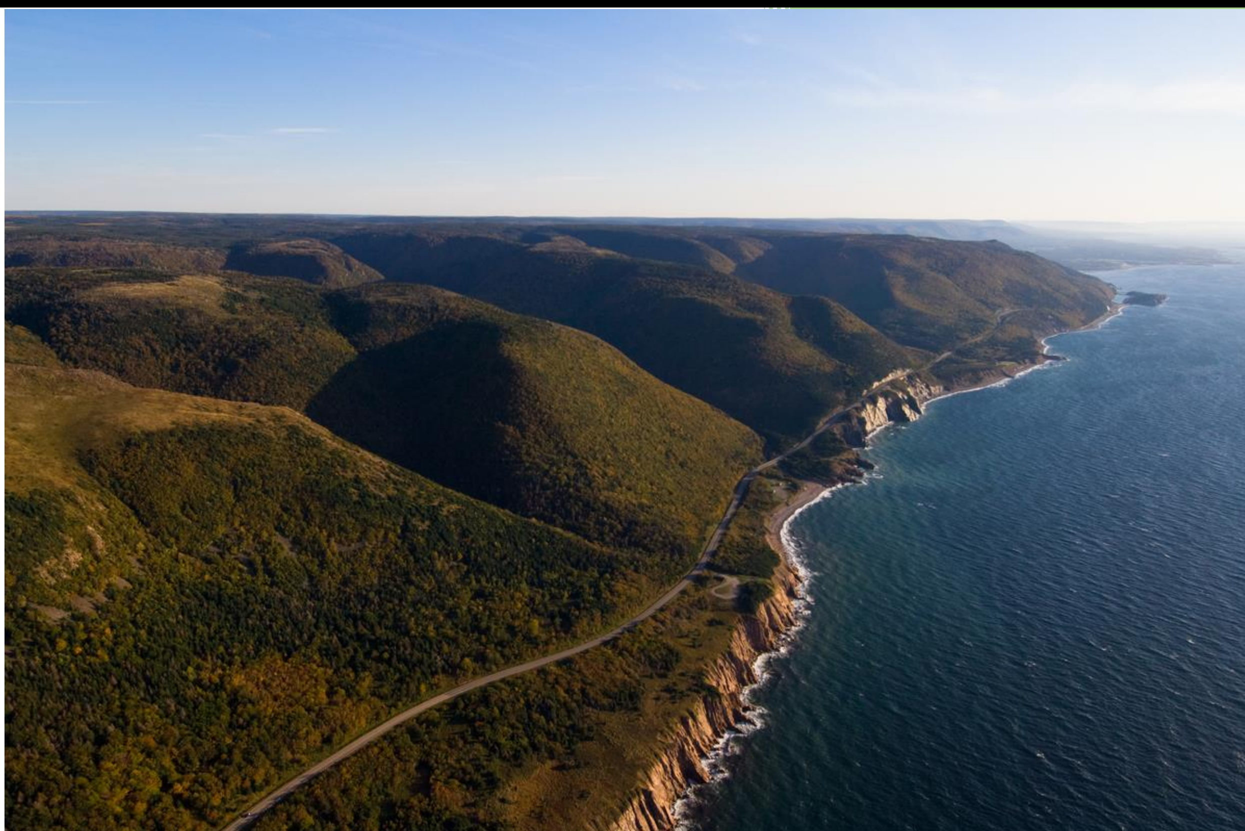
December 12th, 2018

# Supplemental Climate Information for Cape Breton Highlands National Park




Prepared by:

Scott Parker, Ph.D.
Office of the Chief Ecosystem Scientist

Garrett Mombourquette, MCC
Cape Breton Highlands National Park

Liam Bray
Dalhousie University


Parks Canada Parcs Canada

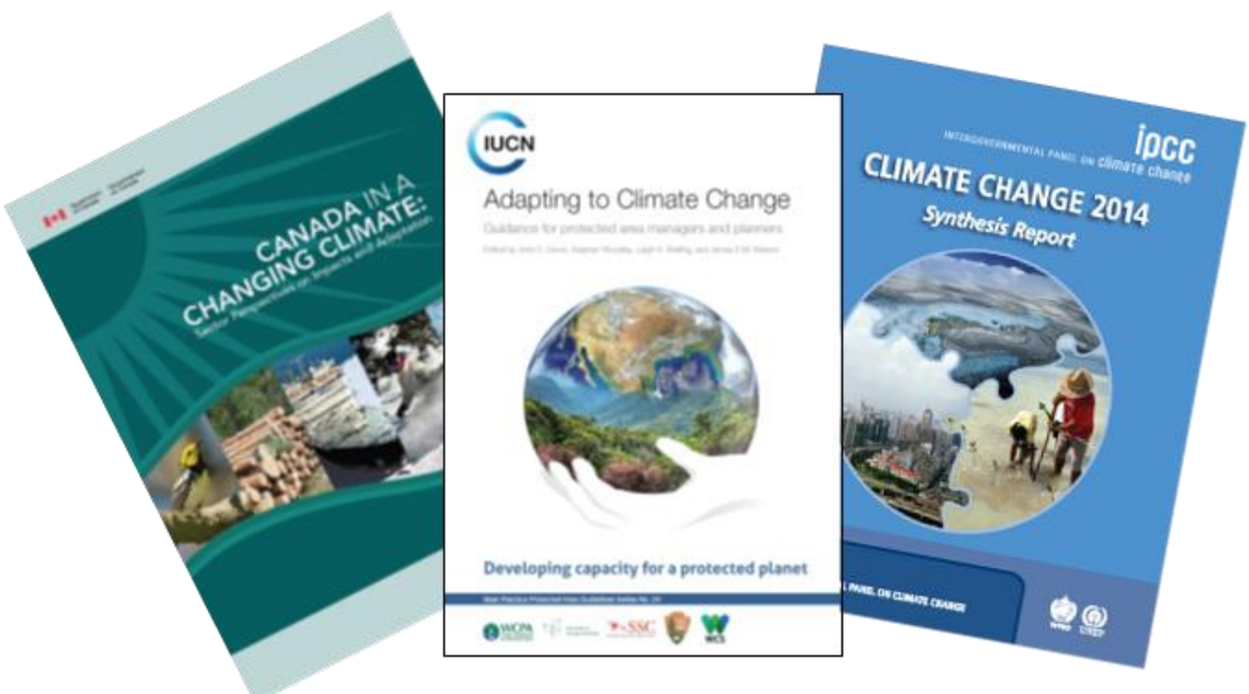
# Contents

# Preface

This is a supplement to the "Let's Talks about Climate Change: Atlantic Region" (Parker, 2017) report and is intended to support climate change discussions at Cape Breton Highlands National Park (CBHNP).

Future climate projections are modelled with several different 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 "status quo" throughout the 21st century.

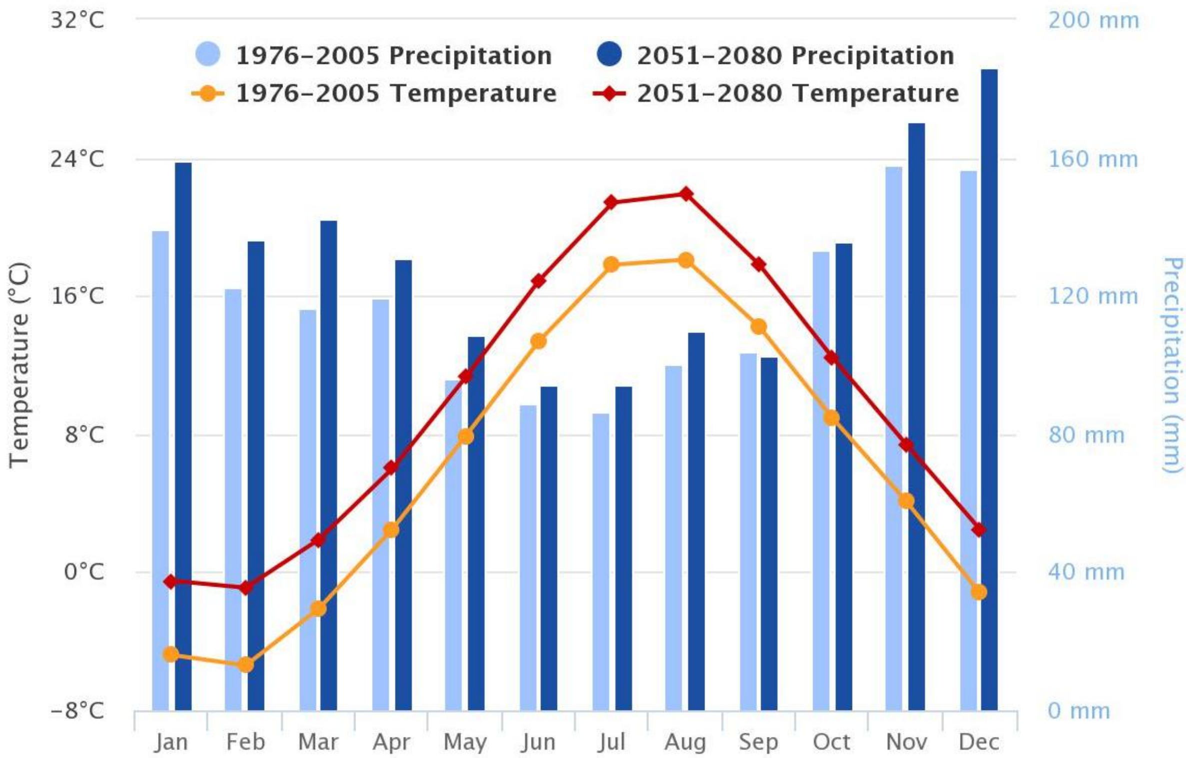
This is a site focussed document and to understand the larger climate change context please review Canada's Changing Climate assessment reports (e.g., Lemmen *et al.*, 2016) and the Intergovernmental Panel on Climate Change assessment reports (e.g., IPCC, 2014). With respect to adaptation options, consider Gross *et al.* (2016), Parker *et al.* (2018), or Rockman *et al.* (2016).




***Disclaimer***
Views, statements, findings and conclusions are solely those of the authors and do not necessarily reflect the views and policies of Parks Canada. Although the authors have made every effort to ensure that the information is accurate, complete and correct, neither Parks Canada nor the authors can guarantee its integrity. Readers are encouraged to verify with original sources.

## Highlights

- Mean annual air temperature in the region has increased by ~1˚C since 1870 and is projected to continue to increase an additional ~3.7˚C by 2051-2080 (RCP 8.5), with the greatest increase occurring for winter and nighttime periods.
- The number of extreme heat days (+30˚C) is projected to increase from 0.6 days to 9 days per year by 2051-2080 (RCP 8.5).
- Total annual precipitation has increased by ~22% since 1870 and is projected to increase an additional 10% by 2051-2080. Winter is projected to continue to be the wettest season.
- Rainfall intensity is projected to increase, e.g., the future one in 25 year event is projected to be similar to today's one in 100 year event (~52 mm/hr).
- Mean annual and seasonal wind speed has decreased since 1953.
- Relative sea level has increased by ~90 cm since the 1740's and is project to continue to increase. A vertical allowance of up to 107 cm by 2100 is recommended.
- The length of the wildfire season is projected to increase by 12-25 days/year.

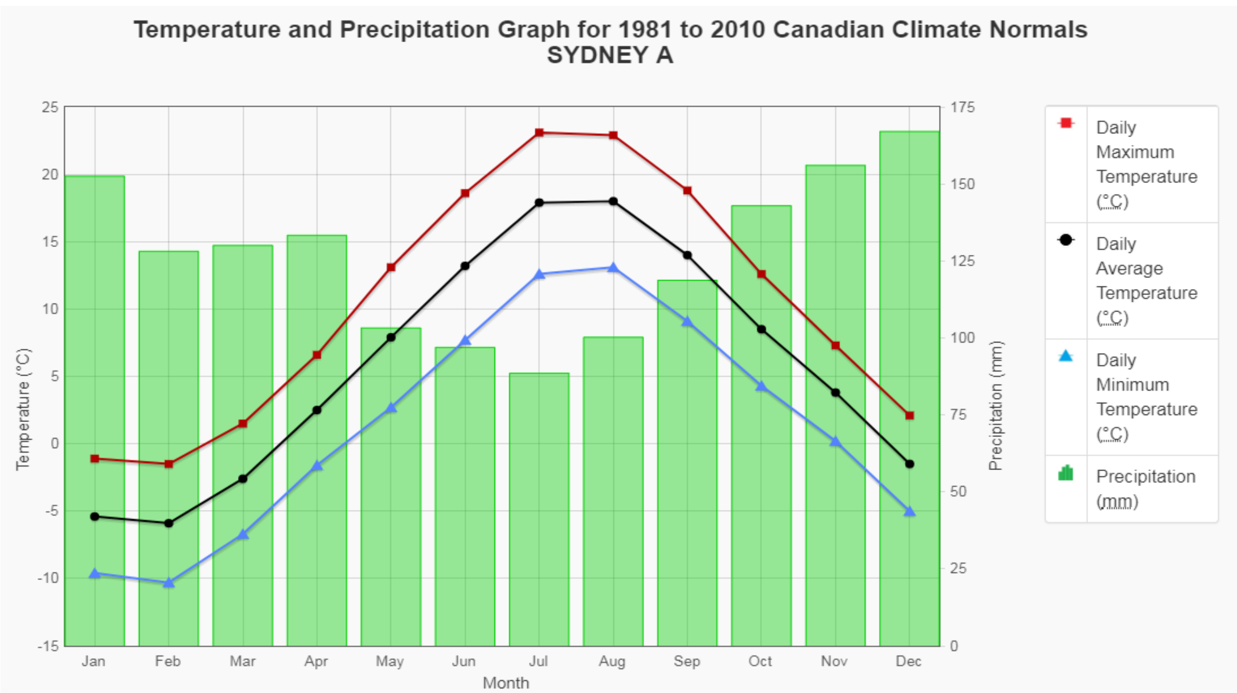



**Climograph for Sydney area**. Modelled monthly mean temperature and total precipitation for the 1976-2005 baseline and 2051-2080 future projection (RCP 8.5). Figure source: Climate Atlas of Canada, https://climateatlas.ca/.

# 1. Historic Climate

Cape Breton Highlands experiences a humid (mean RH 69%) continental climate (Köppen *Dfb*) with warm summers (daily mean 16.4˚C) and cool winters (daily mean -4.3˚C). Moderated by its proximity to the Atlantic Ocean, there tends to be a seasonal lag in temperatures with February being the coldest month and August the warmest. Winters are relatively windy, wet and stormy (on the nor'easter pathway). Winds are predominately from the west and southwest, with mean speeds of 17 km/hr, however, maximum gust events tend to come from south and can exceed 90 km/hr.

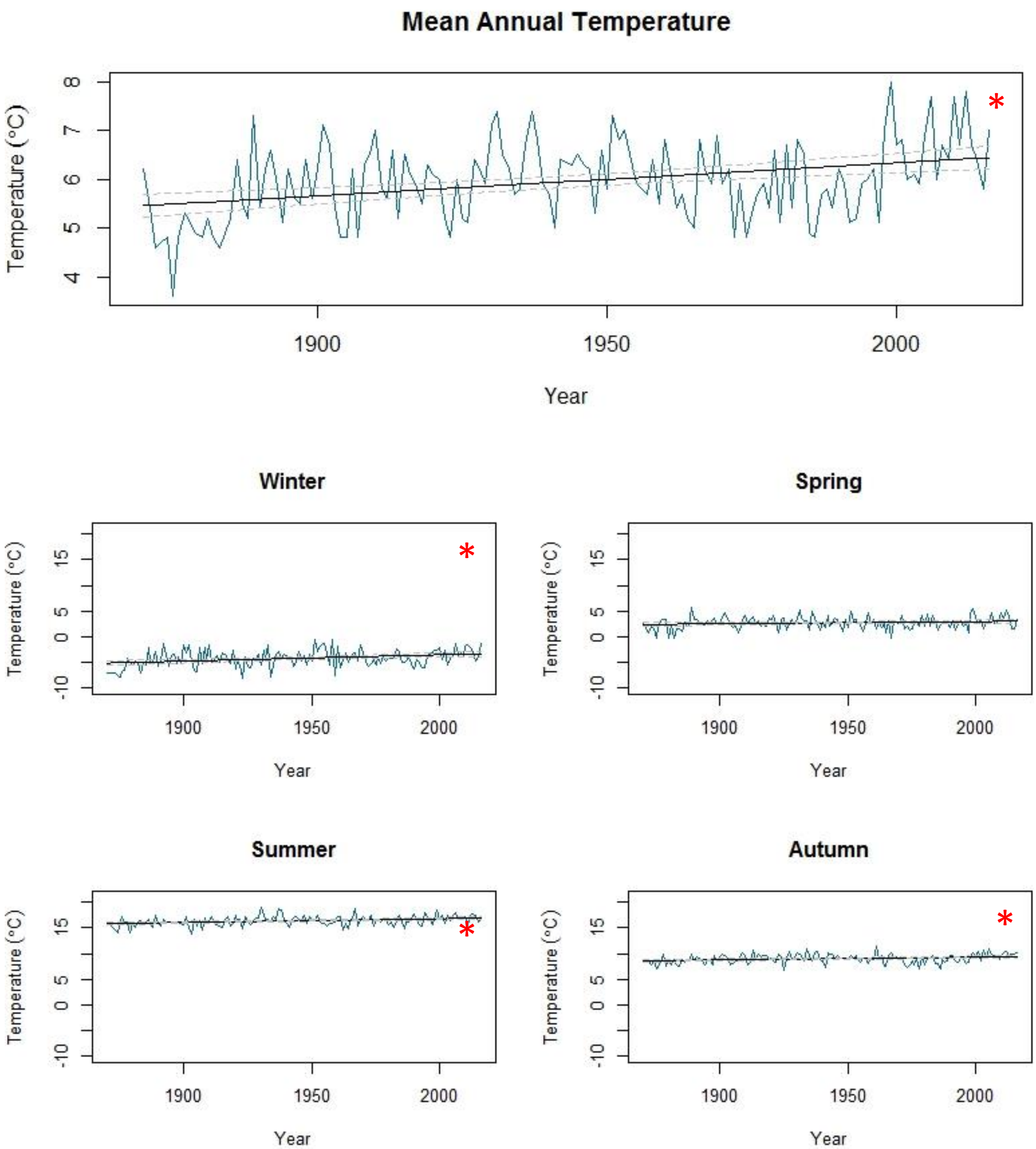
Of specific relevance, Ouranos (Vescovi and Logan, 2007) analysed the historic climate for CBHNP and provided recommendations for future climatic monitoring measures.



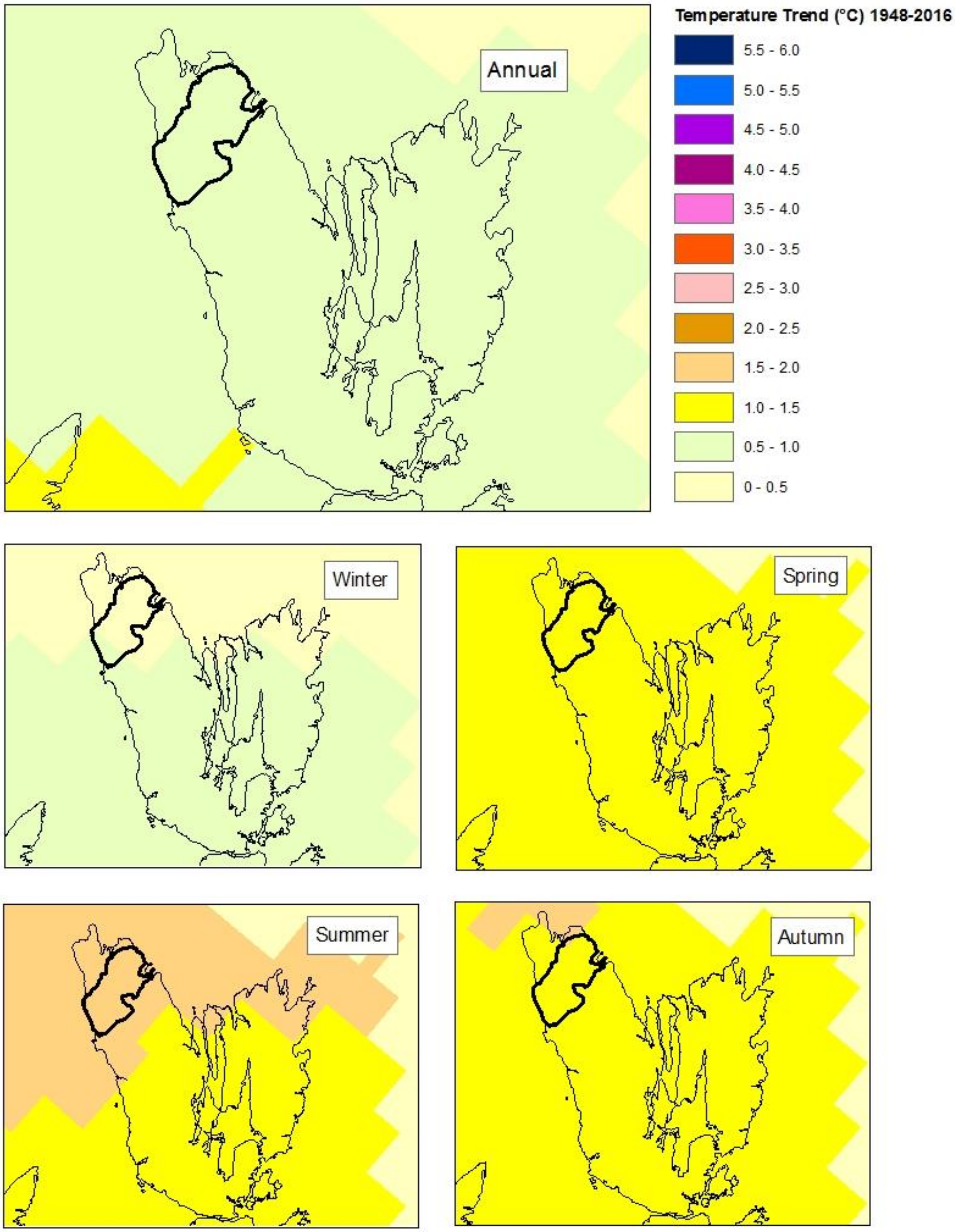

**Climate "normals" (1981-2010) for Sydney.** Figure source: Environment and Climate Change Canada (http://climate.weather.gc.ca/climate_normals/).

## 1.1 Temperature

Sydney (8205701) is the closest meteorological station with long term temperature data (ECCC, 2017). Trends from 1870 to 2016 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



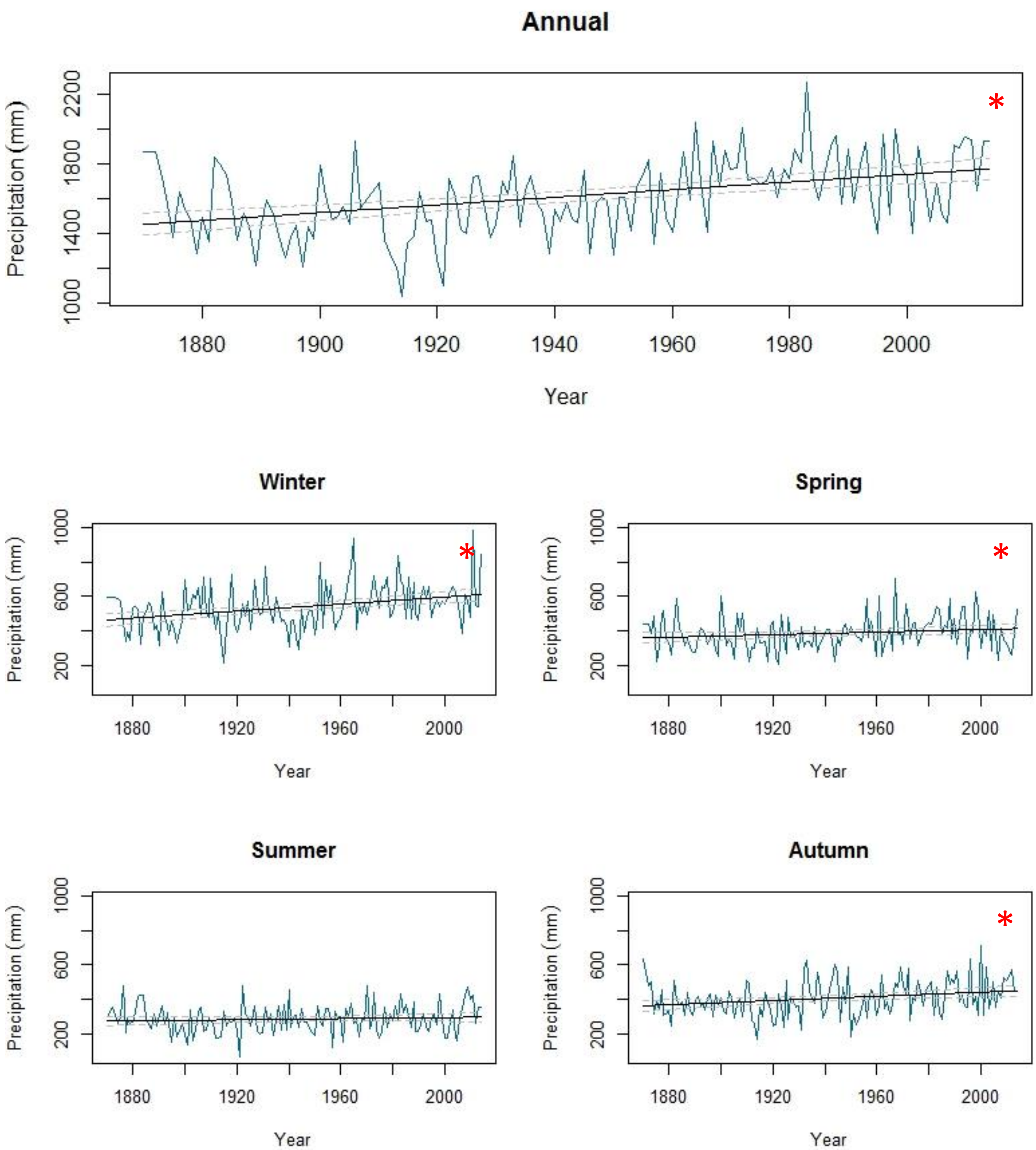

**Sydney mean annual and seasonal temperature**. A statistically significant ($P<0.05$) increase observed in mean annual and seasonal temperatures, except spring (Mar, Apr, May). Mean annual temperature has increased by ~1°C since 1870. Of all the seasons, winter temperature has increased the greatest, ~1.8°C since 1870.



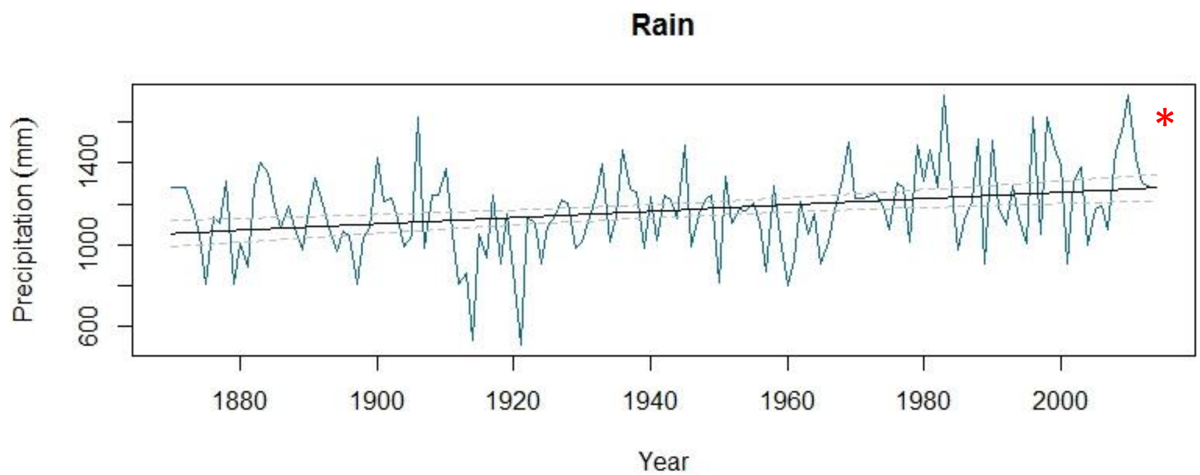

**Mean annual and seasonal temperature trend (˚C) for Cape Breton Island from 1948 to 2016.** Based on Canadian gridded data (CANGRD) it illustrates the change in temperature over the period of record (1948-2016). Data source: https://climate-change.canada.ca/climate-data/#/historical-gridded-data.

## 1.2 Precipitation

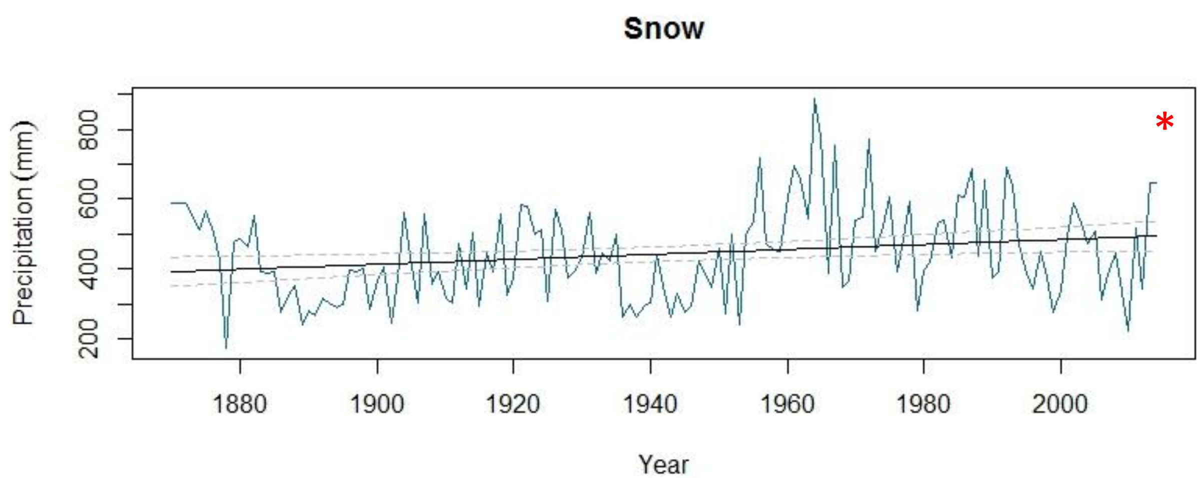
Sydney (8205700) is the closest meteorological station with long term precipitation data (ECCC, 2017). Trends from 1870 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



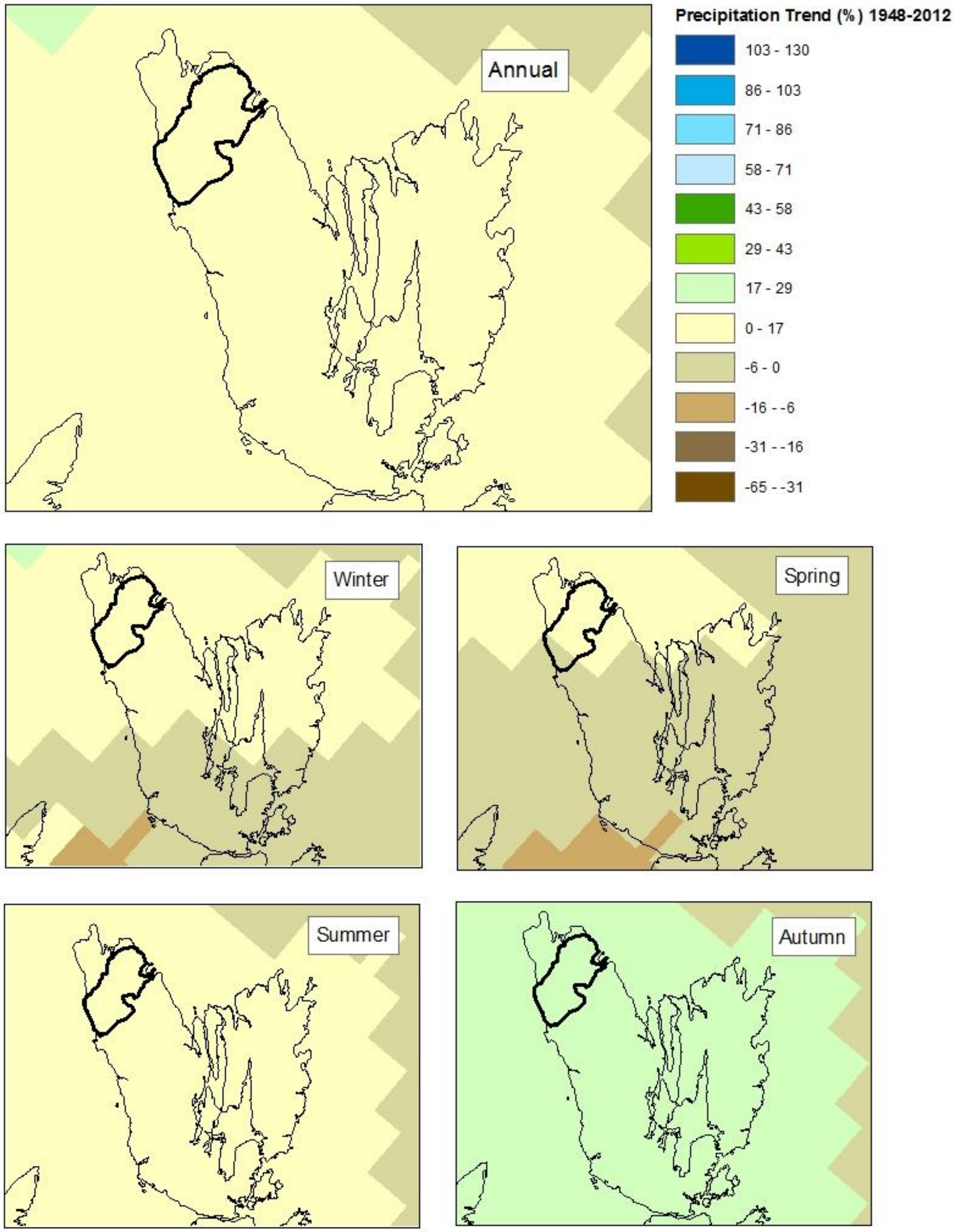

**Sydney total annual and seasonal precipitation.** Total annual precipitation demonstrated a statistically significant increase ($P<0.05$), ~371 mm (22%) since 1870. All seasons except summer (Jun, Jul, Aug) demonstrated a statistically significant ($P<0.05$) increase, the greatest being observed for autumn, ~146 mm (32%).




**Sydney total annual rain** demonstrated a statistically significant (P<0.05) increase since 1870, ~223 mm (21%).



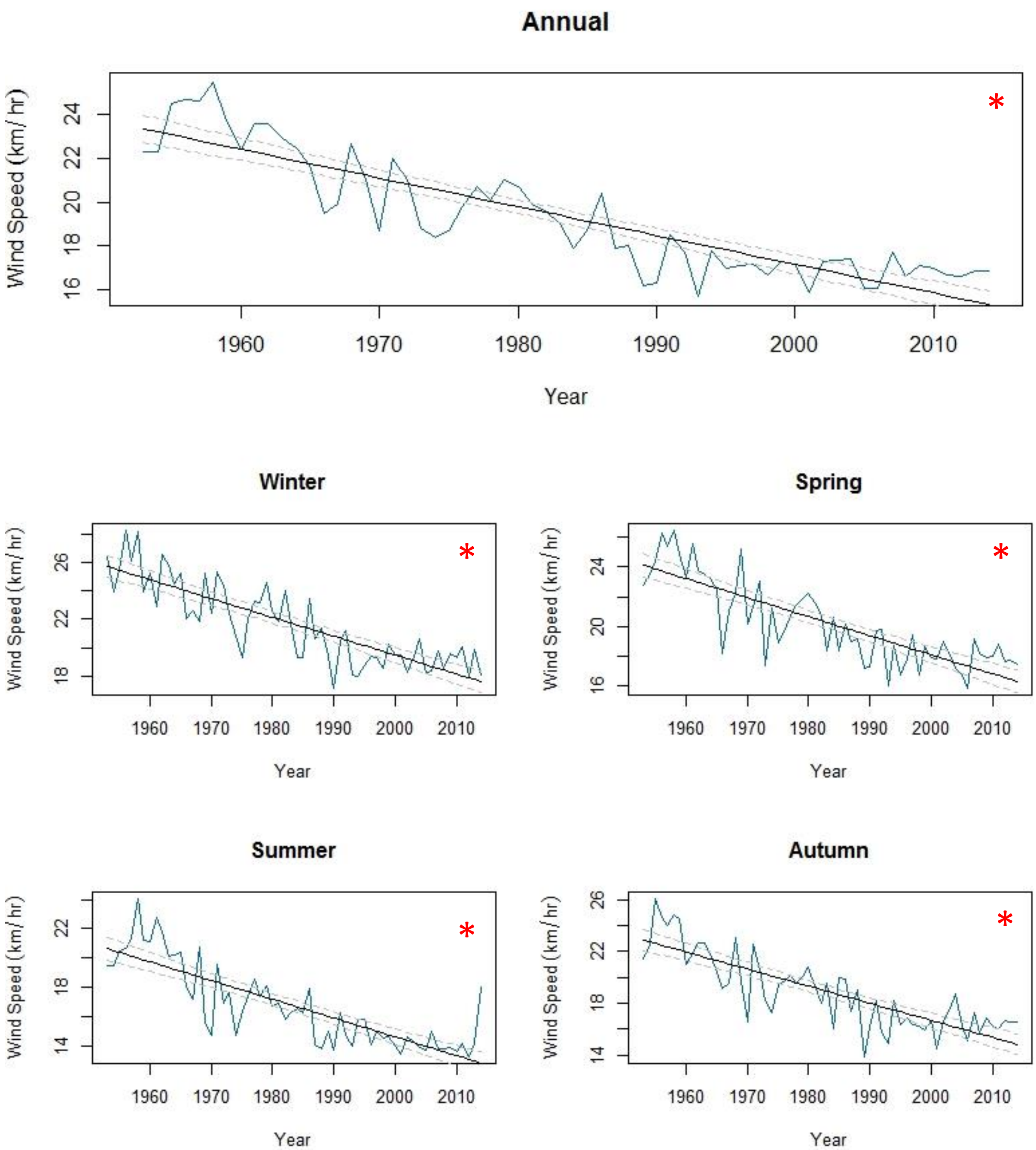

**Sydney total annual snow** demonstrated a statistically significant (P<0.05) increase since 1870, ~101 mm (26%).




**Total annual and seasonal precipitation trend (%) for Cape Breton Island from 1948 to 2012.** Based on Canadian gridded data (CANGRD) the relative trend illustrates the percent change in total precipitation over the period of record (1948-2012). Data source: https://climate-change.canada.ca/climate-data/#/historical-gridded-data.

## 1.3 Surface Wind Speed

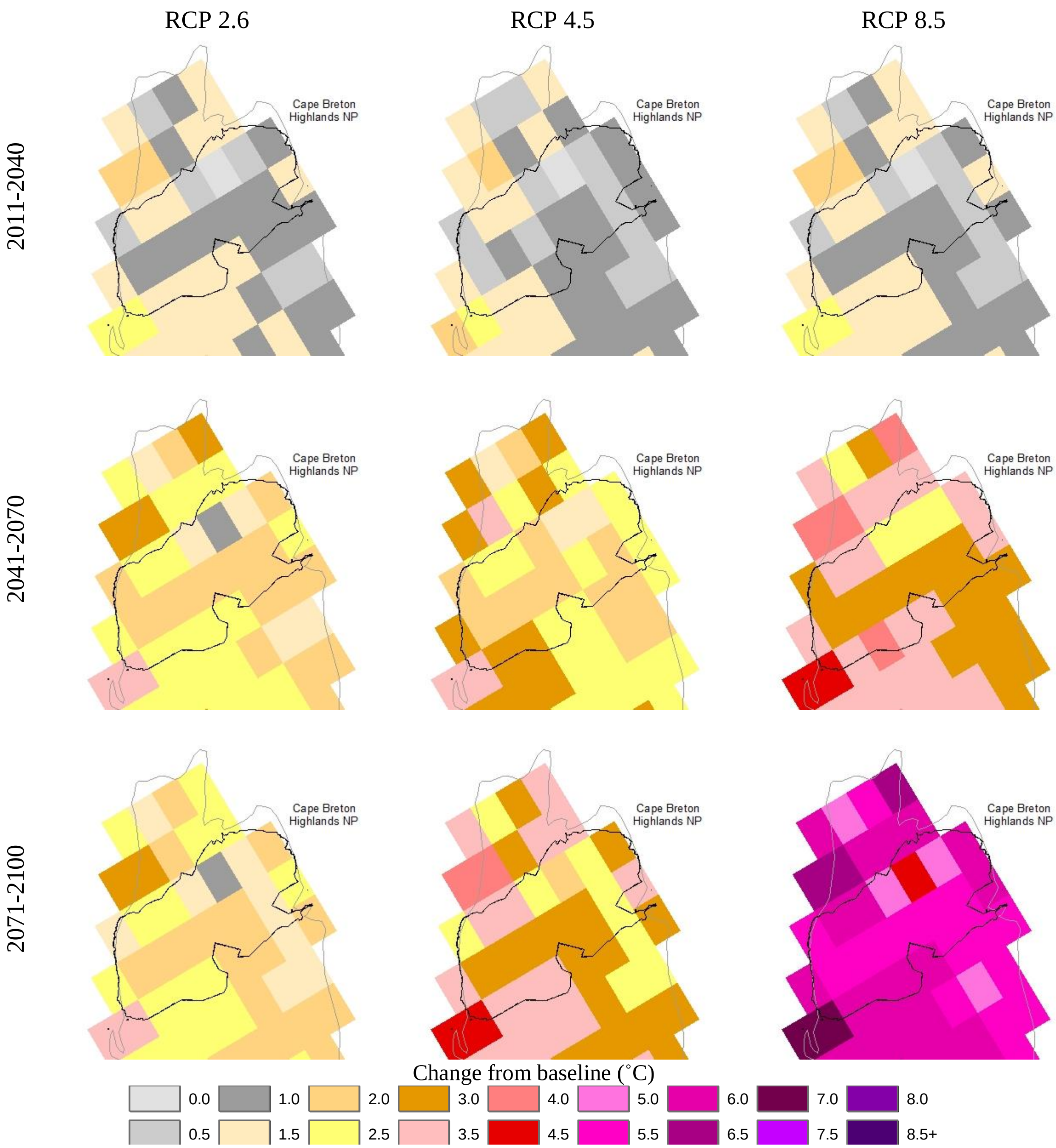
Sydney (8205701) is the closest meteorological station with long term wind data (ECCC, 2017). Trends from 1953 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. “*” = statistically significant trend (P<0.05).



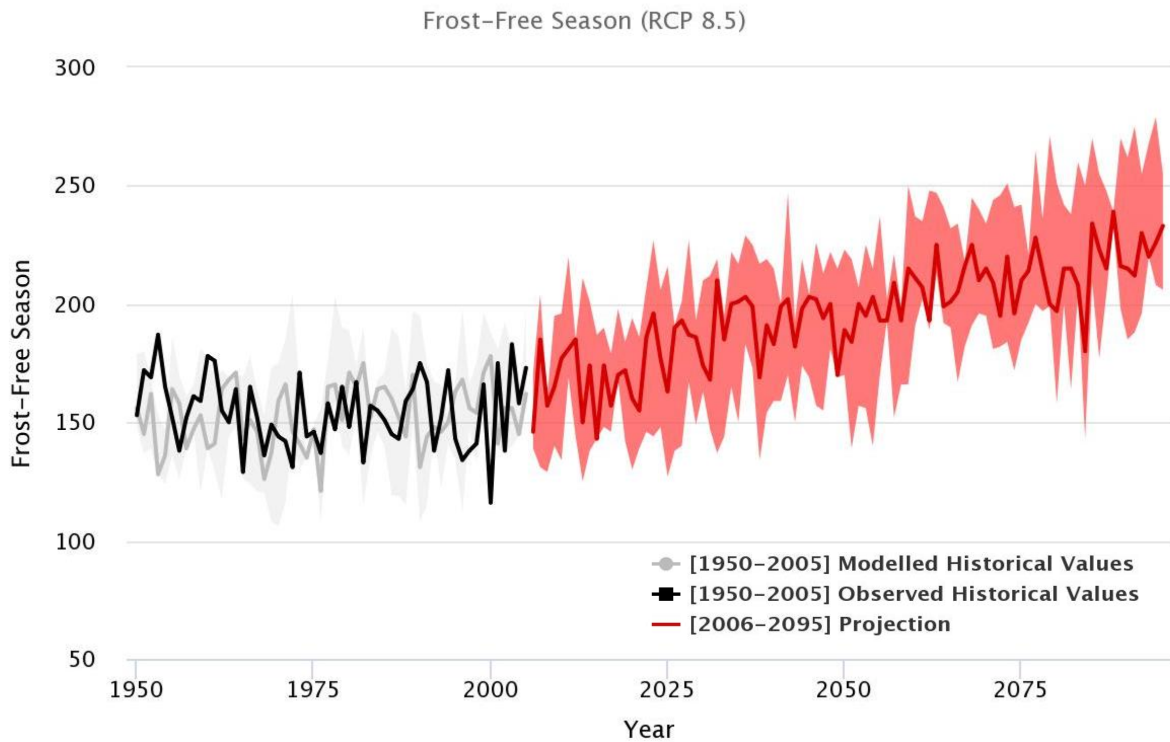

**Sydney mean annual and seasonal wind speeds**. Mean annual wind speeds have demonstrated a statistically significant (P<0.05) decrease, ~8 km/hr (34%) since 1953. All seasons have demonstrated a statistically significant (P<0.05) decrease, the greatest being observed for autumn, ~8 km/hr (35%) since 1953.

# 2. Projected Climate Trends

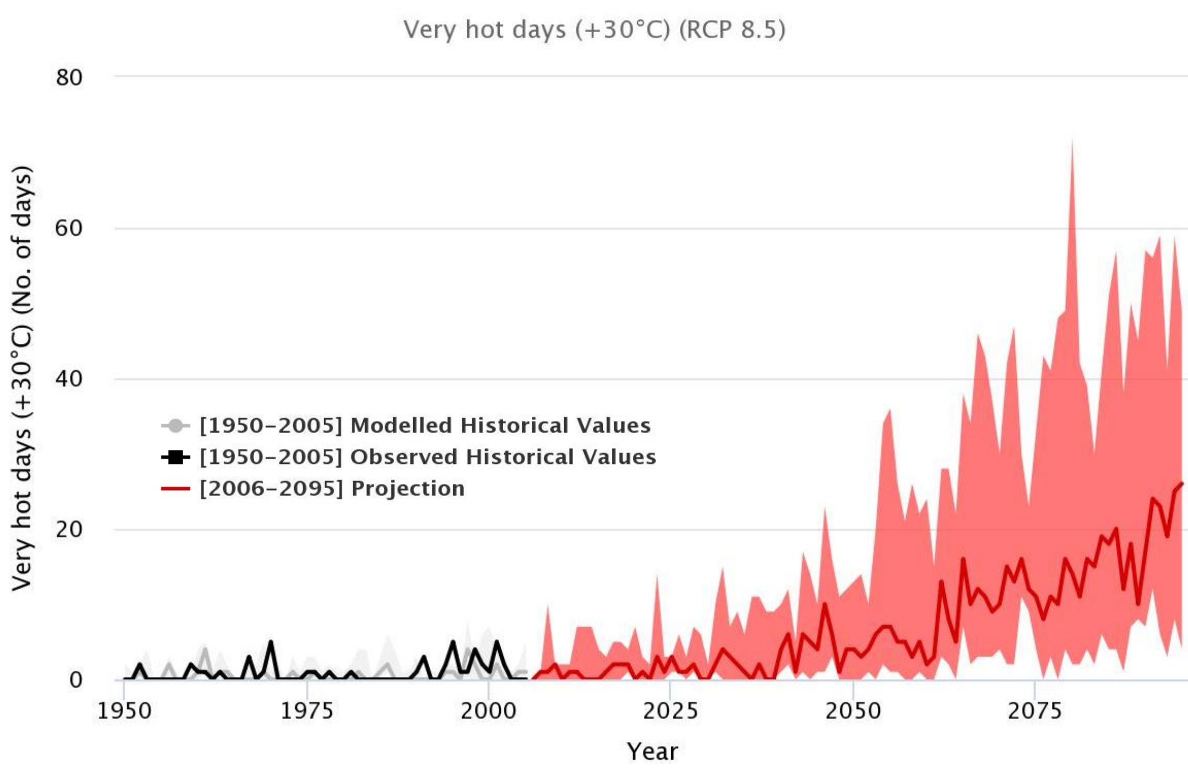
## 2.1 Temperature




**Projected mean annual temperature increase for Cape Breton Highlands from a 1980-2010 baseline.** Composite projection of CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Data source: Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011). Depending on the RCP scenario, mean annual temperatures are projected to increase 3.5 to 6.0 °C by 2071-2100.

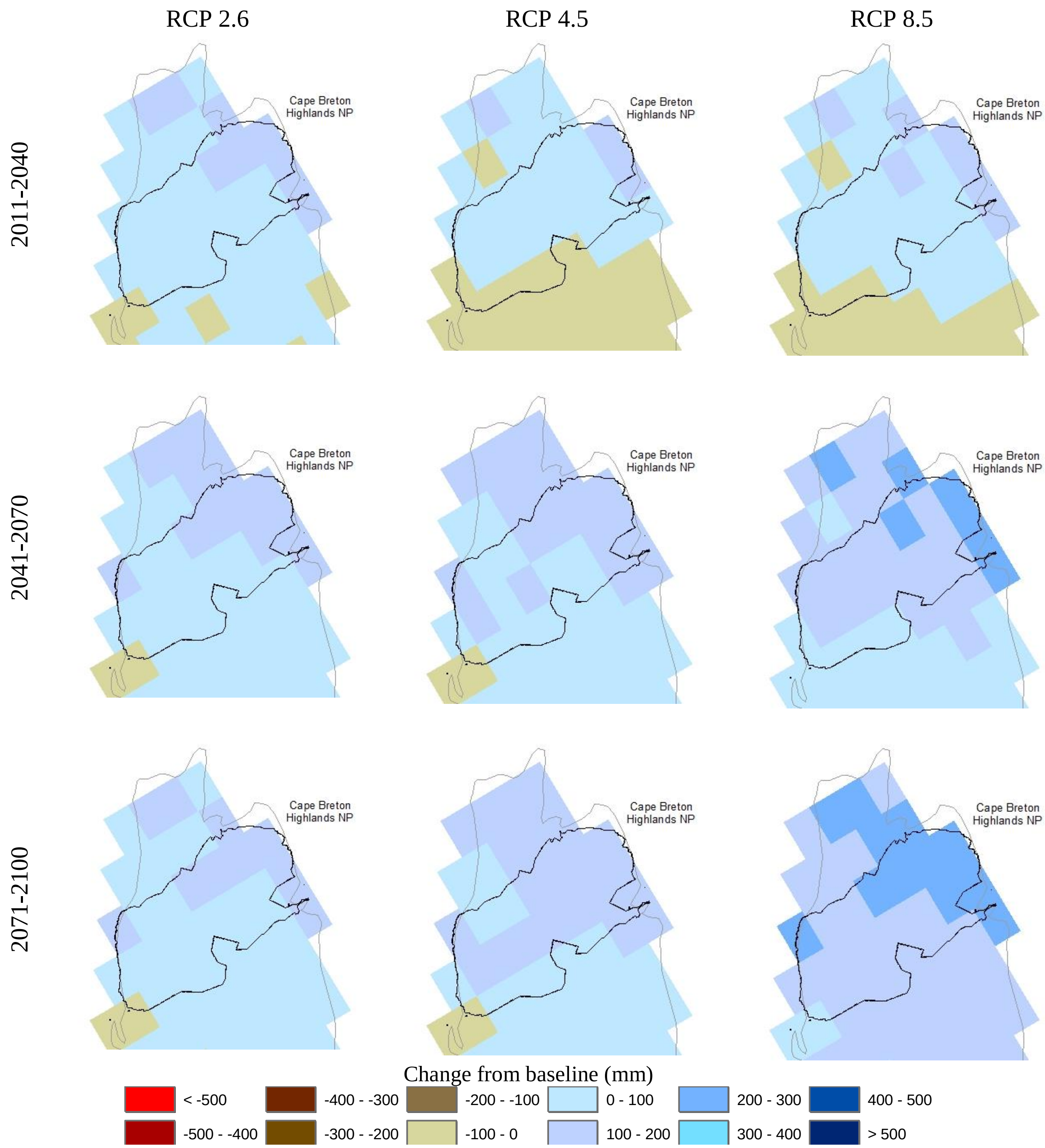



The frost-free season (days) for Sydney. It approximates the length of growing season (i.e., no freezing temperatures to kill or damage plants) and is projected to increase by 49.5 days by 2051-2080 (https://climateatlas.ca/).




Very hot days for Sydney (+30˚C) are projected to increase from 0.6 days/year for the 1976-2005 mean to 8.4 days/year by 2051-2080 (https://climateatlas.ca/).

## 2.2 Precipitation




**Projected total annual precipitation change for Cape Breton Highlands 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). Depending on the RCP scenario and location, total annual precipitation is projected to increase 50 to 260 mm by 2071-2100.

## *Rainfall Intensity, Duration and Frequency (IDF)*

These rainfall IDF values are calculated with IDF_CC Tool 3.0 (http://www.idf-cc-uwo.ca/) using Generalized Extreme Values (Simonovic *et al.*, 2017).

**Baseline** total precipitation amounts (mm) for Sydney from 1973-2007.

| T (years) | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| 5 min | 5.26 | 6.86 | 7.91 | 9.23 | 10.19 | 11.14 |
| 10 min | 7.91 | 10.19 | 11.64 | 13.40 | 14.67 | 15.88 |
| 15 min | 9.90 | 13.01 | 15.05 | 17.62 | 19.52 | 21.39 |
| 30 min | 13.56 | 18.40 | 21.69 | 25.96 | 29.20 | 32.49 |
| 1 h | 18.05 | 24.54 | 29.79 | 37.75 | 44.80 | 52.92 |
| 2 h | 26.10 | 34.45 | 40.67 | 49.42 | 56.62 | 64.43 |
| 6 h | 44.80 | 56.21 | 63.99 | 74.10 | 81.80 | 89.61 |
| 12 h | 56.44 | 69.52 | 78.04 | 88.67 | 96.44 | 104.06 |
| 24 h | 66.76 | 81.19 | 91.69 | 106.12 | 117.75 | 130.12 |

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

| T (years) | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| 5 min | 6.59 | 8.98 | 10.13 | 12.21 | 13.95 | 15.11 |
| 10 min | 9.90 | 13.33 | 14.94 | 17.79 | 20.16 | 21.61 |
| 15 min | 12.40 | 17.01 | 19.26 | 23.31 | 26.70 | 29.00 |
| 30 min | 17.02 | 24.04 | 27.62 | 34.19 | 39.71 | 43.98 |
| 1 h | 22.84 | 32.07 | 37.50 | 48.55 | 58.53 | 70.22 |
| 2 h | 32.88 | 45.10 | 51.61 | 64.38 | 75.43 | 86.81 |
| 6 h | 56.23 | 73.67 | 81.94 | 97.66 | 111.21 | 121.30 |
| 12 h | 70.72 | 91.11 | 100.29 | 117.36 | 131.97 | 141.10 |
| 24 h | 83.93 | 106.64 | 117.34 | 139.06 | 158.18 | 175.69 |

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

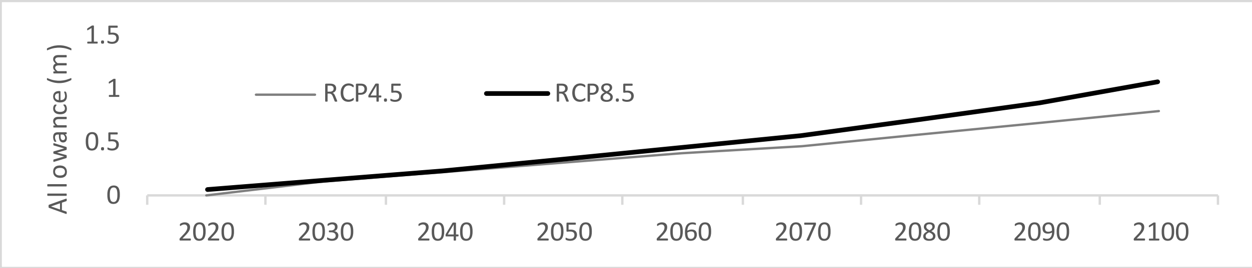
| T (years) | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| 5 min | 7.07 | 9.56 | 11.23 | 13.16 | 14.32 | 15.39 |
| 10 min | 10.63 | 14.20 | 16.52 | 19.20 | 20.75 | 22.15 |
| 15 min | 13.31 | 18.13 | 21.36 | 25.11 | 27.39 | 29.49 |
| 30 min | 18.27 | 25.62 | 30.73 | 36.75 | 40.60 | 44.24 |
| 1 h | 24.04 | 34.37 | 42.65 | 56.08 | 65.80 | 76.30 |
| 2 h | 34.99 | 48.24 | 58.53 | 71.69 | 81.84 | 92.66 |
| 6 h | 60.21 | 78.64 | 90.66 | 105.16 | 113.66 | 121.48 |
| 12 h | 75.72 | 97.16 | 110.72 | 126.65 | 135.49 | 143.38 |
| 24 h | 89.67 | 114.10 | 130.53 | 149.55 | 161.09 | 171.80 |

**Sydney IDF observations and projections.** Observe that today's "one in 100 year" rainfall event (i.e., 52.92 mm/hr) is projected to be closer to a "one in 25 year" event by 2050-2100 for both RCP scenarios and the future "one in 100 year" rainfall event is projected to increase in intensity (i.e., 70.22 – 76.30 mm/hr). In addition, the Climate Atlas of Canada (https://climateatlas.ca/) projects that the number of heavy precipitation days (>20mm) will increase from the 1976-2005 baseline of 15.7 days to 19.6 days (+4 days) by 2051-2080.

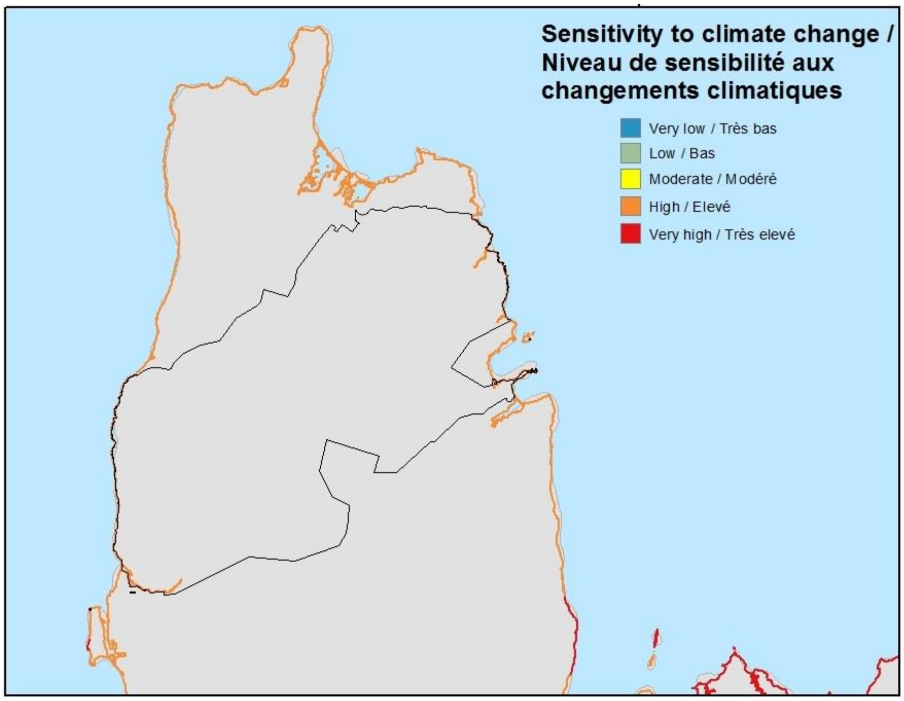
# 3. Climate Change Impacts

## 3.1 Sea Level Rise

Relative sea level in the region is increasing due to the combined effect of sea level rise (~1.6 mm/yr) and land subsidence (~1.6 mm/yr). For example, between 1900 and 2016 sea level at Halifax increased by 3.28 ± 0.19 mm/yr (total = ~38 cm) (http://www.psmsl.org/products/trends/). A top storm surge record (1970-2008) at North Sydney was 0.75 m during 2002 subtropical storm Gustav (https://www.ec.gc.ca/hurricane).



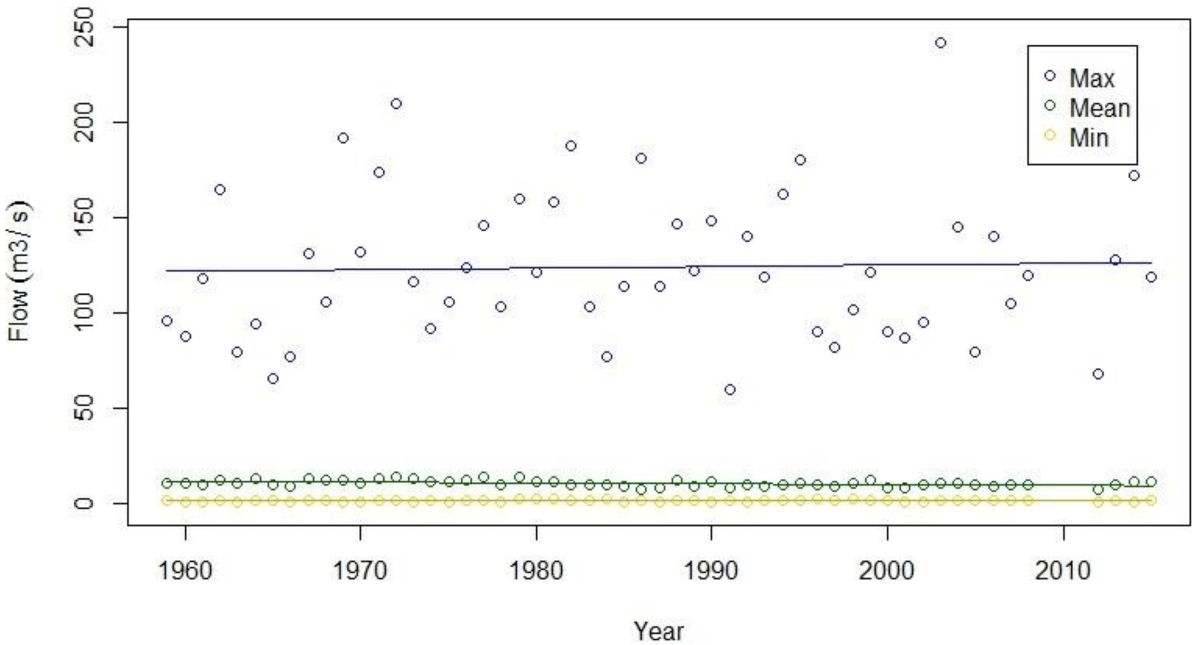

Pleasant Bay, NS projected vertical allowance of 79 to 107 cm by 2100 acquired from the Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT, http://www.bio.gc.ca/science/data-donnees/index-en.php). The vertical allowances are "recommended changes in the elevation of coastal infrastructure required to maintain the current level of flooding risk in a future scenario of sea level rise". These estimates are based on a future projection of regional sea level rise using the RCP 4.5 and RCP 8.5 scenarios and the historical water level records, including both tides and storm surge. The historical records do not incorporate predicted changes in storm tides.



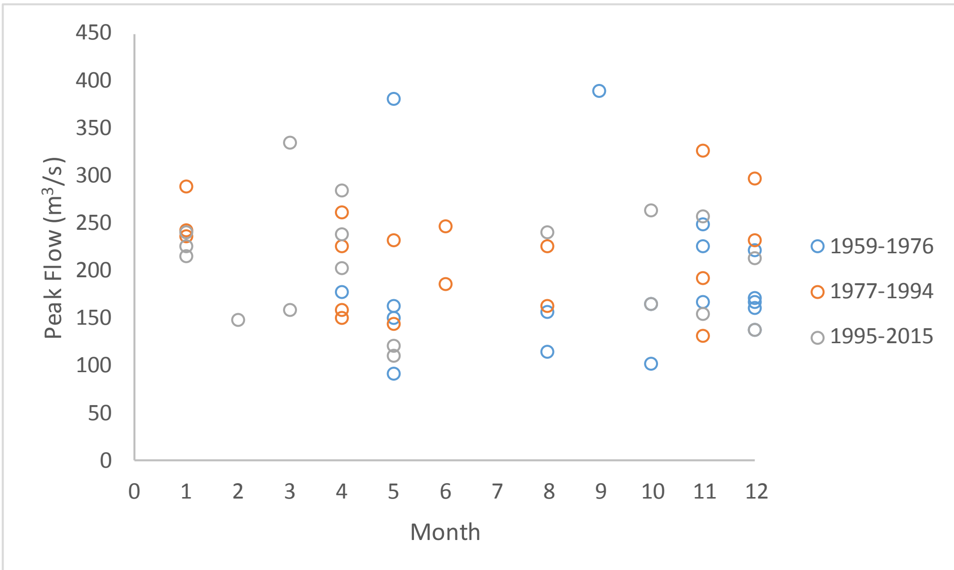

Map of coastal sensitivity to climate change along Cape Breton Highland's coast. Sensitivity is based on coastal materials, landforms, relief, ground ice, wave height, tidal range, recent trends in sea ice concentration, and projected sea level rise to 2050. Data provided by Natural Resources Canada (Couture and Manson, 2016). Naturally, areas of bedrock cliff are more resistant to erosion (ACASA, 2013).

## 3.2 Stream Hydrology

Changes to temperature (e.g., snowmelt) and precipitation (e.g., intensity, duration, frequency, rain vs snow) affects stream hydrology.




**Cheticamp River above Robert Brook (01FC002) annual flow data for 1959 to 2015.** A statistically significant (P<0.05) decrease trend observed for mean flow (-20%). A slight decrease in minimum and a slight increase in maximum flows observed, but they are not statistically significant (P<0.05). Trend determined using a generalized linear model (R Core Team, 2017) and data from EC Data Explorer, HYDAT (July 16, 2018) (https://ec.gc.ca/rhc-wsc/). Additional analysis is recommended and could reveal patterns in minimum, maximum, and mean flows and levels, as well as timing and seasonal patterns.




**Cheticamp River above Robert Brook (01FC002) maximum peak flow value and the month it occurred for 1959 to 2015.** The annual maximum peak flow value appear to have occurred in all months, except July.

## 3.3 Cultural Resources

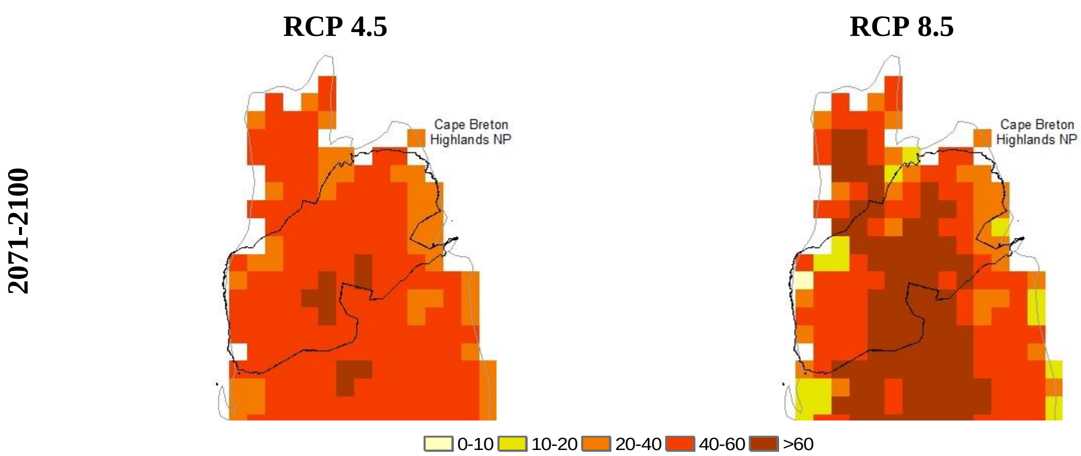
Regionally, the Fortress of Louisbourg has undertaken considerable research and monitoring on climate change impacts to cultural resources (e.g., Duggan, 2014; Dunham, 2017; Johnston, 2011; Taylor, 1992; Taylor *et al.*, 2011; Taylor *et al.*, 2000). In fact, FOL has undertaken "rescue archaeology" as a proactive means to protect archaeological sites threatened by coastal erosion (e.g., Canadian Historic Sites, 1971; Dunham, 2017).

Other possible impacts and considerations:

- Physical damage from storm surge and changing winds and currents can impact submerged cultural resources. As well, increased ocean temperatures and acidification can increase corrosion rates (Beavers *et al.*, 2016).
- Efforts to FireSmart (e.g., replace wood shake roofing) may influence the character or cultural integrity of a facility (Marissa *et al.*, 2016).
- There is a potential for increased deterioration of facilities and collections (with non-mechanically ventilated interiors, HVACs) from increased temperature, humidity, and precipitation, e.g., increased mold, rot and fungal decay; increased corrosion, etc… (Brimblecombe, 2014; Brimblecombe and Brimblecombe, 2016; Horowitz *et al.*, 2016; Marissa *et al.*, 2016).
- Longer growing seasons and warmer conditions may lead to increased presence and abundance of invasive plant species and pests (Marissa *et al.*, 2016)
- Micro-climates which allow historic gardens to flourish may be affected (e.g., Neill, 1983; Percy *et al.*, 2015).

## 3.4 Wildfire

Due to positive trends in drying and escalation of potential fire severity and intensity, a moderate increase in wildfire risk is projected for this area (Whitman *et al.*, 2015).



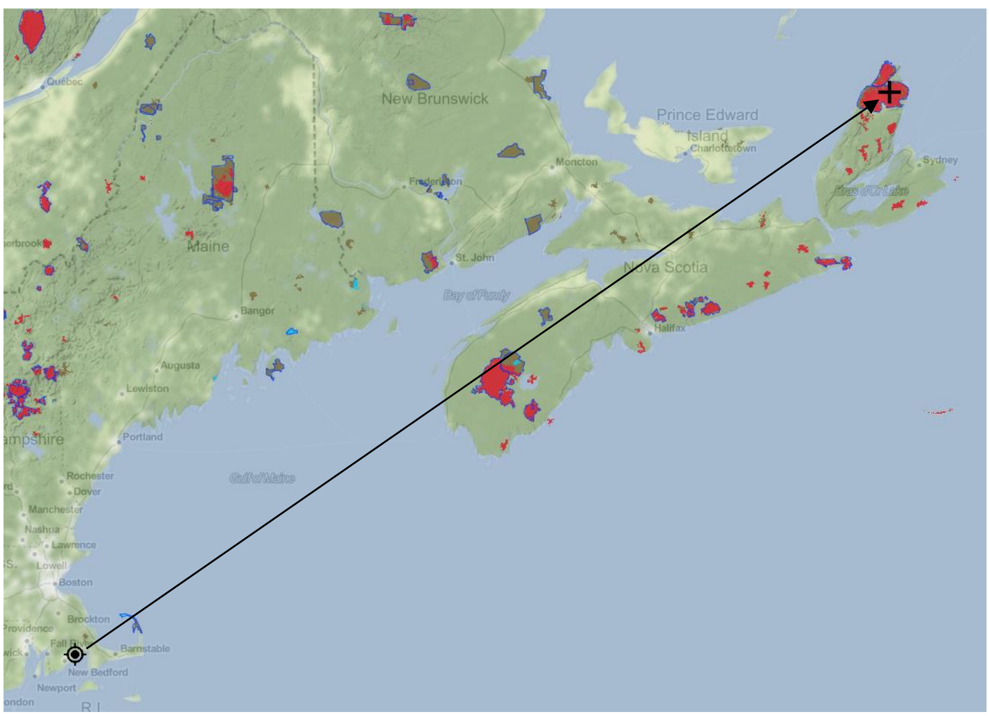

**Projected increase in wildfire season for Cape Breton Highlands**. Increased length in days from baseline (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. Depending on the RCP scenario and location, an increase of 15-70 days is projected by 2071-2100. Data source: Natural Resources Canada, http://cfs.nrcan.gc.ca/fc-data-catalogue.

## 3.5 Biodiversity

Biodiversity is the variety of genes, species and ecosystems and is essential to our social, economic and ecological well-being. The effects of climate change on biodiversity include: shifts in species distribution; changes in phenology; decoupling of interactions (plant-pollinator); reductions in population size; species extinction and extirpation; habitat loss; increased disease and spread of invasive species and pests; competitive exclusion; and, change to ecosystem services (Nantel *et al.*, 2014; Nituch and Bowman, 2013).

Osawa (2015; see Table 4.2) completed a climate change vulnerability assessment for select species in CBHNP. As reported, American marten, balsam fir, yellow birch, eastern larch, black spruce, and red spruce were classified as “Highly Vulnerability” and Bicknell's thrush, white birch, and white spruce were classified as “Highly Vulnerable/Moderately Vulnerable”. In contrast, hermit thrush, chimney swift, blue jay, American redstart, American robin, red-eyed vireo, Canada warbler, American eel, coyote, white-tailed deer, red fox, and red oak were classified as “Increase Likely”.

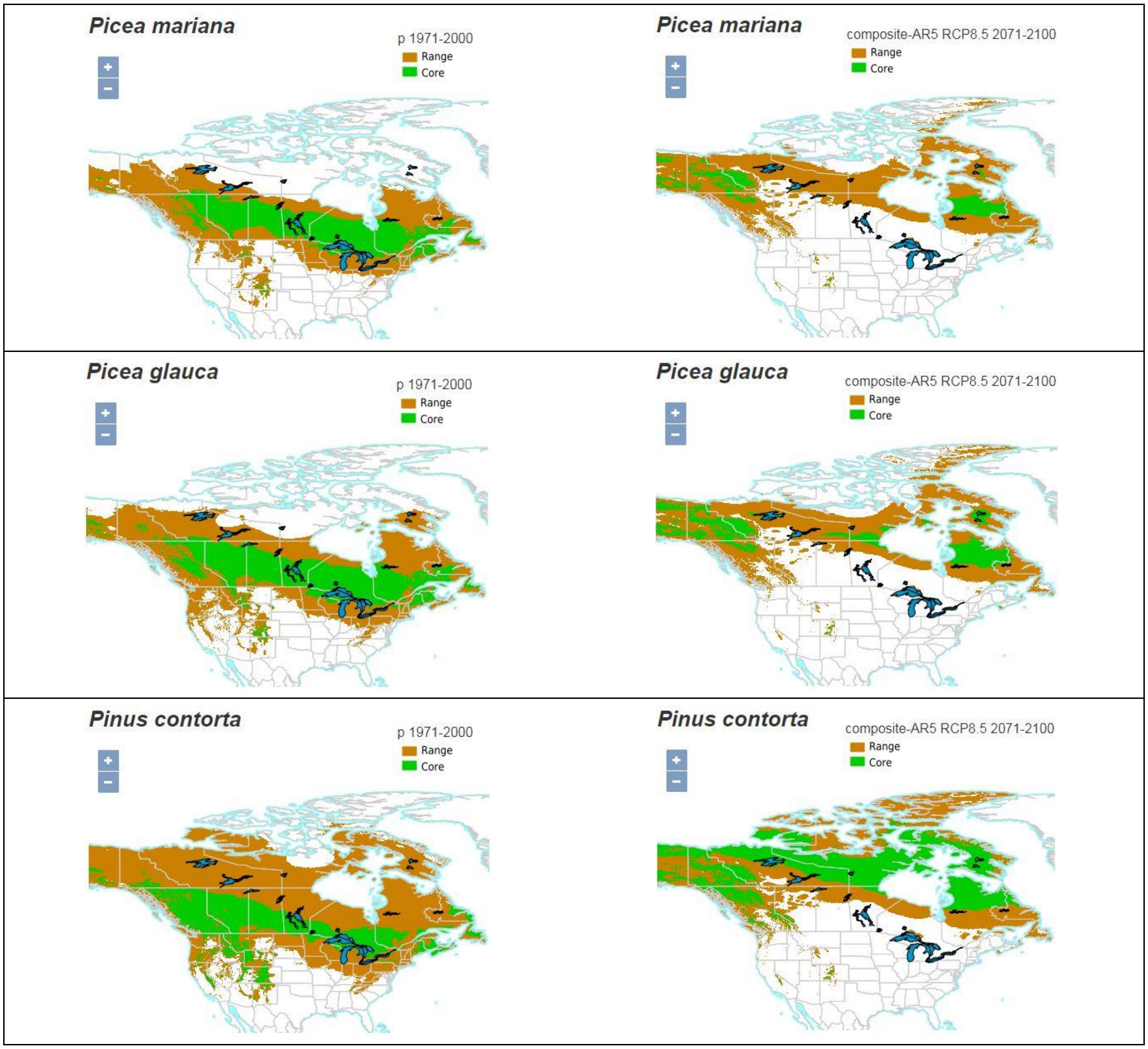
By the late twenty-first century, boreal forests within CBHNP are expected to “fail to regenerate and survive” (Taylor *et al.*, 2017). There may be a lag period between when the boreal forest begins to decline, and when another type of forest can successfully take its place (Taylor *et al.*, 2017). This lag threatens the future of forests in CBHNP, as grasslands may become established before a new forest type can establish itself in areas that were previously boreal forest.

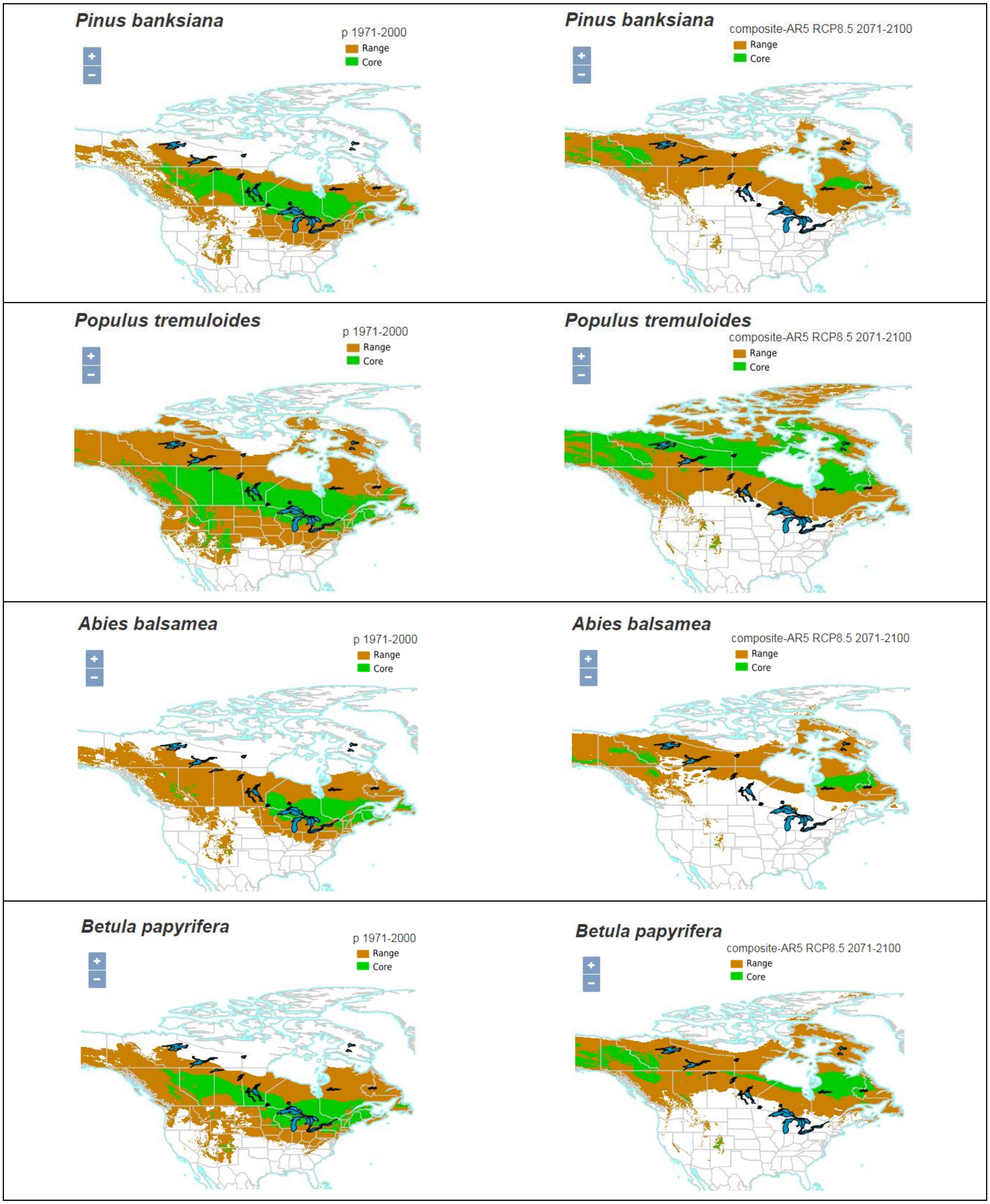


Origin of the future climate type for Cape Breton Highlands (2080’s, RCP 8.5) determined using AdaptWest Climate Displacement Tool, https://adaptwest.databasin.org/pages/climate-displacement-protected-areas.

### *Plant Hardiness*

Plant Hardiness is associated with probabilities of plant survival in relation to average, broad scale climatic conditions. As the climate changes, habitat suitability for plant species also changes. Natural Resources Canada maintains a database that includes future projections of plant hardiness (http://www.planthardiness.gc.ca/).

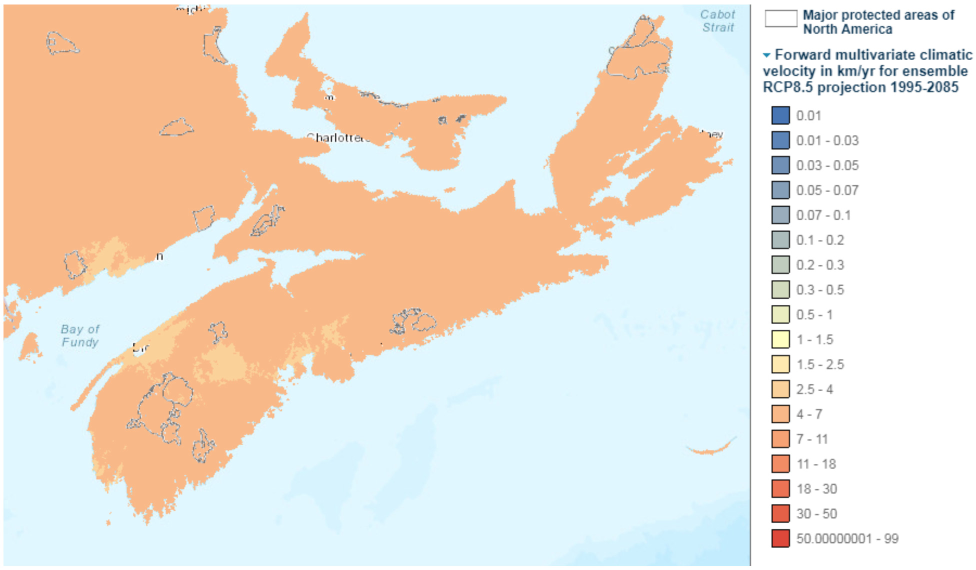




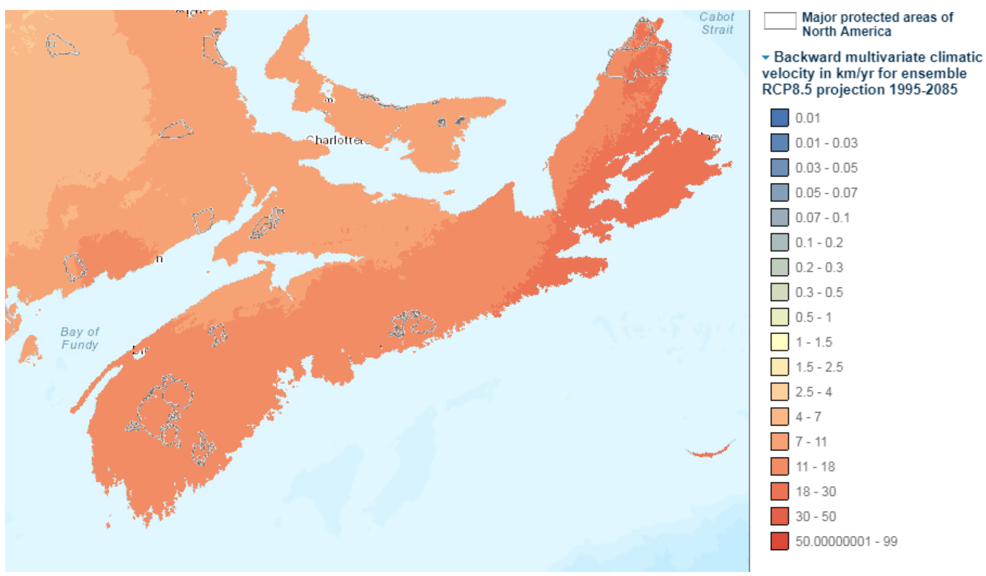

Change in core and full range for example tree species from a 1971-2000 baseline to 2071-2100 future projection (RCP 8.5) based on plant hardiness.

## *Climate Velocity*

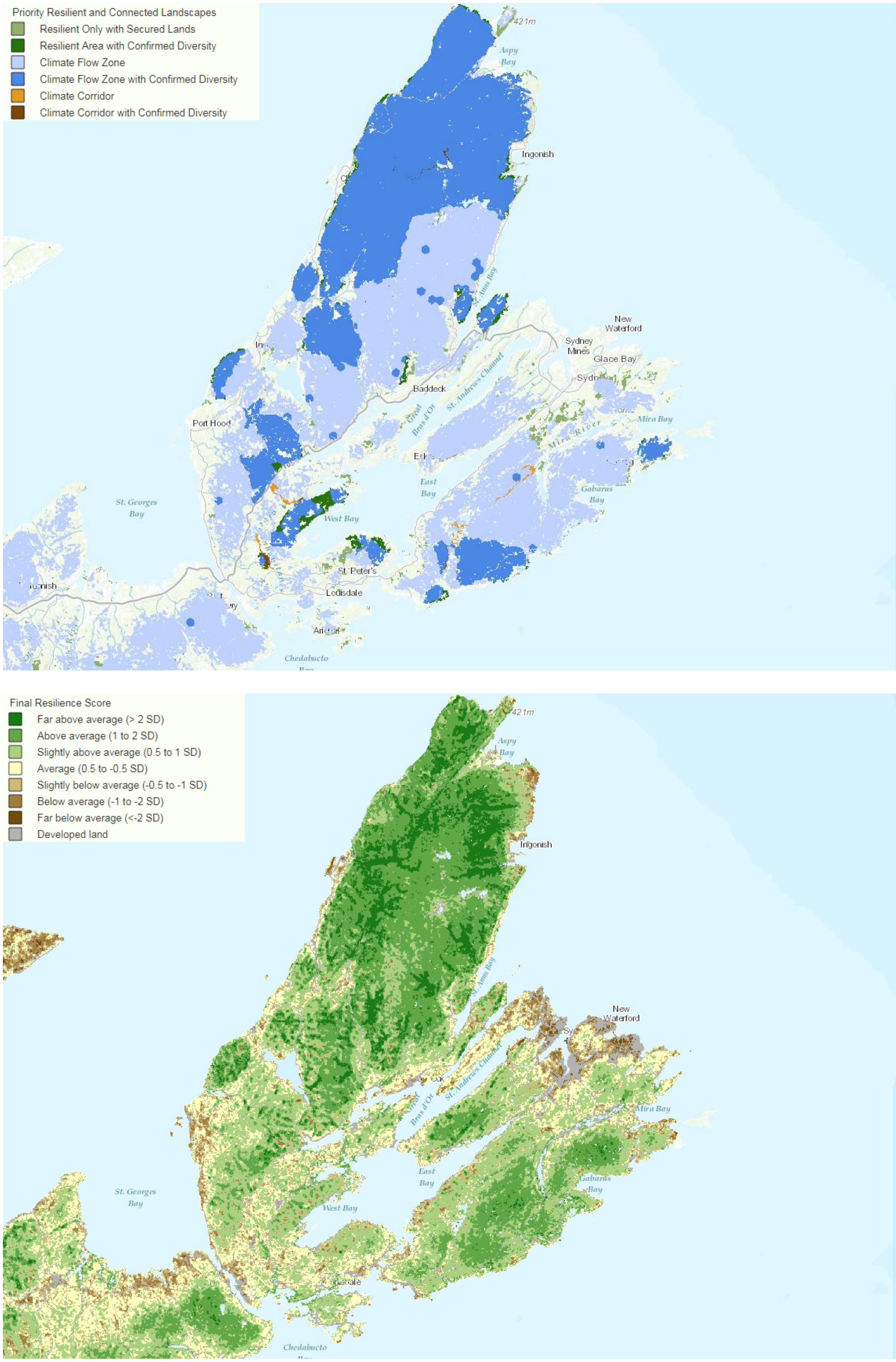
AdaptWest (https://adaptwest.databasin.org/) provides integrative tools that can inform conservation planning, including the following analysis on climate velocity.




**Forward climate velocity (km/yr).** The rate at which an organism in the current landscape has to migrate to maintain constant climate conditions. At FOL the projected rate is 5 **km/yr** for the 2071-2100 (RCP 8.5) period.




**Backward climate velocity (km/yr).** Given the projected future climate habitat of a grid cell, it is the minimum rate of migration for an organism from equivalent climate conditions to colonize this climate habitat. At FOL the projected rate is **20 km/yr** for the 2071-2100 (RCP 8.5) period.




The Nature Conservancy's Resilient Land Mapping Tool (Anderson *et al.*, 2016; http://maps.tnc.org/resilientland/). Highlights those areas with sufficient variability and microclimate options to enable species and ecosystems to persist in the face of climate change.

## 3.6 Visitor Experience

The effects of climate change on visitor experience may include: increased length of visitation season, increased visitation during shoulder seasons; increased prevalence of climate and weather-related medical emergencies such as heat exhaustion, heat stroke and dehydration; and, reduced opportunities for campfires due to higher wildfire risk.

## 3.7 Visitor Safety

Visitor safety may be effected by an increased incidence of extreme weather events and higher average temperatures. Some anticipated effects of climate change include: increased incidence of high bacteria counts at CBHNP beaches; increased incidence of heat-related illness; increased incidence of insect-borne disease (e.g. west-nile disease, lyme disease); a potential increase in the occurrence of hazard trees; reduced air quality due to an increased prevalence of wildfires combined with increased humidity.

## 3.8 Assets

Increased precipitation, higher temperatures, and more frequent and severe extreme weather events are all expected to affect park assets such as vehicles, facilities, campgrounds and trails. Anticipated impacts of climate change on park assets include: more frequent road erosion and washout; more frequent trail erosion and washout; more frequent and severe flooding of campgrounds; increased damage to visitor accommodations (e.g., oTENTiks and equipped campsites); loss of coastal assets to coastal inundation or storm surge; possible blockage of emergency exits due to flooding or tree blow-down.

An increase in the frequency of slope failure on Cape Breton Island has been observed and may be associated with spring rain intensity and loss of soil strength due to spruce budworm induced root decay (Finck, 1993; Spooner *et al.*, 2013).

# 4. References

ACASA. (2013). *Coastal Erosion and Climate Change*. Alantic Climate Adaptation Solutions Association and Prince Edward Island Department of Environment, Labour and Justice. https://atlanticadaptation.ca/

Anderson, M. G., Barnett, A., Clark, M., Prince, J., Olivero Sheldon, A., and B., V. (2016). *Resilient and Connected Landscapes for Terrestrial Conservation*. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office, Boston, MA. http://easterndivision.s3.amazonaws.com/Resilient_and_Connected_Landscapes_For_Terrestial_Conservation.pdf

Beavers, R. L., Babson, A. L., and Schupp, C. A. (Eds.). (2016). *Coastal Adaptation Strategies Handbook* (Vol. NPS 999/134090.). Washington, DC.: U.S. National Park Service.

Brimblecombe, P. (2014). Refining climate change threats to heritage. *Journal of the Institute of Conservation, 37*(2), 85-93. doi:10.1080/19455224.2014.916226.

Brimblecombe, P. and Brimblecombe, C. (2016). Climate Change and Non-mechanically Ventilated Historic Interiors. *APT Bulletin, 47*(1), 31-38. http://www.jstor.org/stable/43799261

Canadian Historic Sites. (1971). *Occasional Papers in Archaeology and History No. 2. Contributions from the Fortress of Louisbourg - No. 1*. National Historic Sites Service, National and Historic

Parks Branch, Department of Indian Affairs and Northern Development, Ottawa. http://parkscanadahistory.com/series/chs/2/chs2-eng.pdf
Couture, N. J. and Manson, G. K. (2016). *CanCoast: a tool for helping to assess climate vulnerability*. Natural Resources Canada. Geological Survey of Canada.
Duggan, R. (2014). *Coastal Heritage Conservation Plan: Fortress Louisbourg National Historic Site of Canada*. Parks Canada, Halifax, Nova Scotia.
Dunham, R. (2017). A Cultural Legacy under Threat: Managing Eroding Coastal Heritage at the Fortress of Louisbourg National Historic Site. *Ocean Yearbook, 31*(1), 27-54. doi:10.1163/9789004347137_003.
ECCC. (2017). *Adjusted and Homogenized Canadian Climate Data (AHCCD)*. Environment and Climate Change Canada. https://www.ec.gc.ca/dccha-ahccd/
Finck, P. W. (1993). *An evaluation of debris avalanches in the central Cape Breton Highlands, Nova Scotia*. Mines and Energy Branch, Nova Scotia Department of Natural Resources. https://novascotia.ca/natr/meb/pdf/93pap01.asp
Gross, J. E., Woodley, S., Welling, L. A., and Watson, J. E. M. (Eds.). (2016). *Adapting to Climate Change. Guidance for Protected Area Managers and Planners* (Vol. No. 24). Gland, Switzerland: IUCN.
Horowitz, A. D., Lopez, M. F., Ross, S. M., and Sparenberg, J. A. (2016). *Climate Change and Cultural Heritage Conservation. A Literature Review*. Association for Preservation Technology (APT), Technical Committee on Sustainable Preservation's Education and Research focus group. http://www.apti.org/clientuploads/Technical%20Committees/2015-2016/APT%20TC-SP%20Literature%20Review%20Climate%20Change%20%20Cultural%20Heritage%20Conservation%202016June30.pdf
IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change (IPCC). Geneva, Switzerland. http://www.ipcc.ch/report/ar5/
Johnston, A. J. B. (2011). Land & Sea & Louisbourg: 5000 Years and Counting. *The Nashwaak Review, 26/27*(1), 209-245.
Lemmen, D. S., Warren, F. J., James, T. S., and Mercer Clarke, C. S. L. (Eds.). (2016). *Canada's Marine Coasts in a Changing Climate*. Ottawa, ON: Government of Canada.
Marissa, M., Rockman, M., Smith, C., and Meadow, A. (2016). *Climate Change Impacts on Cultural Resources*. Cultural Resources Partnerships and Science, United States National Park Service (US NPS), Washington, DC. https://www.nps.gov/subjects/climatechange/upload/CR-Impacts-Identification-Guide-v4-1.pdf
Nantel, P., Pellatt, M. G., Keenleyside, K. A., and Gray, P. A. (2014). Biodiversity and Protected Areas. In F. J. Warrenand D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 159-190). Ottawa, ON: Government of Canada.
Neill, A. O. (1983). The gardens of 18th-century louisbourg. *Journal of Garden History, 3*(3), 176-178. doi:10.1080/01445170.1983.10412440.
Nituch, L. A. and Bowman, J. (2013). *Community-Level Effects of Climate Change on Ontario's Terrestrial Biodiversity*. Ontario Ministry of Natural Resources. http://www.climateontario.ca/MNR_Publications/CCRR-36.pdf
Osawa, T. (2015). *Climate-Change Vulnerability Assessment for Selected Species in Three National Parks in Eastern Canada.* (Master of Environmental Studies), Dalhousie University
Parker, S. (2017). *Let's Talk about Climate Change: Atlantic Region*. Parks Canada, Office of the Chief Ecosystem Scientist. doi:10.13140/RG.2.2.26281.70244.
Parker, S., Barr, S., and Harrop Archibald, H. (2018). *Climate Change Adaptation Options for Biodiversity: Part 1. Context and Guidance Report*. Office of the Chief Ecosystem Scientist, Parks Canada Agency, Gatineau, QC. doi:10.13140/RG.2.2.31409.02403/1.

PCIC. (2014). *Statistically Downscaled Climate Scenarios*. Pacific Climate Impacts Consortium, University of Victoria. https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

Percy, K., Ward, S., Quintero, M. S., and Morrison, T. (2015). Integrated Digital Technologies for the Architectural Rehabilitation & Conservation of Beinn Bhreagh Hall & Surrounding Site, Nova Scotia, Canada. In Y. N. Yen, K. H. Weng, and H. M. Cheng (Eds.), *25th International CIPA Symposium 2015* (pp. 235-241). Kensington: Int Soc Photogrammetry Remote Sensing C/O School of Surveying.

Price, D. T., McKenney, D. W., Joyce, L. A., Siltanen, R. M., Papadopol, P., and Lawrence, K. (2011). *High-Resolution Interpolation of Climate Scenarios for Canada Derived from General Circulation Model Simulations*. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. http://cfs.nrcan.gc.ca/publications?id=32971

R Core Team. (2017). R: A Language and Environment for Statistical Computing (ver. 3.4.3). http://www.R-project.org

Rockman, M., Morgan, M., Ziaja, S., Hambrecht, G., and Meadow, A. (2016). *Cultural Resources Climate Change Strategy*. Cultural Resources, Partnerships, and Science and Climate Change Response Program, National Park Service (NPS). Washington, DC. https://www.nps.gov/subjects/climatechange/culturalresourcesstrategy.htm

Simonovic, S. P., Schardong, A., and Sandink, D. (2017). Mapping Extreme Rainfall Statistics for Canada under Climate Change Using Updated Intensity-Duration-Frequency Curves. *Journal of Water Resources Planning and Management, 143*(3), 12. doi:10.1061/(asce)wr.1943-5452.0000725.

Spooner, I., Batterson, M., Catto, N., Liverman, D., Broster, B. E., Kearns, K., *et al.* (2013). Slope failure hazard in Canada's Atlantic Provinces: a review. *Atlantic Geology, 49*, 1-14. doi:10.4138/atlgeol.2013.001.

Taylor, A. R., Boulanger, Y., Price, D. T., Cyr, D., McGarrigle, E., Rammer, W., *et al.* (2017). Rapid 21st century climate change projected to shift composition and growth of Canada's Acadian Forest Region. *Forest Ecology and Management, 405*, 284-294. doi:10.1016/j.foreco.2017.07.033.

Taylor, R. B. (1992). *Coastal Stability and Flooding At Grand Etang, Fortress of Louisbourg, Nova Scotia*. Geological Survey of Canada. doi:10.4095/133480.

Taylor, R. B., Frobel, D., Brown, A. O., Duggan, R., and Reeves, L. (2011). *Field Guide for Monitoring Shoreline Change, Fortress of Louisbourg National Historical Site, Nova Scotia*. Geological Survey of Canada. http://publications.gc.ca/collections/collection_2012/rncan-nrcan/M183-2-6966-eng.pdf

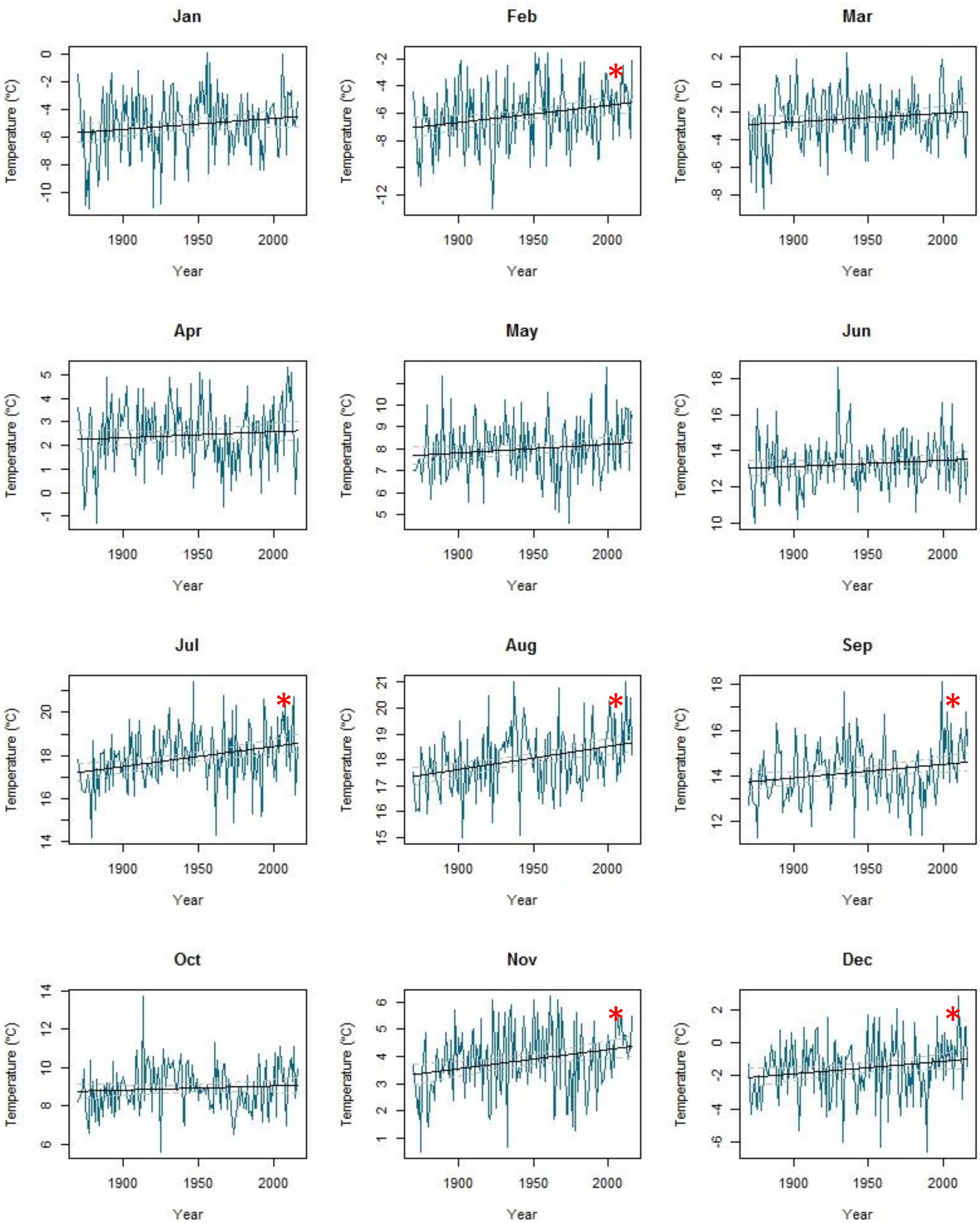
Taylor, R. B., Josenhans, H., Balcom, B. A., and Johnston, A. J. B. (2000). *Louisbourg Harbour through Time*. Geological Survey of Canada Open File Report 3896, poster. http://publications.gc.ca/collections/collection_2016/rncan-nrcan/M183-2-3896-eng.pdf

Vescovi, L. and Logan, T. (2007). *Final report. Selection of climate metrics relevant for monitoring ecological integrity in National Parks*. Prepared for Parks Canada by Ouranos.

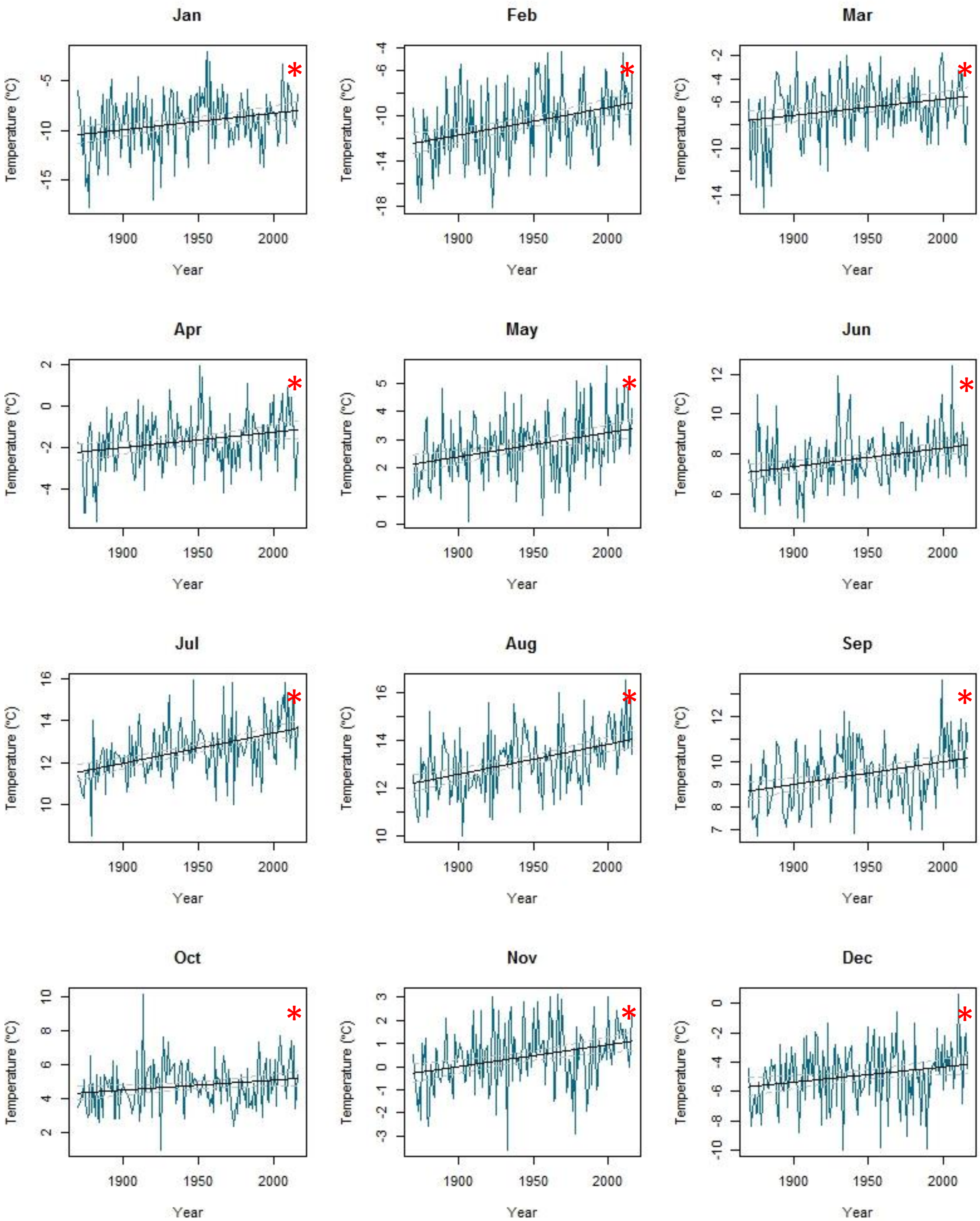
Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., *et al.* (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi:10.1007/s10584-011-0148-z.

Whitman, E., Sherren, K., and Rapaport, E. (2015). Increasing daily wildfire risk in the Acadian Forest Region of Nova Scotia, Canada, under future climate change. *Regional Environmental Change, 15*(7), 1447-1459. doi:10.1007/s10113-014-0698-5.

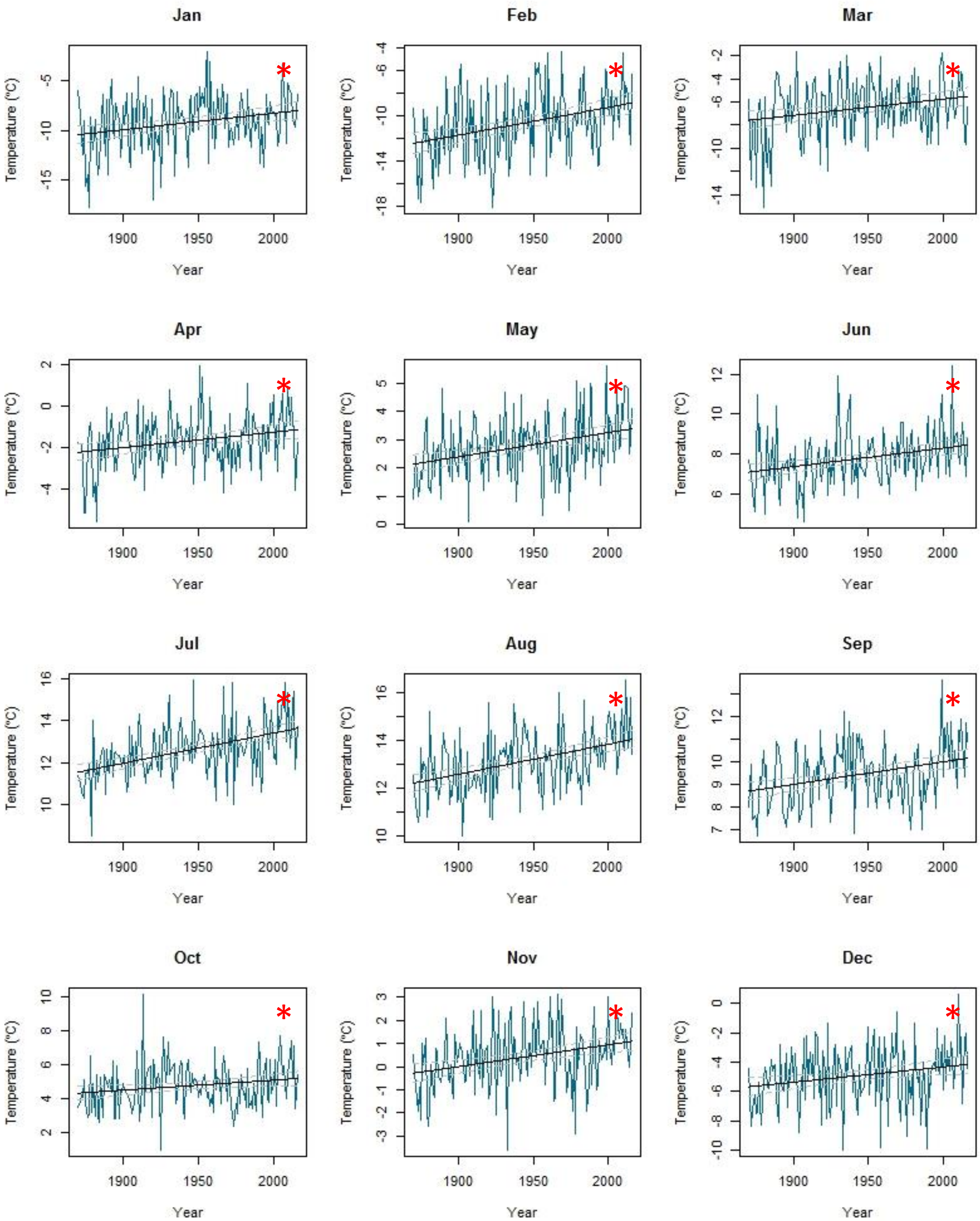
# Appendix 1. Additional Climate Trends



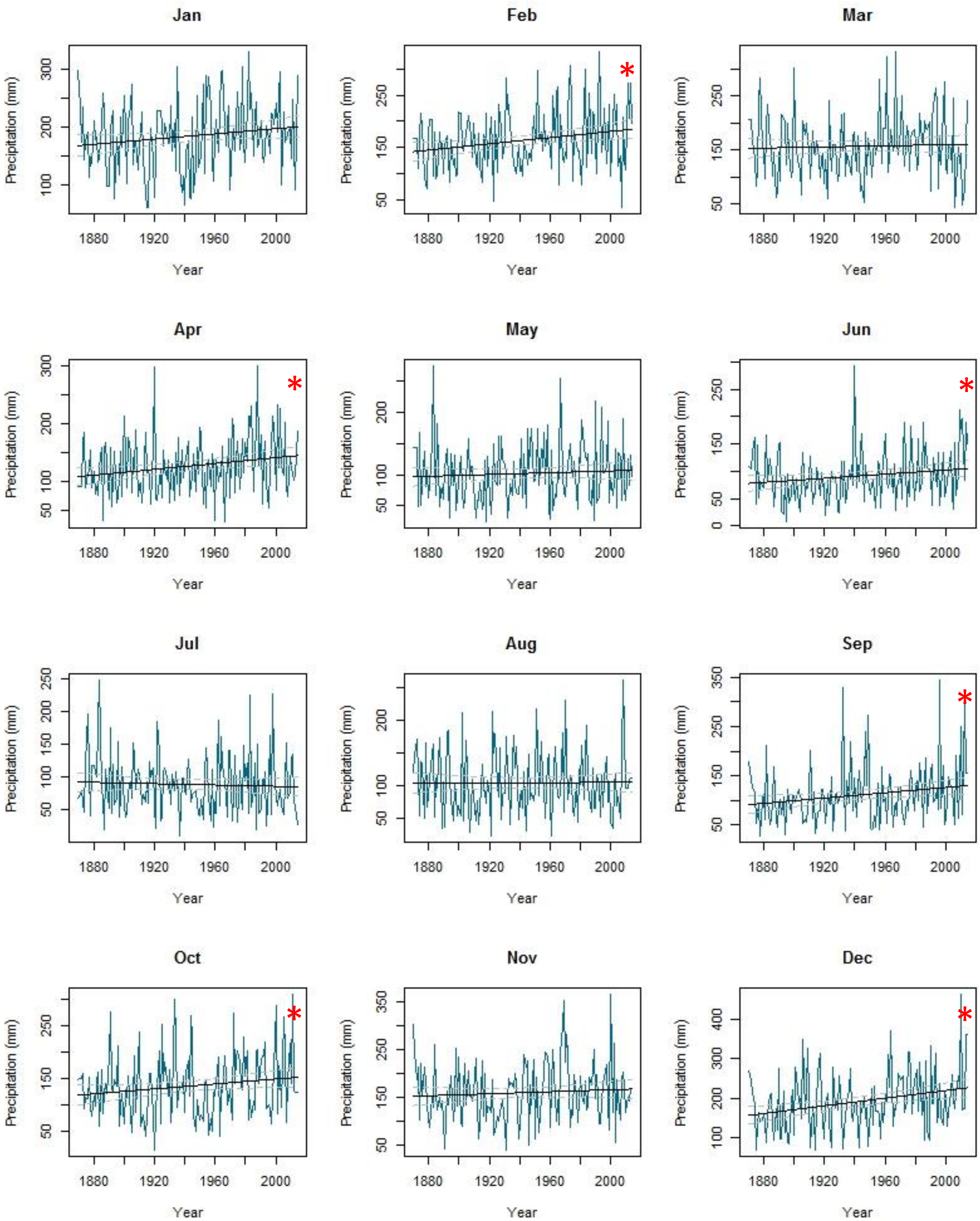

**Sydney mean monthly temperature.** Only Feb, Jul, Aug, Sep, Nov and Dec demonstrated a statistically significant ($P<0.05$) increase. Feb demonstrated the greatest increase, ~1.8°C since 1870.



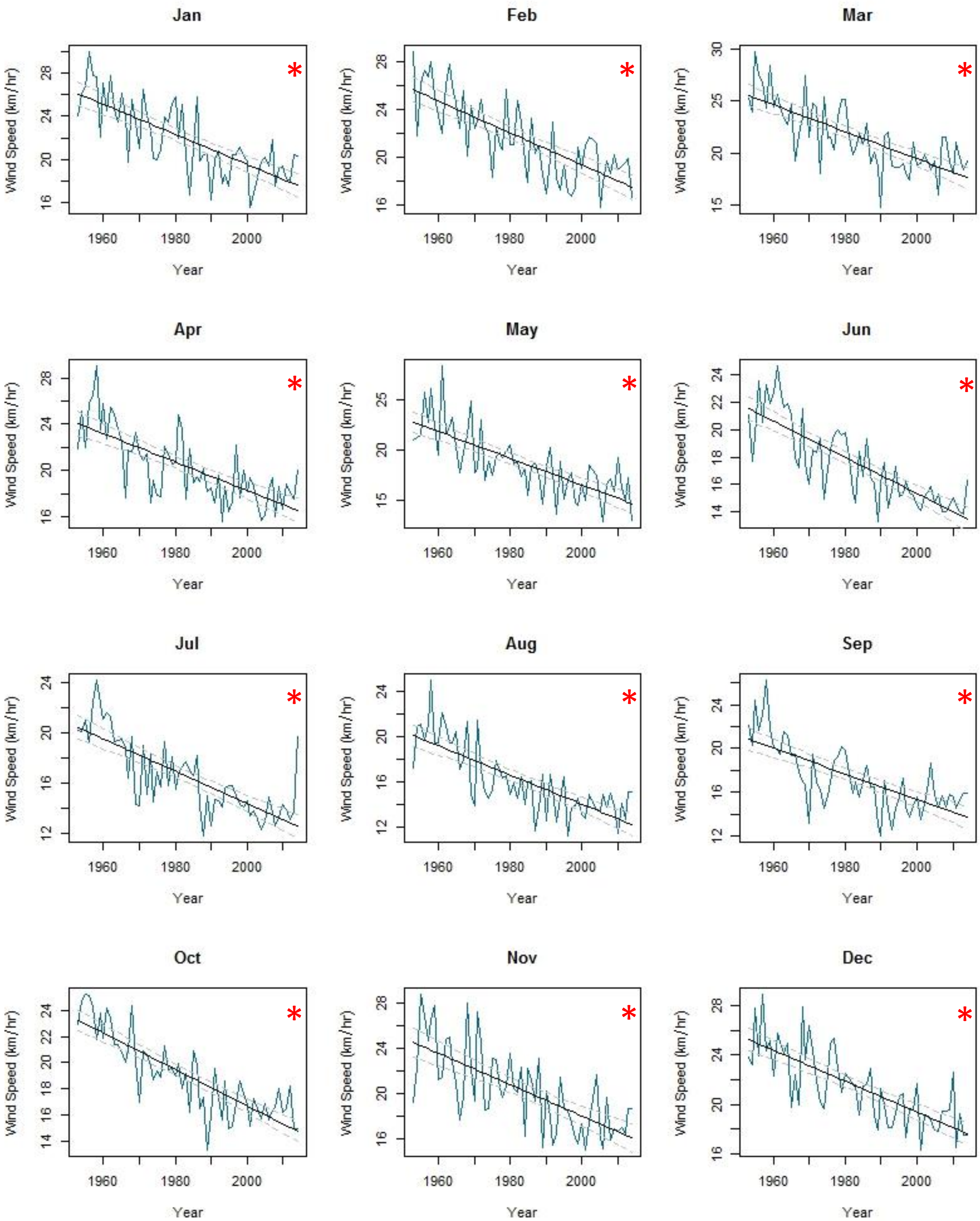

**Sydney mean monthly <u>minimum</u> temperature**. All months demonstrated a statistically significant (P<0.05) increase in mean monthly minimum temperatures (i.e., nighttime). Feb demonstrated the greatest increase, ~3.6°C since 1870.




**Sydney mean monthly <u>maximum</u> temperature.** All months demonstrated a statistically significant (P<0.05) increase in mean monthly maximum temperatures (i.e., daytime). Feb demonstrated the greatest increase, ~3.6°C since 1870.

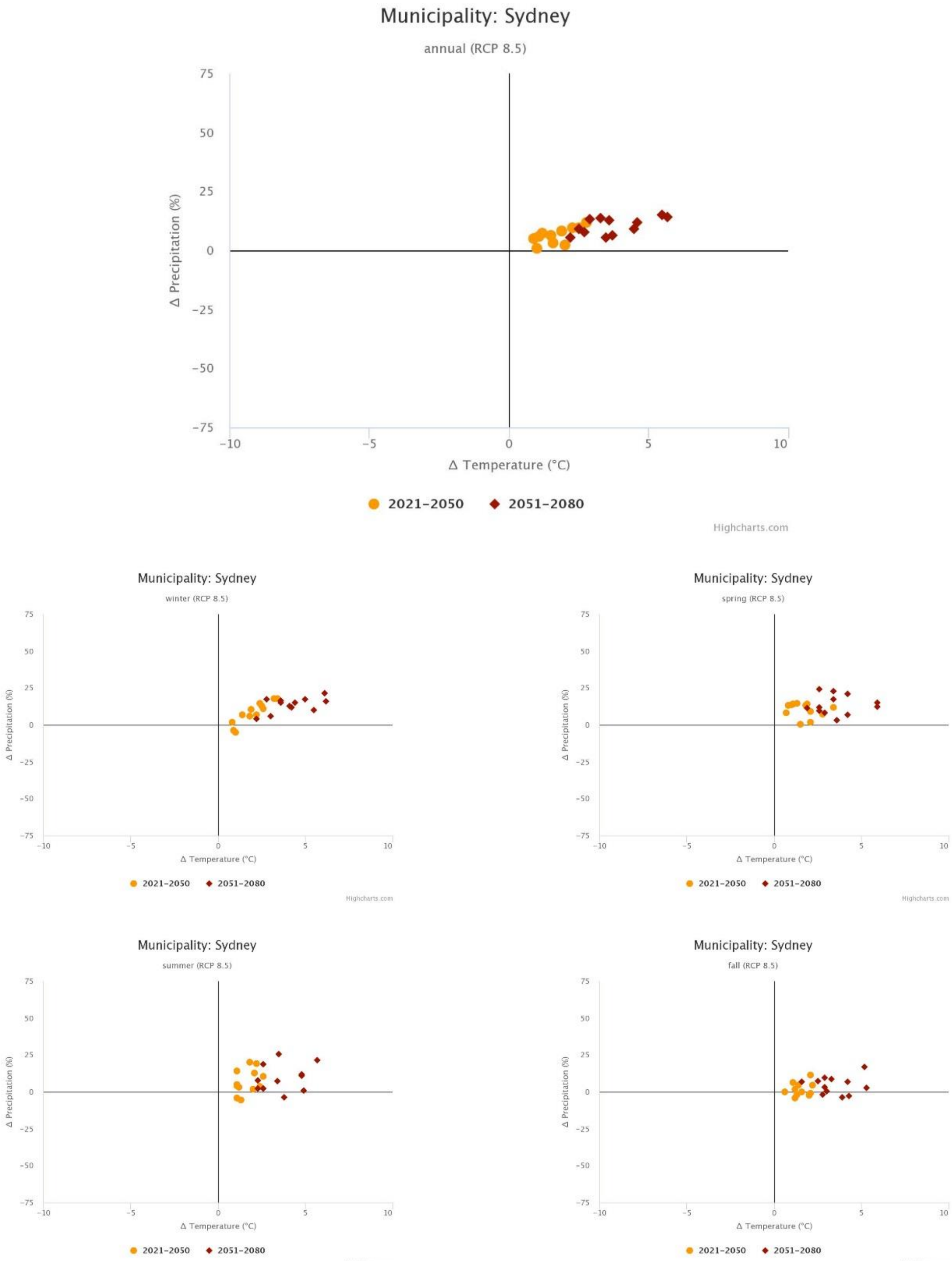



**Sydney total monthly precipitation.** Total monthly precipitation has demonstrated a statistically significant increase (P<0.05) in Feb, Apr, Jun. Sep, Oct and Dec since 1870. The greatest increase being observed in Dec, ~70 mm (45%).



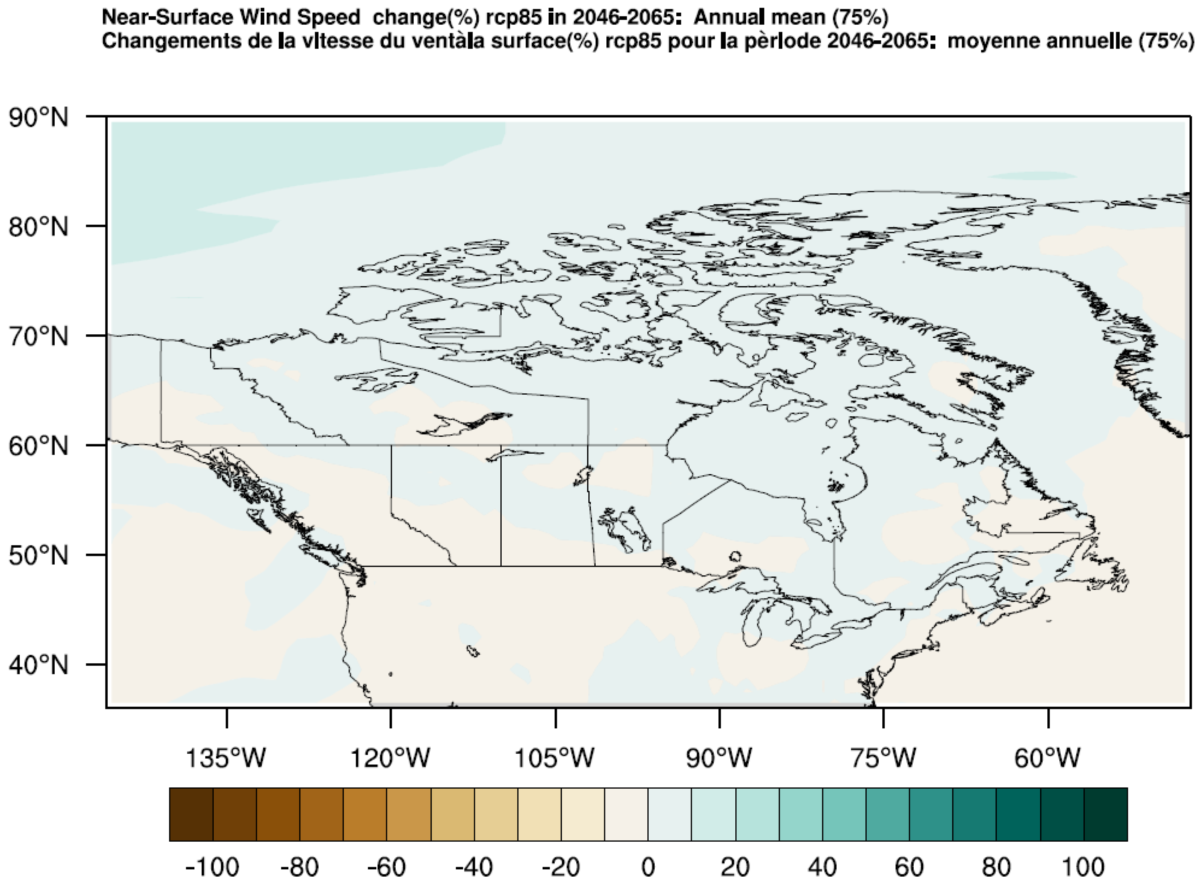

**Sydney mean monthly wind speeds.** All mean monthly wind speeds have demonstrated a statistically significant (P<0.05) decrease since 1953.

# Appendix 2. Model Scatterplots for Temperature and Precipitation




**Climate models for Sydney area.** Each point represents a single model-simulated temperature/precipitation response to the RCP 8.5 scenario. Statistically downscaled data (Bias Corrected Spatial Disaggregation; BCSD) derived from 12 CMIP5 global climate models: ACCESS1.0, CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3-6.0, GFDL-ESM2G, HadGEM2-CC, HadGEM2-LR, INM-CM4, MPI-ESM-LR, MRI-CGCM3, MIROC5 (PCIC, 2014). All the models project warmer conditions and most project wetter conditions.

# Appendix 3. Near-Surface Wind Speed Projections




CMIP5 climate model (http://climate-scenarios.canada.ca/?page=download-cmip5) project decrease in wind speed in 2046-2065 from 1986-2005 reference period (RCP 8.5).