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Supplemental Climate Information for Fortress of Louisbourg National Historic Site

Parks Canada Parcs Canada

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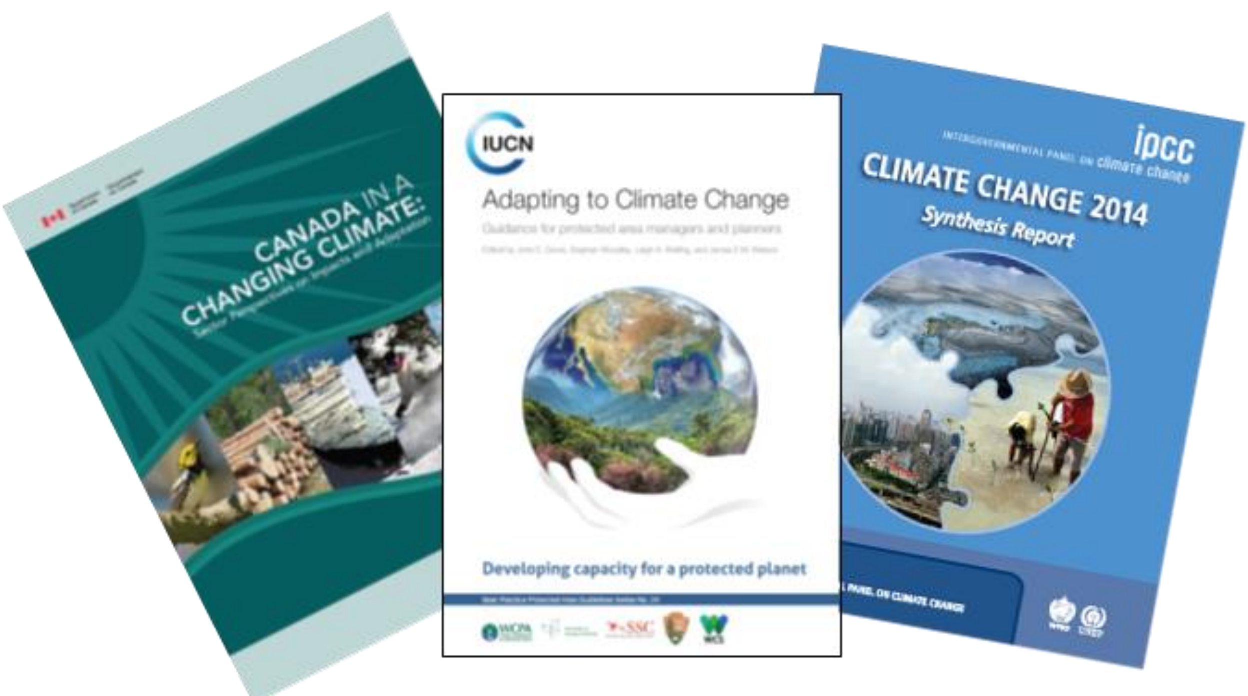
Preface

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 Fortress of Louisbourg National Historic Site.

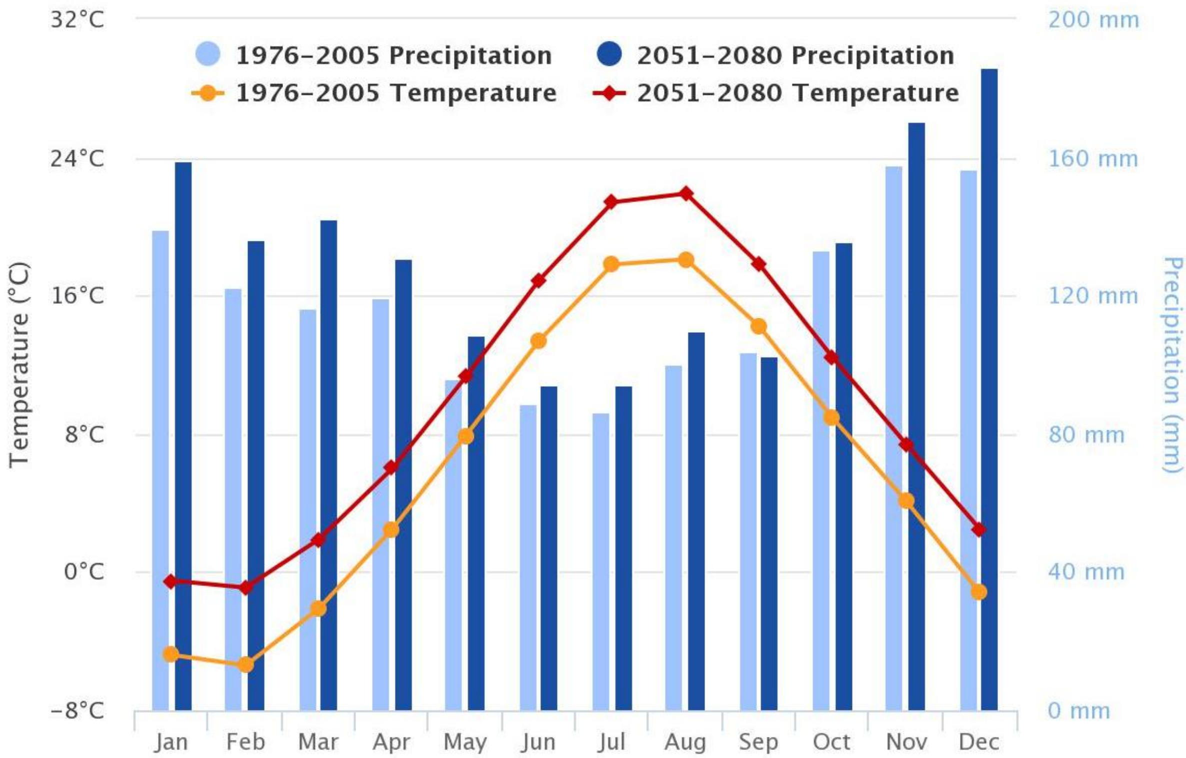
Future climate projections are modelled with several greenhouse gas concentration trajectories, called **Representative Concentration Pathways (RCP)** (Vuuren *et al.*, 2011). They describe possible climate futures and are named after respective radiative forcing values in the year 2100 relative to pre-industrial 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 "status quo" throughout the 21^{st} century.

This is a site focussed document and to understand the larger climate change context please consult Canada's Changing Climate assessment reports (http://www.nrcan.gc.ca/environment/impacts-adaptation/10029) and the Intergovernmental Panel on Climate Change assessment reports (e.g., IPCC, 2014) With respect to adaptation options, please consider Gross *et al.* (2016) or Rockman *et al.* (2016).



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 speeds have 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 by12-25 days/year.

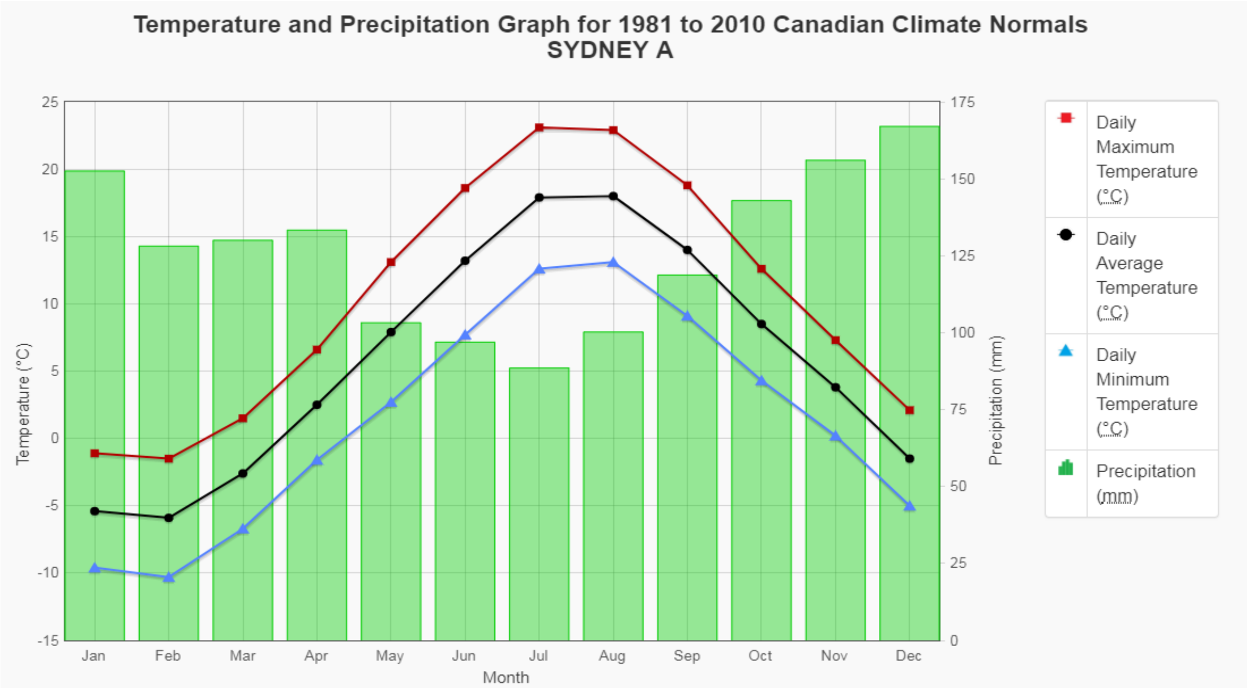


Climograph for Sydney area. Modelled monthly mean temperature and total precipitation for the 1976-2005 baseline and 2051-2080 future projection (RCP 8.5). Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

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

1. Historic Climate

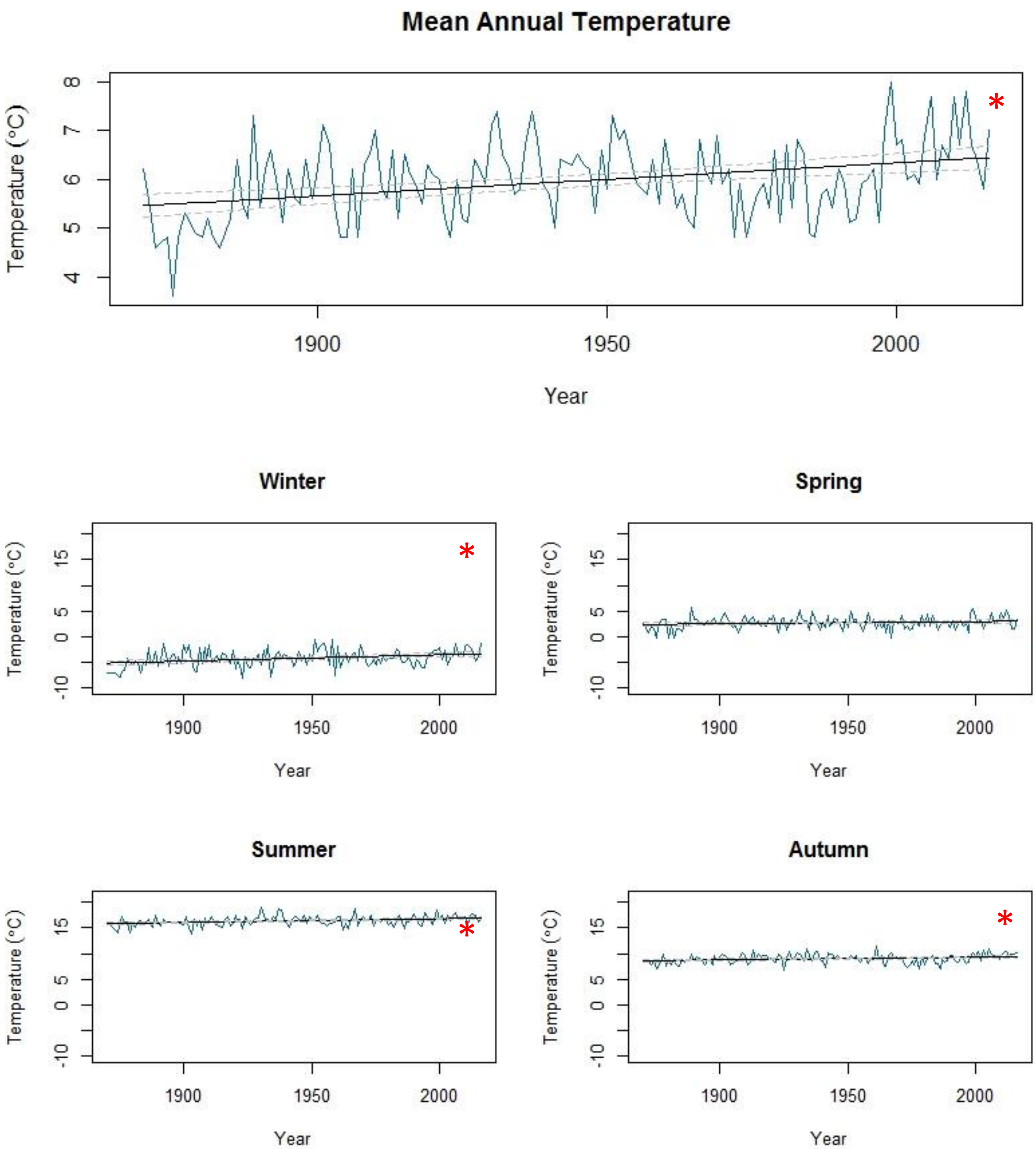
The Fortress of Louisbourg experiences a humid (mean RH 69%) continental climate (Köppen *Dfb*) with warm summers (daily mean 16.4˚C) and cool winters (daily mean -4.3˚C). Moderated by its proximity to the Atlantic Ocean, there tends to be a seasonal lag in temperatures with February being the coldest 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.



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

1.1 Temperature

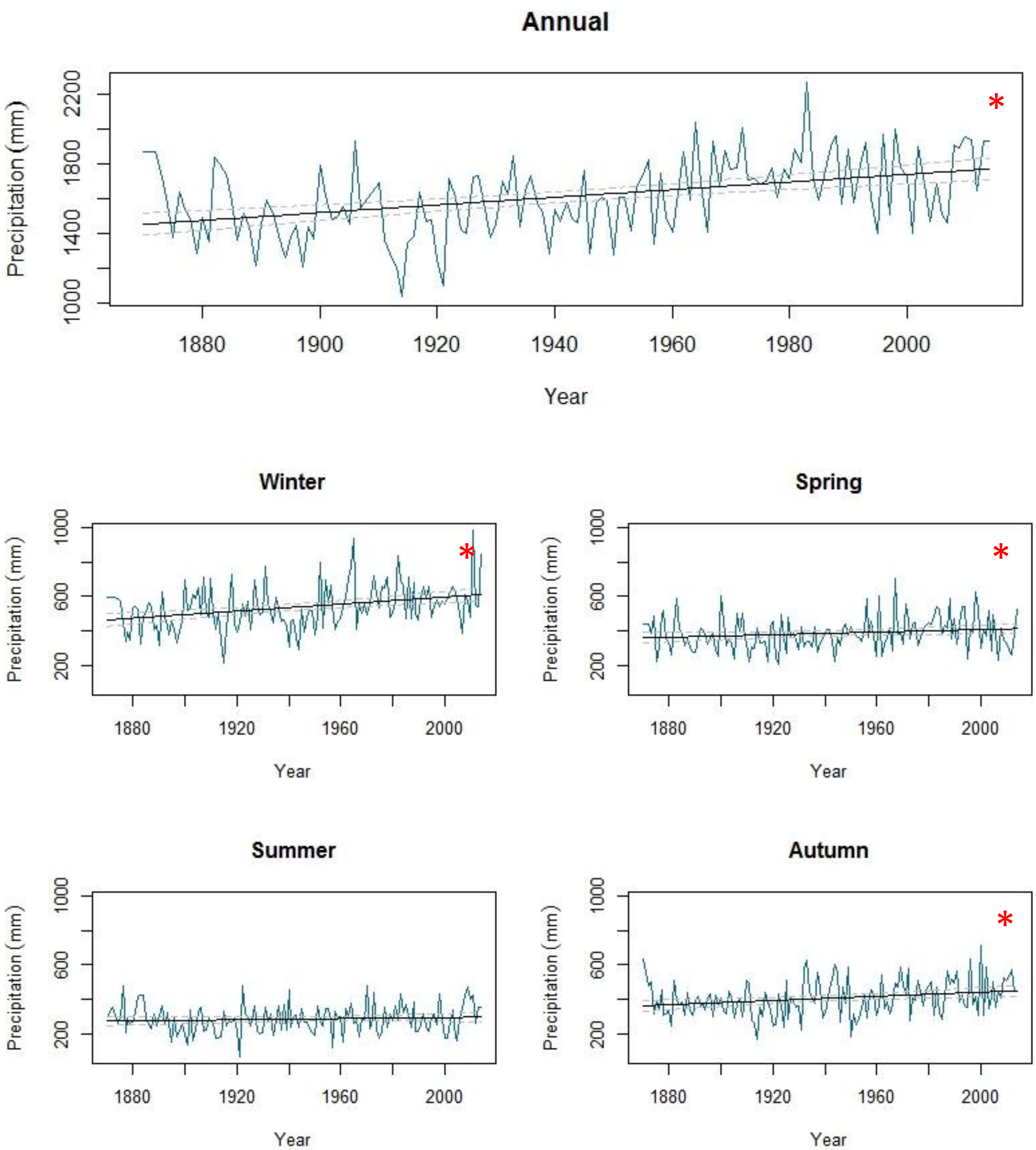
Sydney (8205701) is the closest meteorological station with long term temperature data (ECCC, 2017). Trends from 1870 to 2016 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



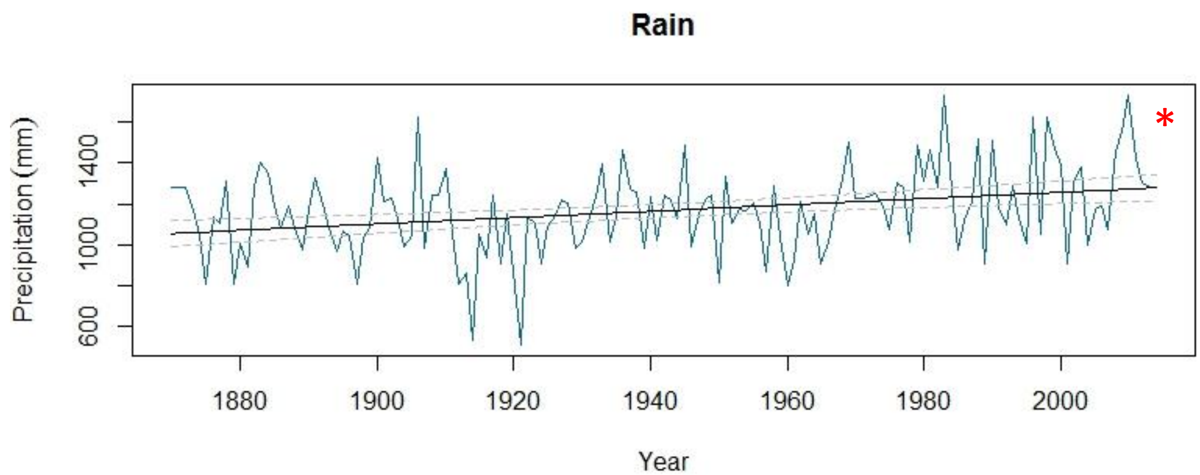
Sydney mean annual and seasonal temperature. A statistically significant ($P<0.05$) increase observed in mean annual and seasonal temperatures, except spring (Mar, Apr, May). Mean annual temperature has increased by ~1°C since 1870. Of all the seasons, winter temperature has increased the greatest, ~1.8°C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

1.2 Precipitation

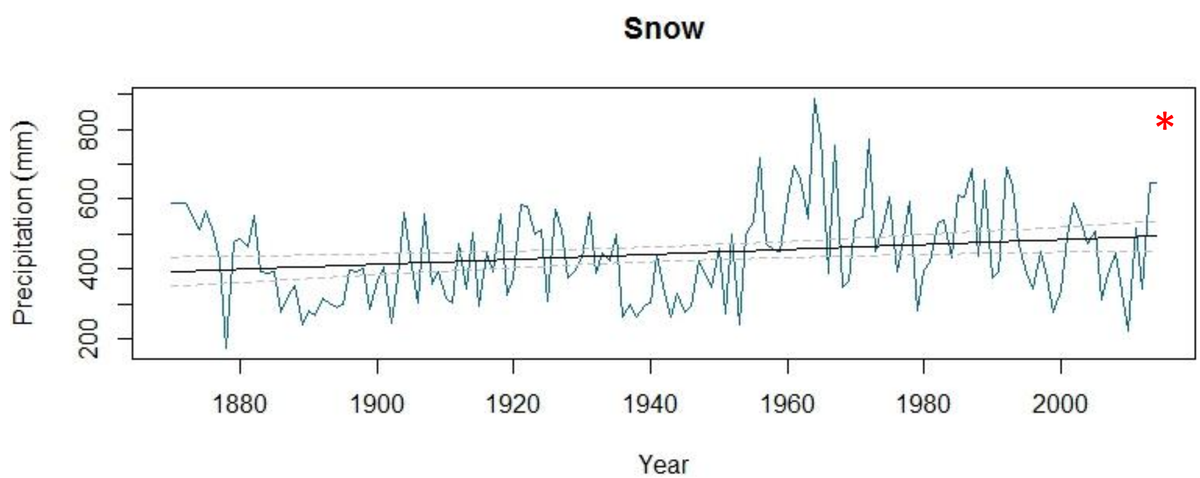
Sydney (8205700) is the closest meteorological station with long term precipitation data (ECCC, 2017). Trends from 1870 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



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%).



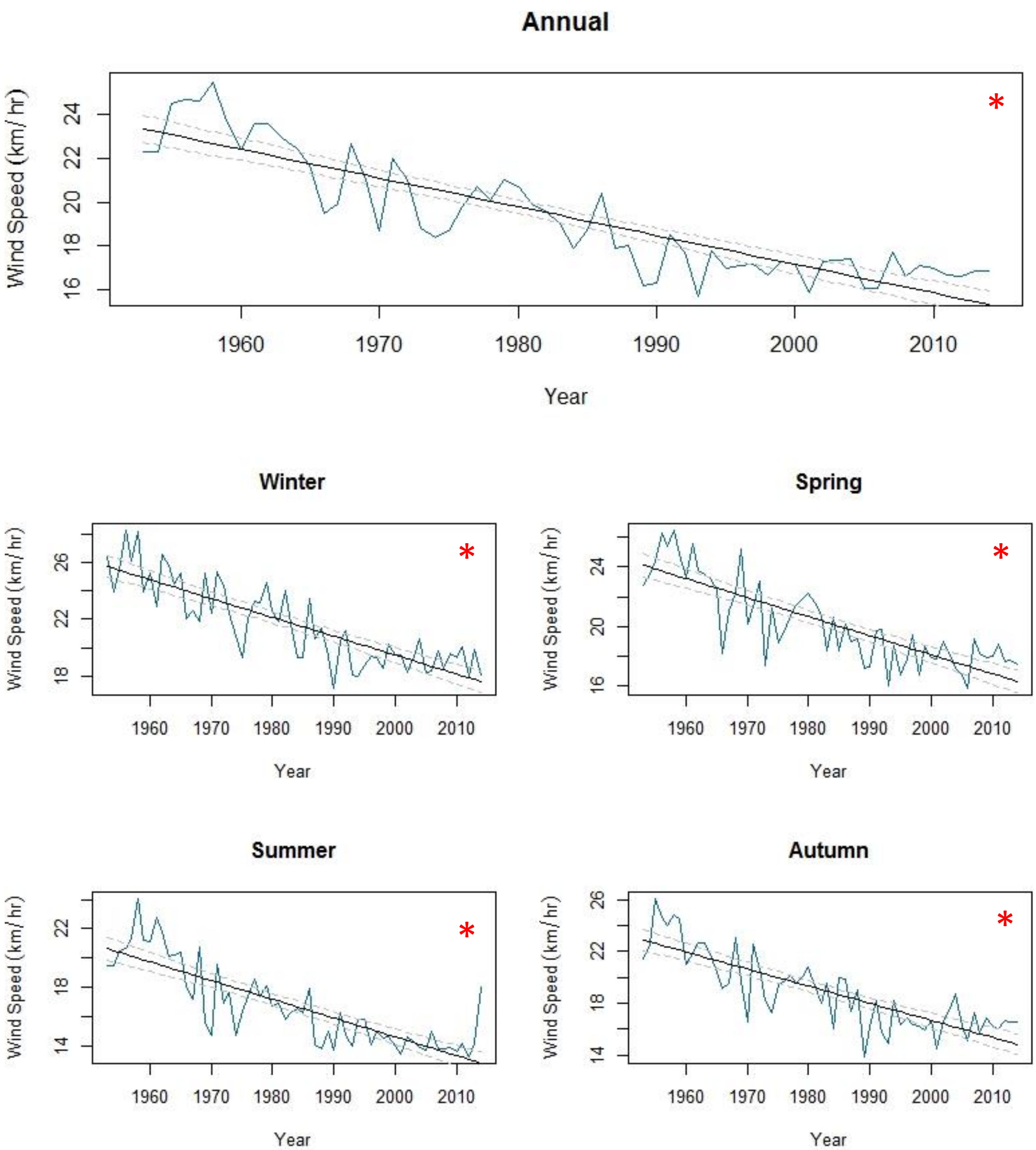
Sydney total annual rain demonstrated a statistically significant (P<0.05) increase since 1870, ~223 mm (21%).



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

1.3 Surface Wind Speed

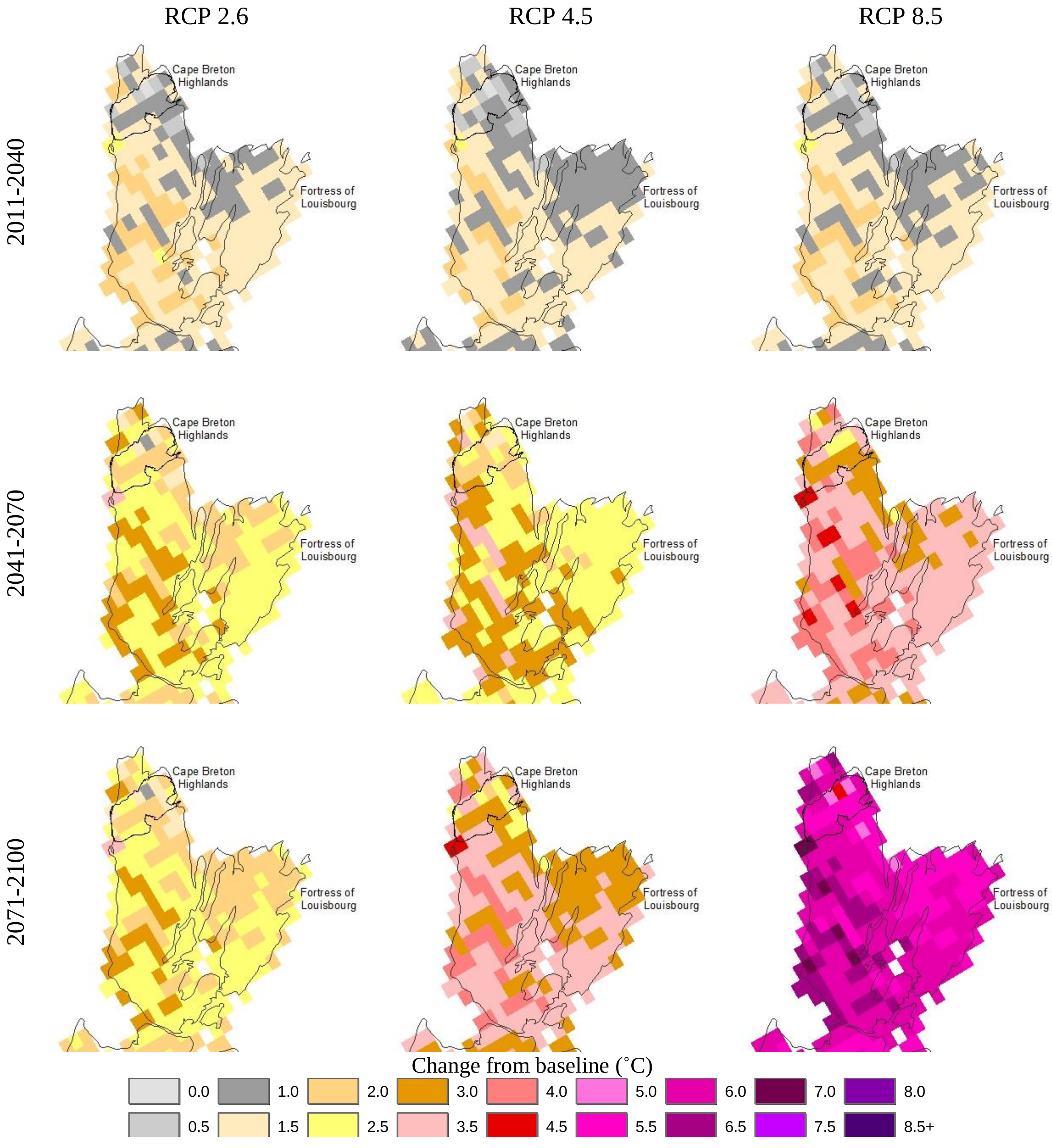
Sydney (8205701) is the closest meteorological station with long term wind data (ECCC, 2017). Trends from 1953 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



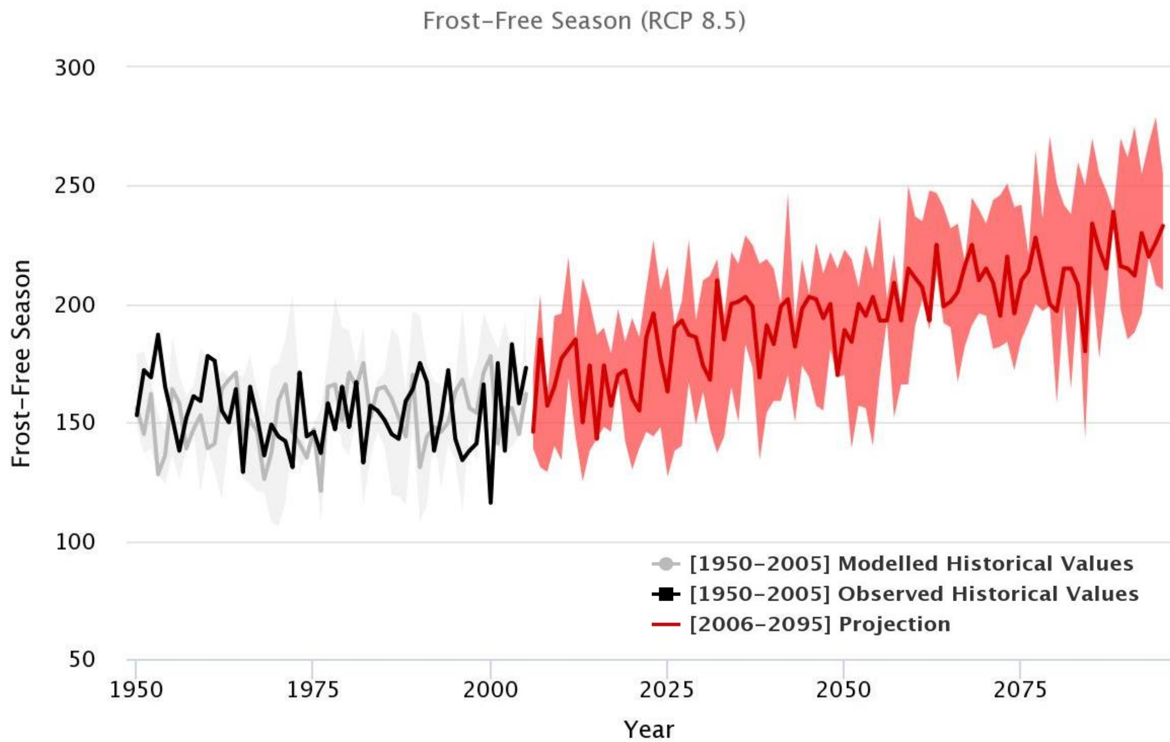
Sydney mean annual and seasonal wind speeds. Mean annual wind speeds have demonstrated a statistically significant ($P<0.05$) decrease, ~8 km/hr (34%) since 1953. All seasons have demonstrated a statistically significant ($P<0.05$) decrease, the greatest being observed for autumn, ~8 km/hr (35%) since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

2. Projected Climate Trends

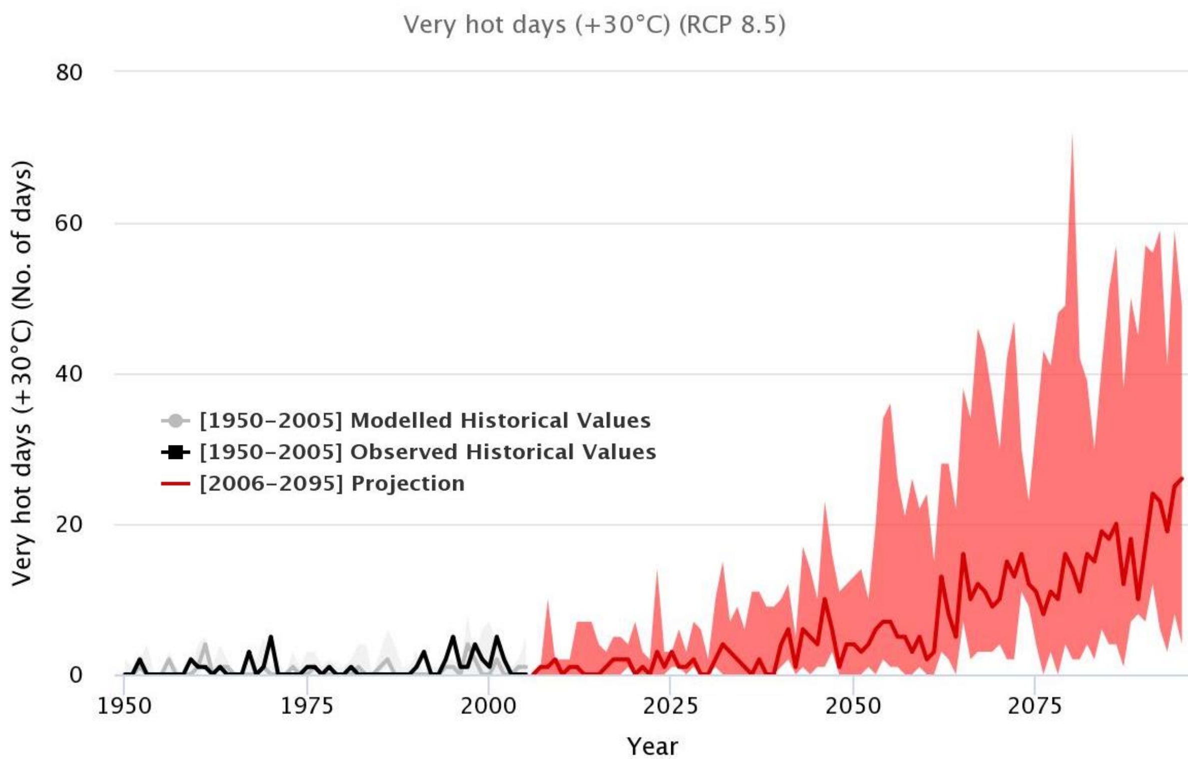
2.1 Temperature



Projected mean annual temperature increase for Cape Breton Island 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 2.5 to 6.0 °C by 2071-2100.

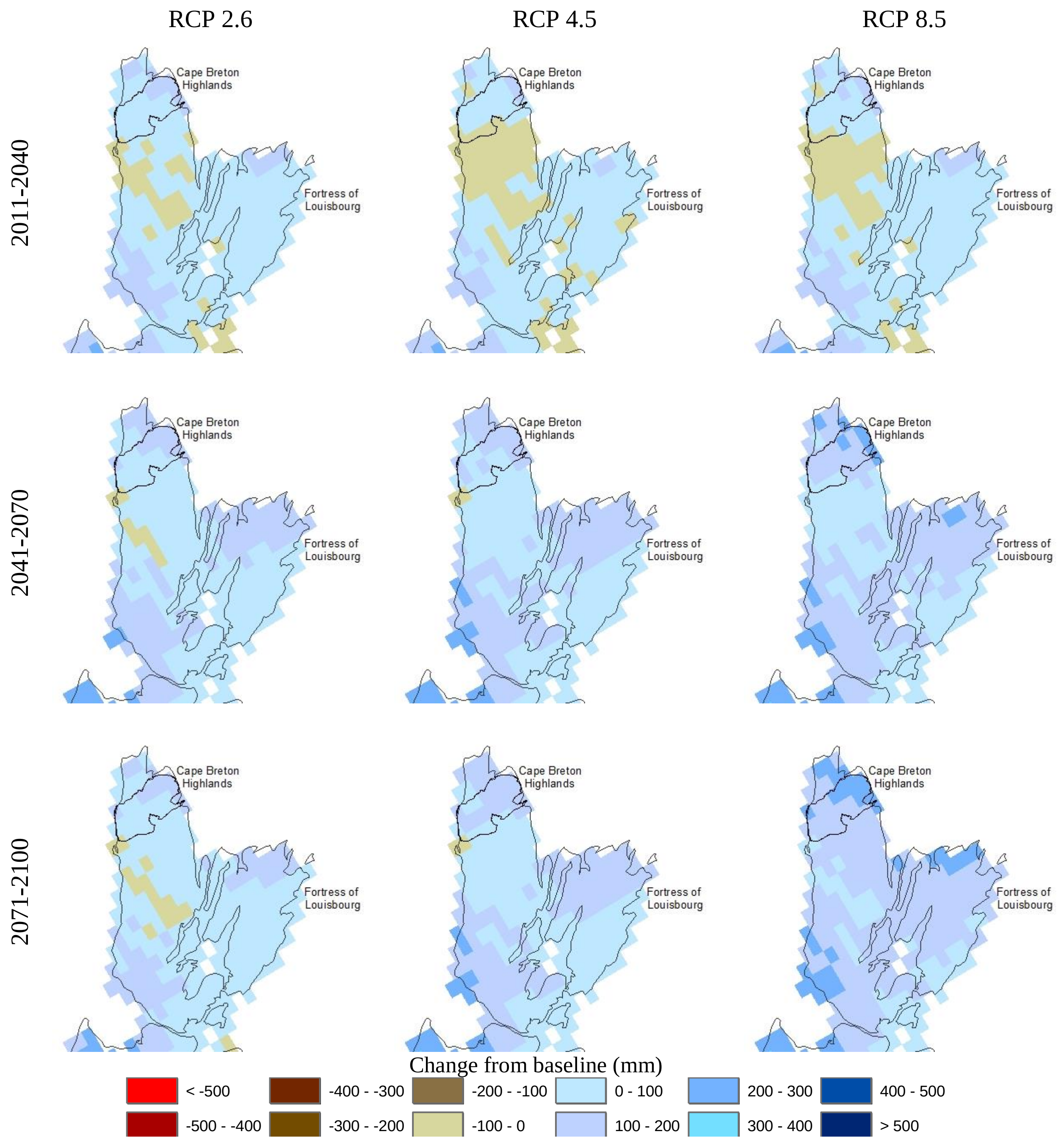


The frost-free season (days) for Sydney. It approximates the length of growing season (i.e., no freezing temperatures to kill or damage plants) and is projected to increase by 49.5 days by 2051-2080 (https://climateatlas.ca/).



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 Island 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, total annual precipitation is projected to increase 52 to 130 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

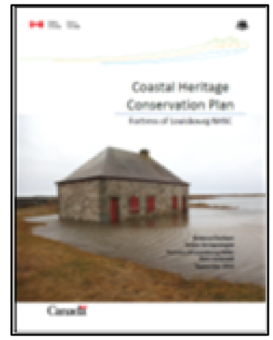
Projected (2050-2100) precipitation (mm) for Sydney using an ensemble of models and **RCP 8.5**.

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

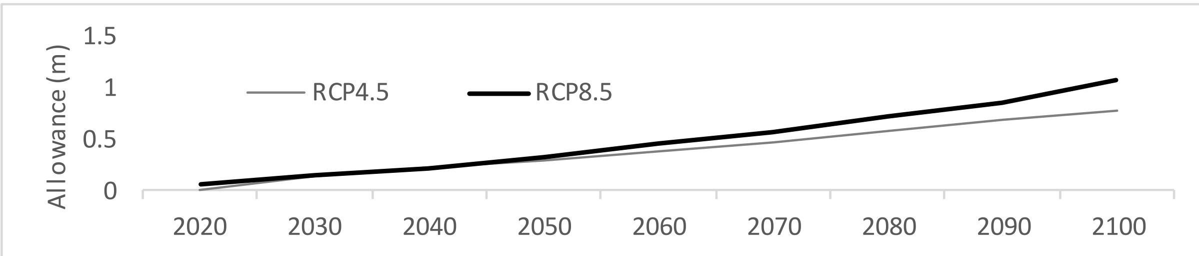
3.1 Sea Level Rise and Coastal Erosion



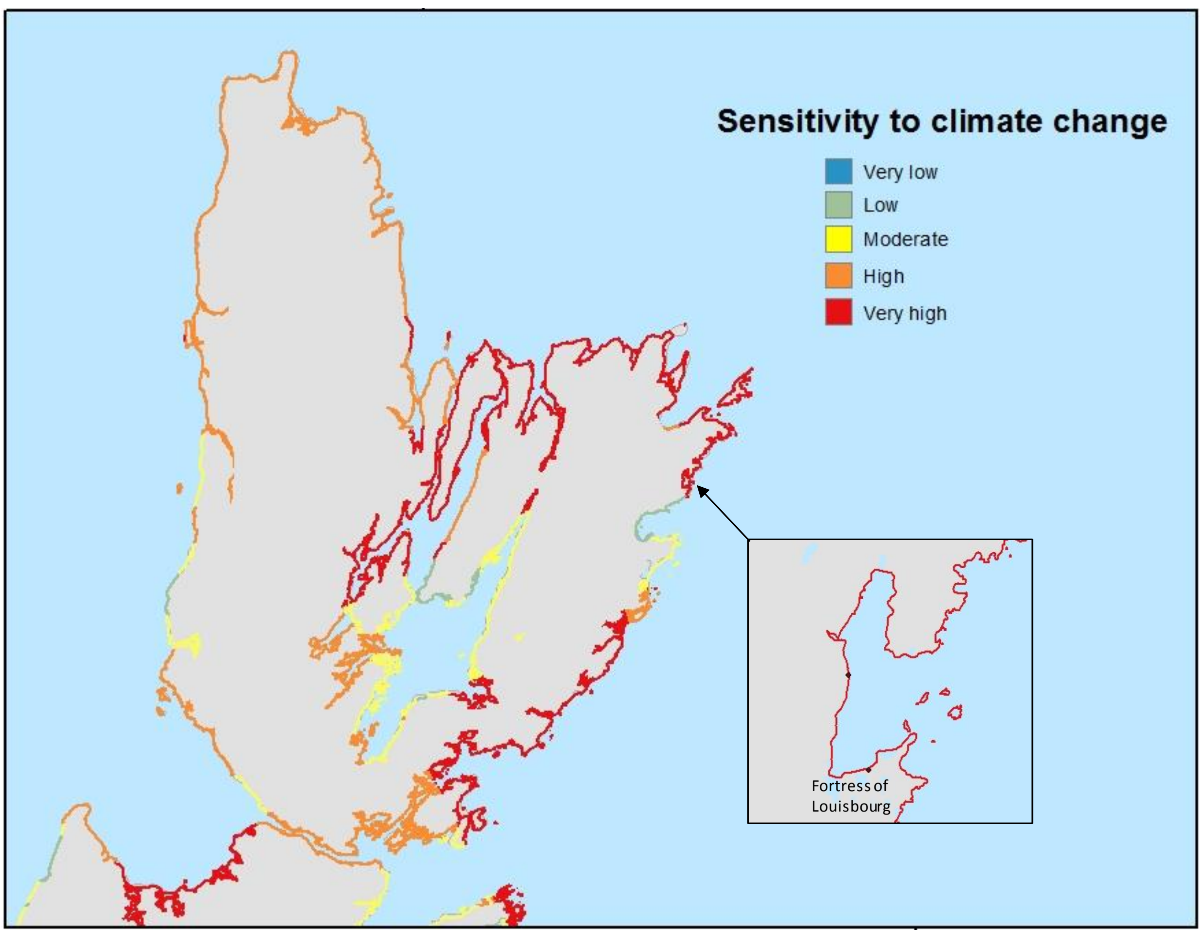
- A detailed review and assessment of coastal trends and impacts is found within: "**Coastal Heritage Conservation Plan: Fortress Louisbourg National Historic Site of Canada**" (Duggan, 2014).
- Relative sea level in the region is increasing due to the combined effect of sea level rise (~1.6 mm/yr) and 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).
- For adaptation planning purposes, the estimated design high water level = +2.3 m geodetic datum (i.e., highest astronomical tide plus estimated 100 year storm surge plus allowance for land subsidence and sea level rise over next 25 years) with a design wave height of 1.8 m (ocean swell transformed on site) (Parks Canada, 2017b).
- Some harbour and coastal locations at FOL have retreated/eroded between 15 – 18 metres (0.17 m/yr) and are estimated to erode as much as 30 m inland by the turn of the century (Duggan, 2014).

1966 image from the Fortress of Louisbourg illustrating that the 1743 ship mooring ring is approximately 50 cm below today's high tide. The total relative sea level rise from the 1740's to the 1990's is determined to be 90 cm (Dunham, 2017; Taylor *et al.*, 2000).

Vertical allowance for Louisbourg 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.

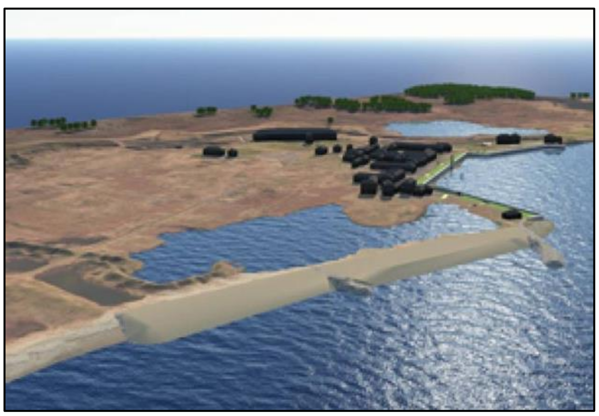


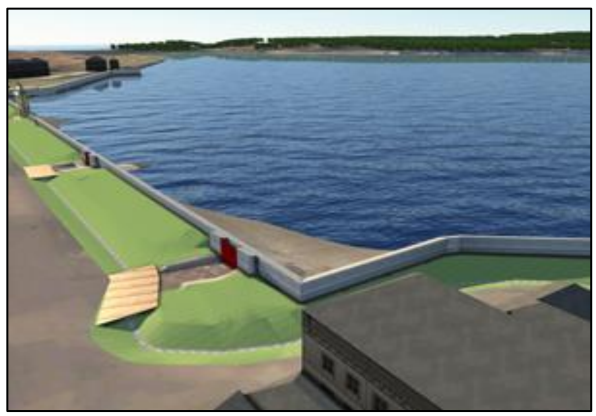
Louisbourg, NS projected vertical allowance of 79 to 107 cm by 2100 (CAN-EWLAT).



Map of coastal sensitivity to climate change along Cape Breton Island'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. FOL has "Very High" sensitivity. Data provided by Natural Resources Canada (Couture and Manson, 2016).

2018-19 Coastal Adaptation Project
In response to rising sea-levels and increasing storm intensity, the Fortress of Louisbourg is undertaking adaptation measures including fortification of the quay wall and building groynes to protect the barrier beach (Parks Canada, 2017b; 2017c).





Barrier Beach Quay Wall
Image source: https://www.pc.gc.ca/en/lhn-nhs/ns/louisbourg/info/erosion

3.2 Cultural Resources

Research and monitoring the climate change impacts to cultural resources at FOL has been undertaken and mostly focuses on sea level rise (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).

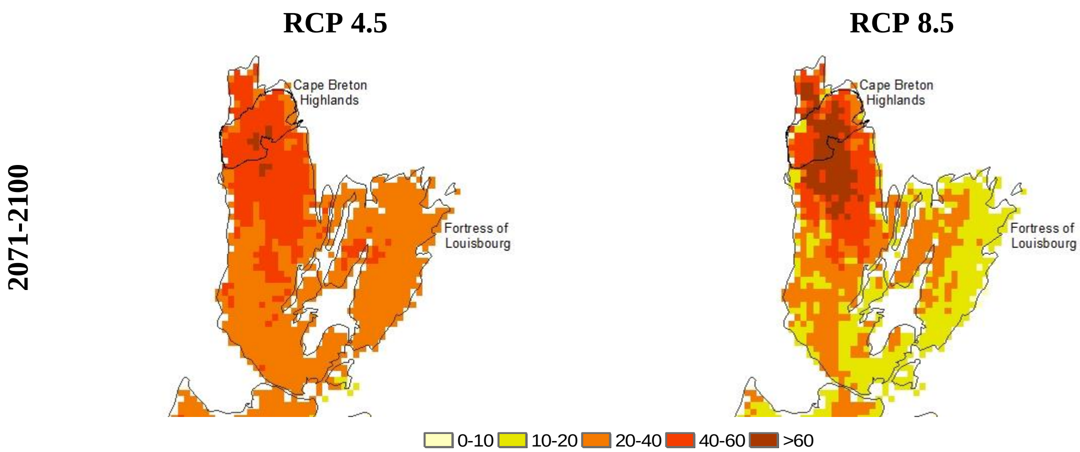
Other possible impacts and considerations:

- 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).

3.3 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 Island. Increased length in days from baseline (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. Depending on the RCP scenario, an increase of 12-25 days is projected by 2071-2100. Data source: Natural Resources Canada, http://cfs.nrcan.gc.ca/fc-data-catalogue.

3.4 Biodiversity

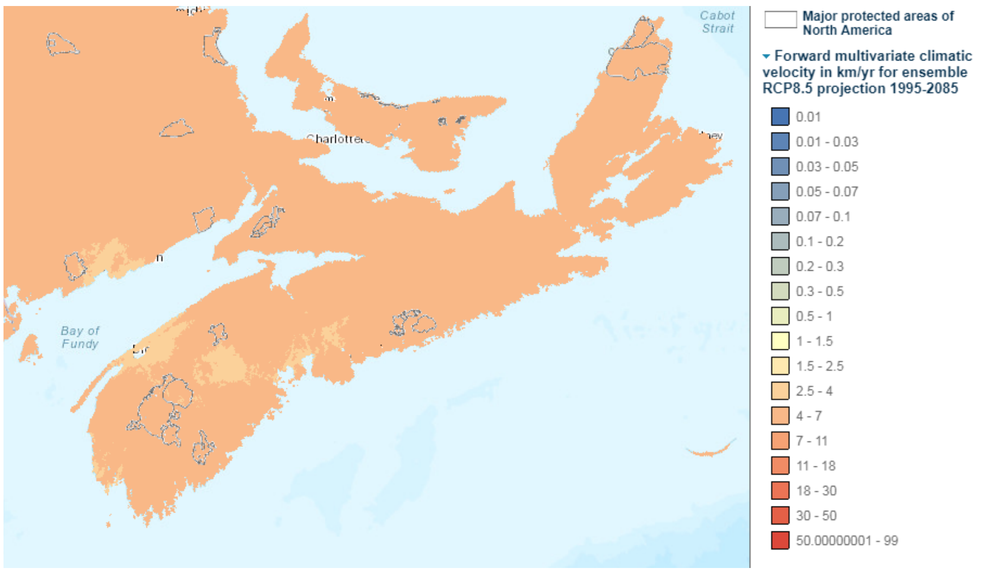
Biodiversity is the variety of genes, species and ecosystems and is essential to our social, economic and ecological well-being. The effects of climate change on biodiversity include: shifts in species distribution; changes in phenology; decoupling of interactions (plant-pollinator); reductions in population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

Natural ecosystems are an integral part of the history and landscape of FOL (Parks Canada, 2011a; 2011b). Although published accounts of climate change impacts to the species of the sites lakes, bogs, coast and forests was undiscovered by this author a few observations may be relevant.

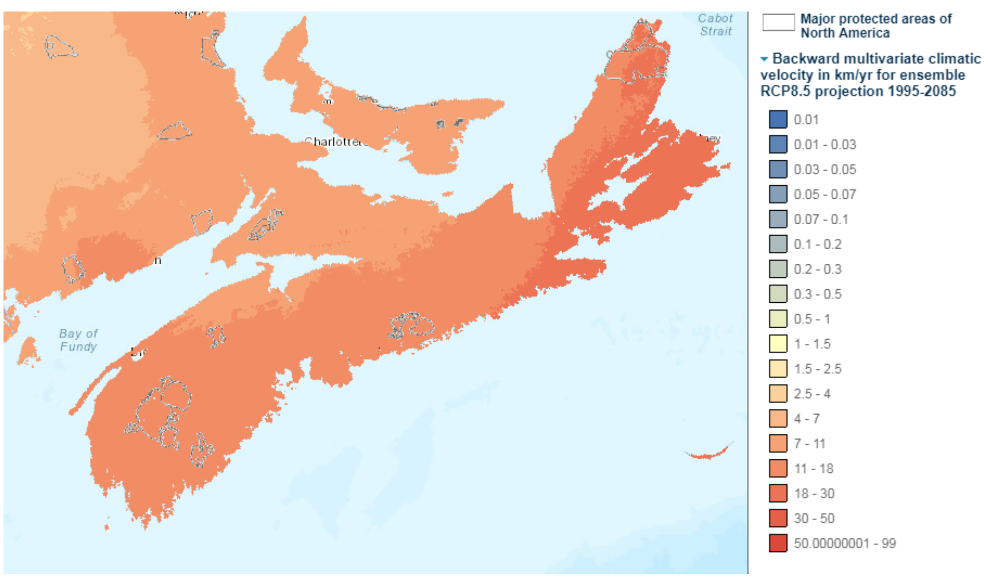
- Changes in hydrological regime and succession by woody species may affect the survival of New Jersey Rush (Special Concern) (COSEWIC, 2004).
- Loss of boreal tree species, such as balsam fir, are projected due to climate change (Taylor *et al.*, 2017).
- Increasing incidences of Lyme disease (tick vector) have been linked to climate change (Eisen *et al.*, 2016; Nova Scotia, 2012). Climatic conditions may become more favourable for some mosquito vector diseases (e.g., West Nile Virus) in the future as well (Wudel and Shadabi, 2016).

Climate Velocity

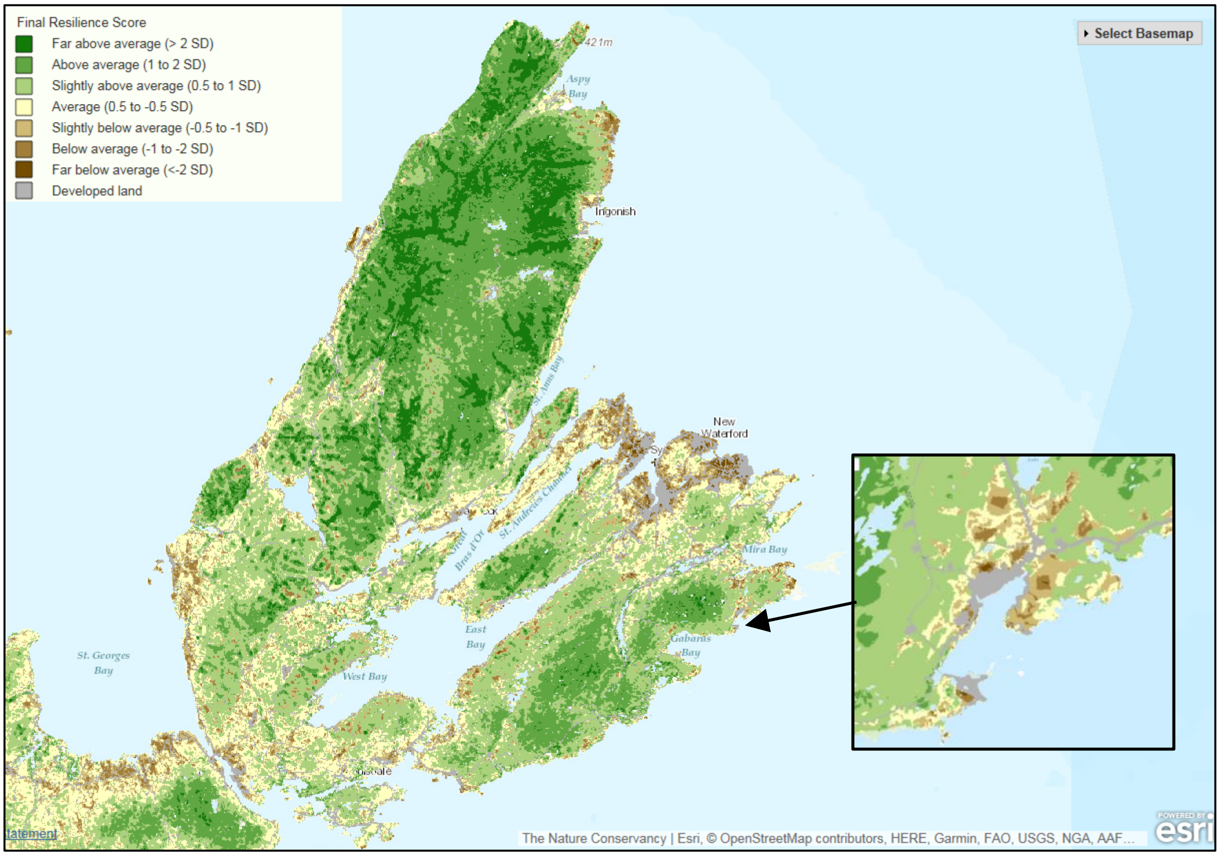
AdaptWest (https://adaptwest.databasin.org/) provides integrative tools that can inform conservation planning, including the following analysis on climate velocity.



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.

4. References

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. https://www.nps.gov/subjects/climatechange/upload/CASH_Entire_Handbook_FINAL_100716.pdf.

Boyle, J., Cunningham, M., and Dekens, J. (2013). *Climate Change Adaptation and Canadian Infrastructure. A review of the literature*. International Institute for Sustainable Development (IISD). http://www.iisd.org/sites/default/files/publications/adaptation_can_infrastructure.pdf.

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

Canada. (2017). *Pan-Canadian Framework on Clean Growth and Climate Change first annual report*. Government of Canada. https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/first-annual-report.html.

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.

Chen, C. C., Jenkins, E., Epp, T., Waldner, C., Curry, P. S., and Soos, C. (2013). Climate Change and West Nile Virus in a Highly Endemic Region of North America. *International Journal of Environmental Research and Public Health, 10*(7), 3052-3071. doi:10.3390/ijerph10073052.

COSEWIC. (2004). *COSEWIC Assessment and Update Status Report on the New Jersey Rush Juncus caesariensis in Canada*. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_new_jersey_rush_e.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

CPC. (2013). *Canadian Parks and Protected Areas: Helping Canada Weather Climate Change*. Parks Canada Agency on behalf of the Canadian Parks Council. http://www.parks-parcs.ca/english/CPC%20Climate%20Change%20Report%20FINAL%20engLR.pdf.

Dudley, N., Buyck, C., Furuta, N., Pedrot, C., Renaud, F., and Sudmeier-Rieux, K. (2015). *Protected areas as tools for disaster risk reduction : a handbook for practitioners*. MOEJ and IUCN, Tokyo and Gland, Switzerland. https://portals.iucn.org/library/node/45054.

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/.

Eisen, R. J., Eisen, L., Ogden, N. H., and Beard, C. B. (2016). Linkages of Weather and Climate with *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae), Enzootic Transmission of *Borrelia burgdorferi*, and Lyme Disease in North America. *Journal of Medical Entomology, 53*(2), 250-261. doi:10.1093/jme/tjv199.

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. https://portals.iucn.org/library/node/46685.

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.

Lo, V. (2016). *Synthesis report on experiences with ecosystem-based approaches to climate change adaptation and disaster risk reduction*. Secretariat of the Convention on Biological Diversity (SCBD), Montreal. https://www.cbd.int/climate/.

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.

Murti, R. and Buyck, C. (2014). *Safe Havens: Protected Areas for Disaster Risk Reduction and Climate Change Adaptation*. International Union for Conservation of Nature and Natural Resource (IUCN), Gland, Switzerland. https://portals.iucn.org/library/sites/library/files/documents/2014-038.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. http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2014/16309.

NAWPA. (2012). *North American Protected Areas as Natural Solutions for Climate Change*. North American Intergovernmental Committee on Cooperation for Wilderness and Protected Area Conservation. http://nawpacommittee.org/wp-content/uploads/2012/08/NAWPA-CCWG-Brochure.pdf.

Neill, A. O. (1983). The gardens of 18th-century louisbourg. *Journal of Garden History, 3*(3), 176-178. doi:10.1080/01445170.1983.10412440.

Nelder, M. P., Russell, C. B., Sheehan, N. J., Sander, B., Moore, S., Li, Y., Johnson, S., Patel, S. N., and Sider, D. (2016). Human pathogens associated with the blacklegged tick Ixodes scapularis: a systematic review. *Parasites & Vectors*, *9*, 14. doi:10.1186/s13071-016-1529-y.

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.

Nova Scotia. (2012). *Lyme Disease A report on Lyme Disease Epidemiology and Surveillance in Nova Scotia*. https://novascotia.ca/dhw/populationhealth/documents/Lyme-Disease-Epidemiology-and-Surveillance-in-Nova-Scotia.pdf.

Ogden, N. H., Maarouf, A., Barker, I. K., Bigras-Poulin, M., Lindsay, L. R., Morshed, M. G., O'Callaghan, C. J., Ramay, F., Waltner-Toews, D., and Charron, D. F. (2006). Climate change and the potential for range expansion of the Lyme disease vector Ixodes scapularis in Canada. *International Journal for Parasitology, 36*(1), 63-70. doi:10.1016/j.ijpara.2005.08.016.

Palko, K. and Lemmen, D. S. (Eds.). (2017). *Climate risks and adaptation practices for the Canadian transportation sector 2016*. Ottawa, ON: Government of Canada. http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2017/19623.

Parker, S. (2017). *Let's Talk about Climate Change: Atlantic Region*. Parks Canada, Office of the Chief Ecosystem Scientist

Parks Canada. (2011a). *Fortress of Louisbourg National Historic Site of Canada, Management Plan*, Ottawa, ON. https://www.pc.gc.ca/en/lhn-nhs/ns/louisbourg/info/plan.

Parks Canada. (2011b). *Special Events in the National Historic Sites of Canada in Cape Breton Replacement Class Screening Report*. https://www.ceaa-acee.gc.ca/050/documents/53088/53088e.pdf.

Parks Canada. (2015). *Master Plan For the Reduction of Greenhouse Gas (GHG) Emissions within Parks Canada's Operations*. http://intranet2/media/2163749/master_plan_for_ghg_reduction_2015.pdf

Parks Canada. (2017a). *Parks Canada Agency, 2017–18 Departmental Plan*. http://www.pc.gc.ca/en/agence-agency/bib-lib/plans/dp/dp2017-18/index.

Parks Canada. (2017b). *Specifications Issued for Tender: Barrier Beach Groynes and Renourishment, Fortress of Louisbourg National Historic Site, NS (5P300-17-5437/A)*. Prepared by GEMTEC Eastern Joint Venture. https://buyandsell.gc.ca/procurement-data/tender-notice/PW-17-00802359.

Parks Canada. (2017c). *Specifications Issued for Tender: Quay Wall Improvements Fortress of Louisbourg National Historic Site (5P201-18-0029)*. Prepared by GEMTEC Eastern Joint Venture. https://buyandsell.gc.ca/procurement-data/tender-notice/PW-18-00824521.

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/upload/ClimateChange_01-12_Digital6.pdf.

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.

Soverow, J. E., Wellenius, G. A., Fisman, D. N., and Mittleman, M. A. (2009). Infectious Disease in a Warming World: How Weather Influenced West Nile Virus in the United States (2001-2005). *Environmental Health Perspectives, 117*(7), 1049-1052. doi:10.1289/ehp.0800487.

Taylor, A. R., Boulanger, Y., Price, D. T., Cyr, D., McGarrigle, E., Rammer, W., and Kershaw, J. A. (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

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.

US NPS. (2016). *National Climate Change Interpretation and Education Strategy*. https://www.nps.gov/subjects/climatechange/nccies.htm.

Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S., and Rose, S. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi:10.1007/s10584-011-0148-z.

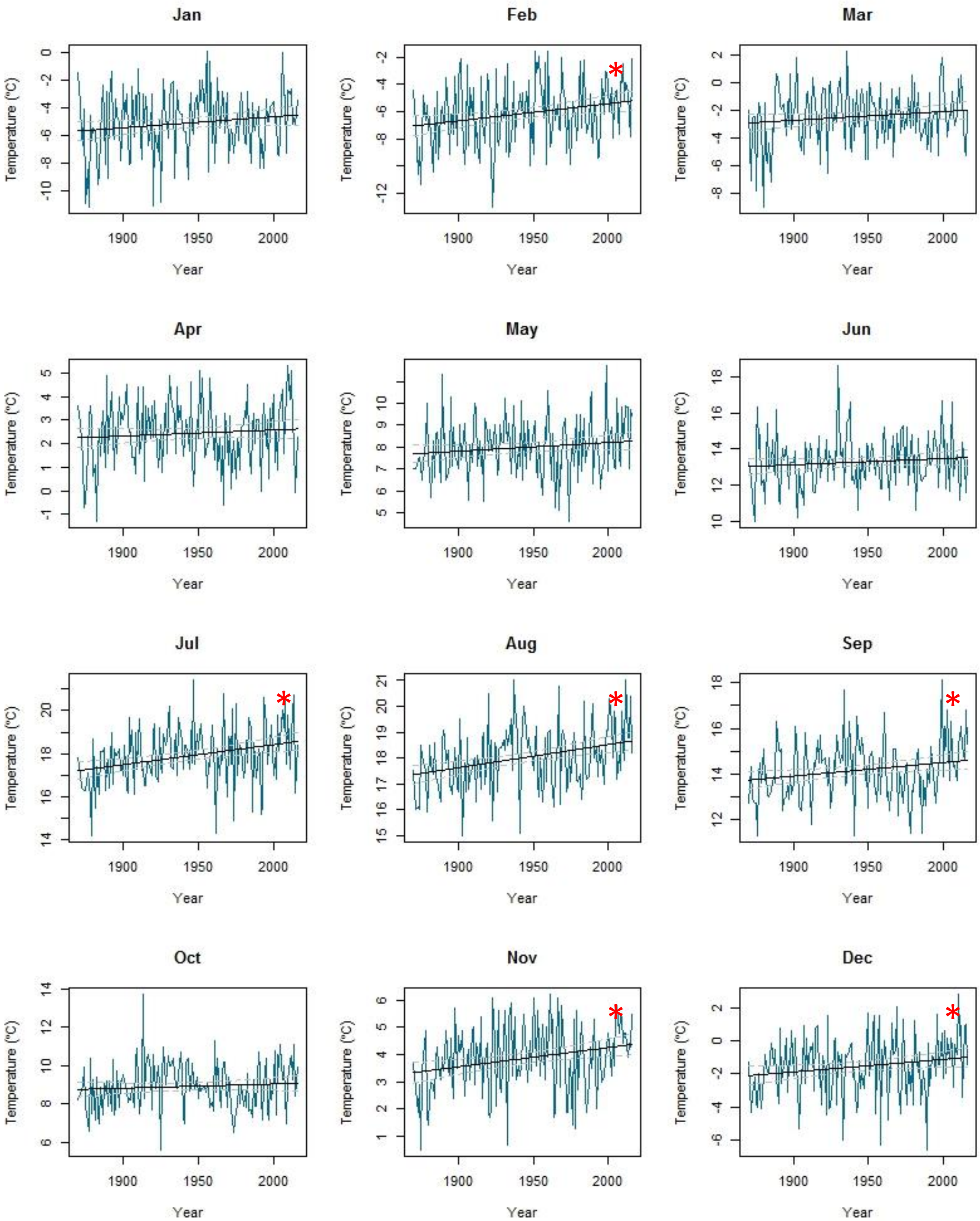
Warren, F. J. and Lemmen, D. S. (Eds.). (2014). *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Government of Canada. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf.

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.

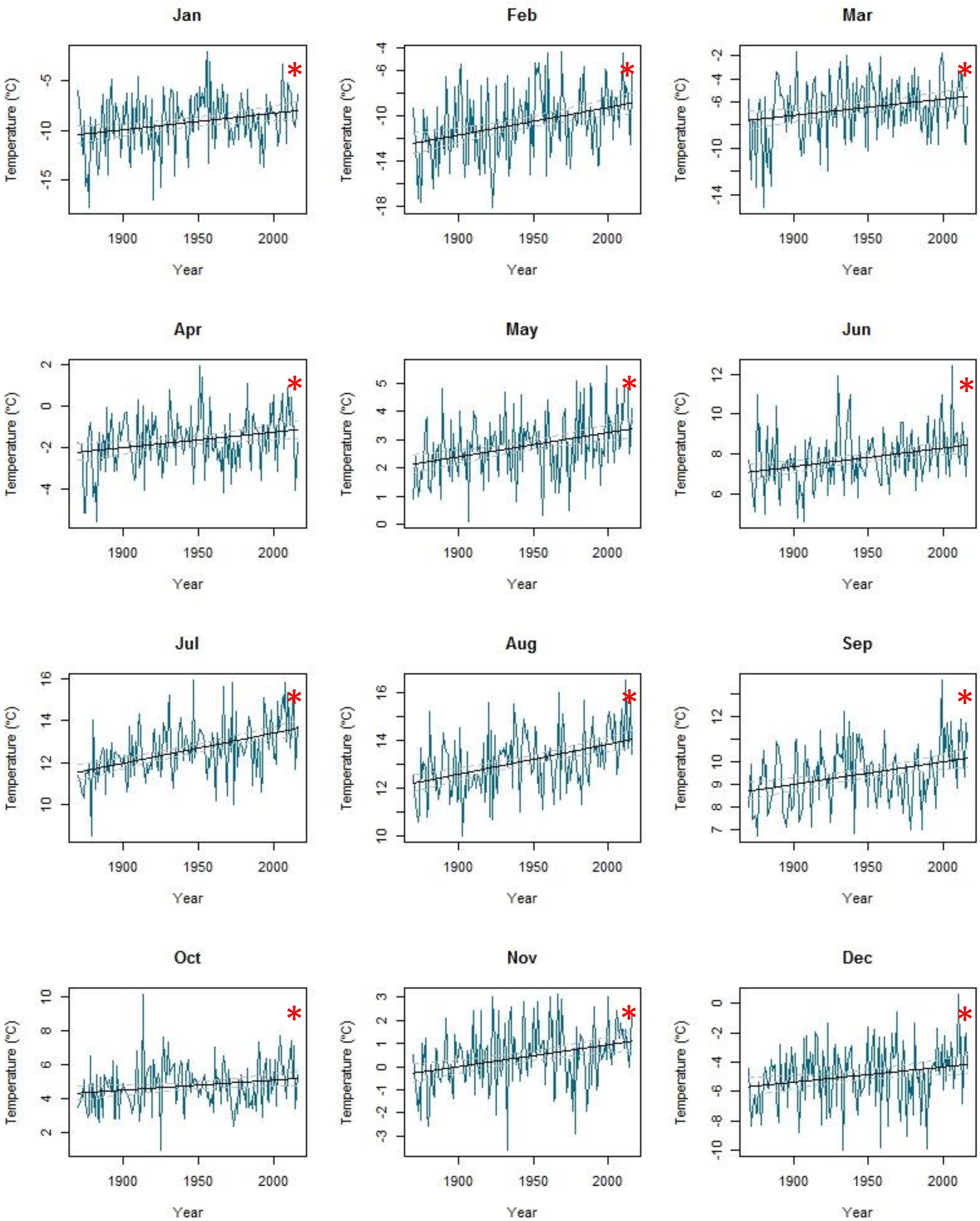
World Economic Forum. (2018). *The Global Risks Report 2018, 13th Edition*, Geneva, Switzerland. http://wef.ch/risks2018.

Wudel, B. and Shadabi, E. (2016). *A Short Review of Literature on the Effects of Climate Change on Mosquito-Bourne Illness in Canada*. National Collaborating Centre for Infectious Disease. https://nccid.ca/wp-content/uploads/sites/2/2016/07/RapidReviewClimateMosquito-EN.pdf.

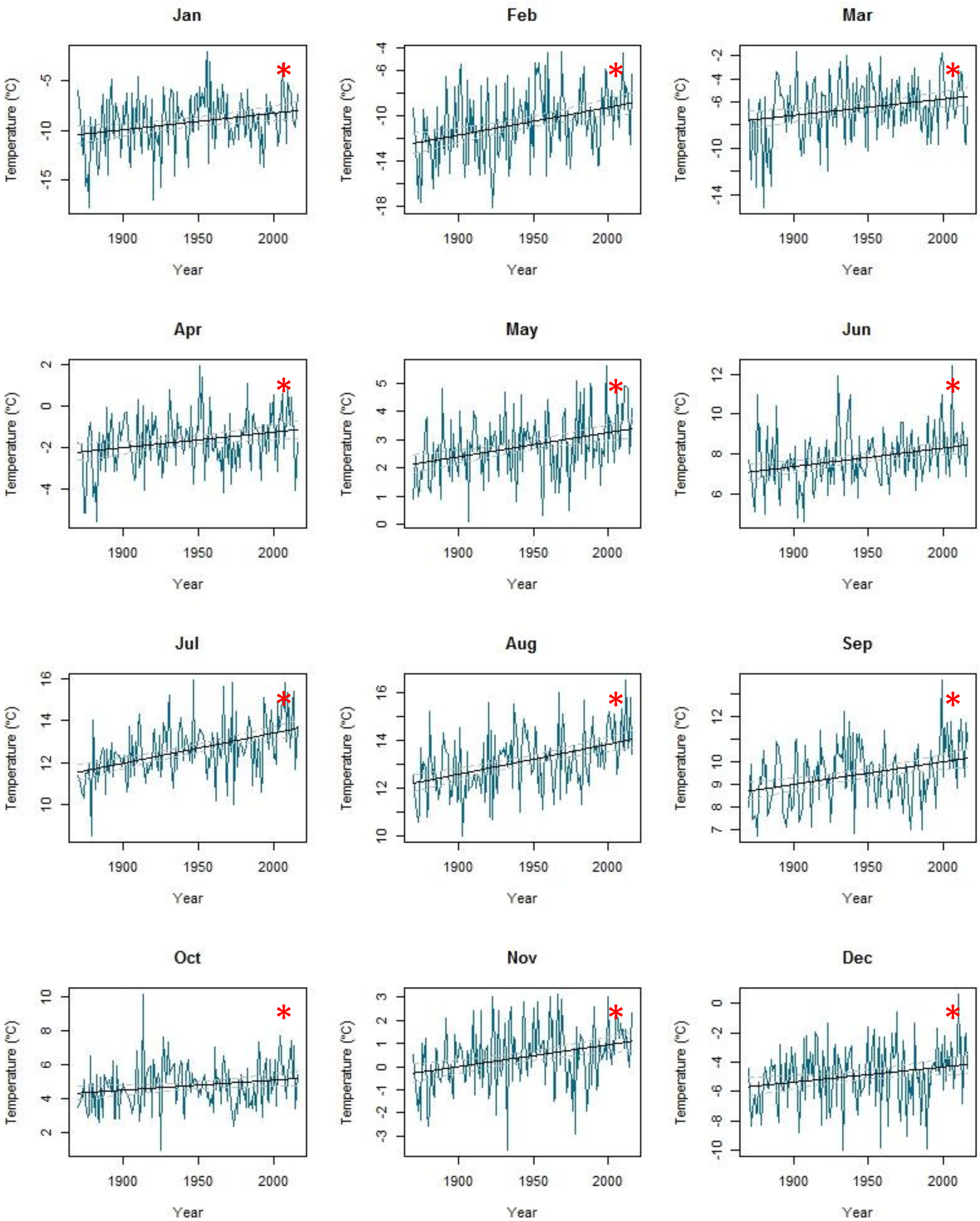
Appendix 1. Additional Climate Trends



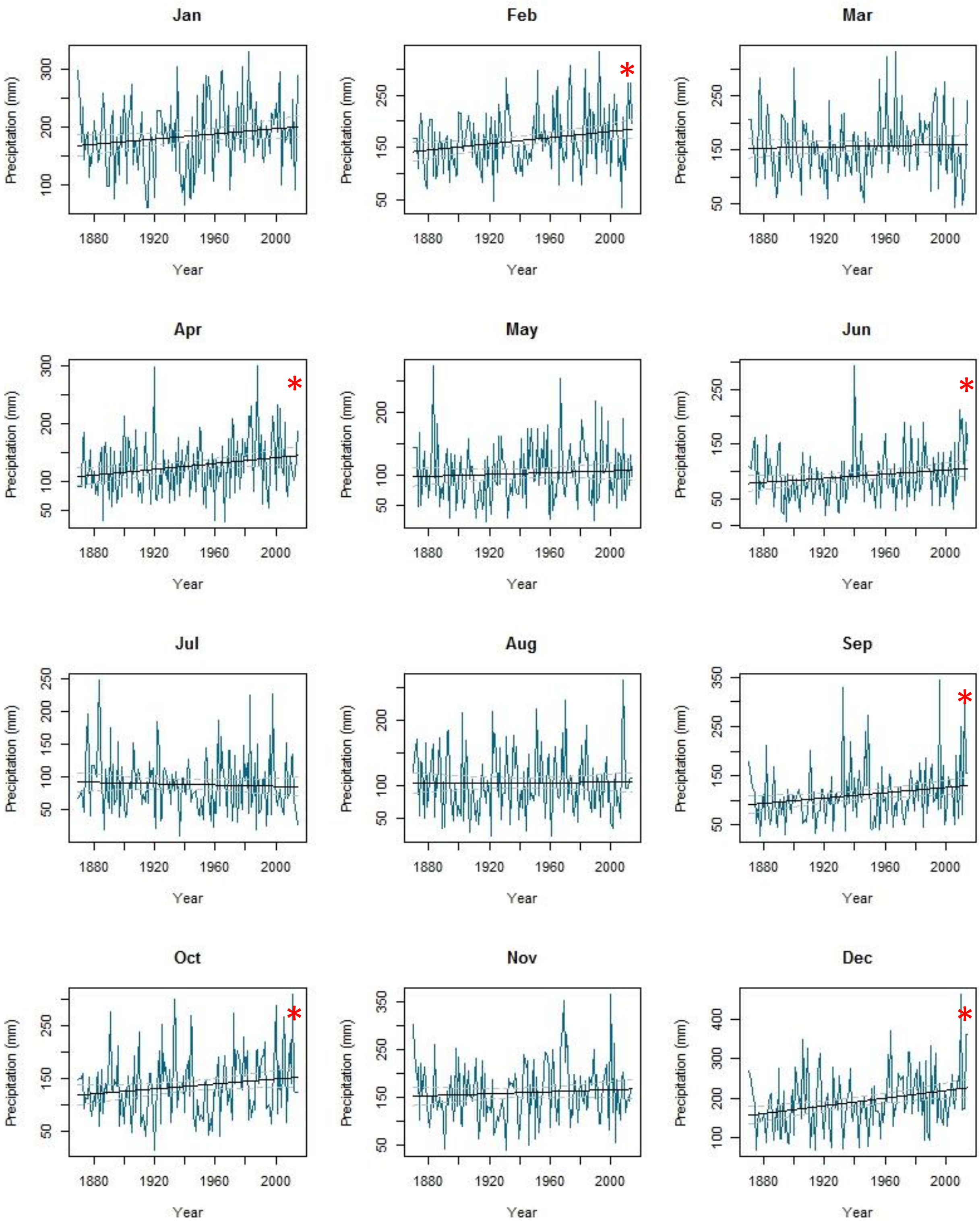
Sydney mean monthly temperature. Only Feb, Jul, Aug, Sep, Nov and Dec demonstrated a statistically significant (P<0.05) increase. Feb demonstrated the greatest increase, ~1.8°C since 1870.



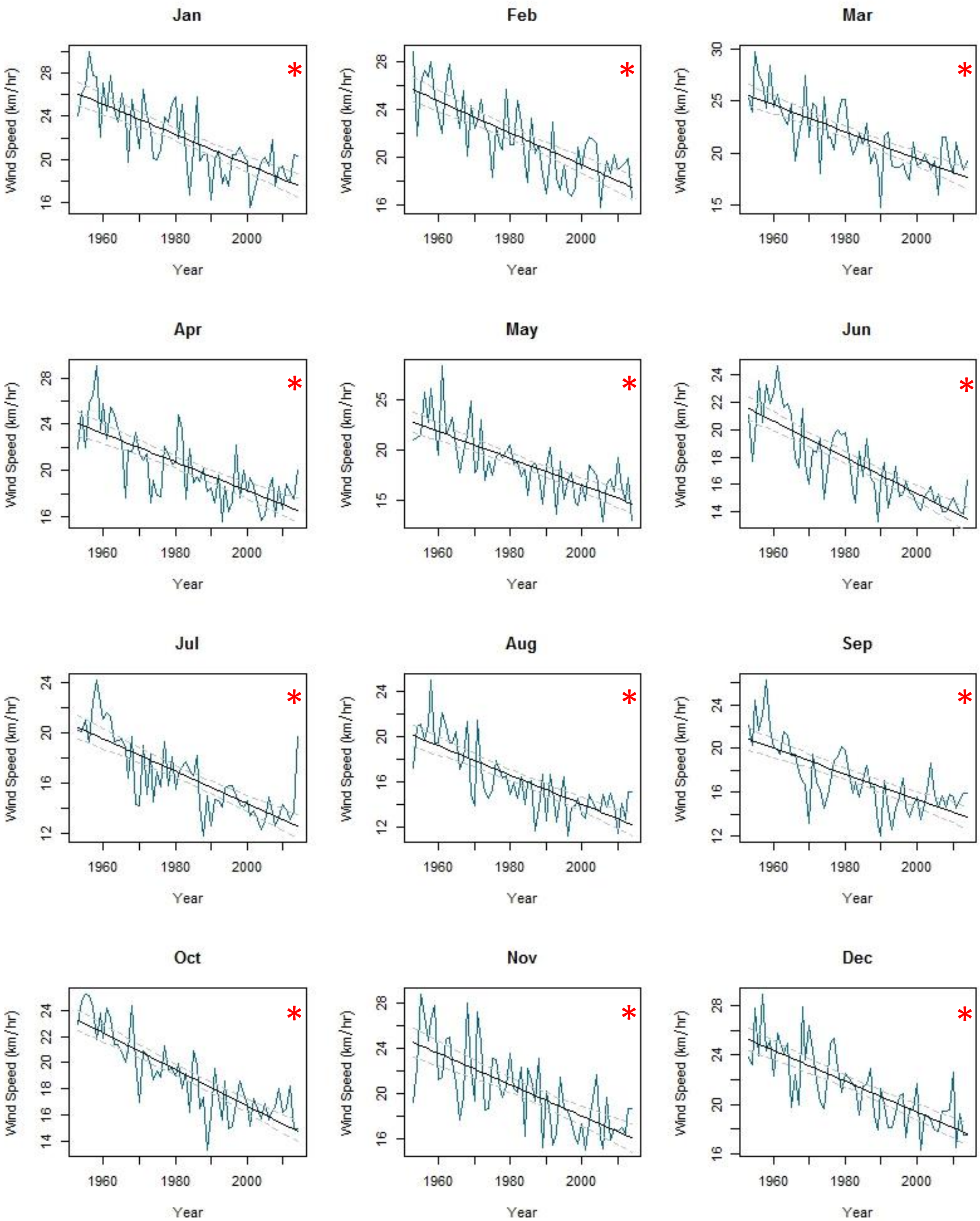
Sydney mean monthly <u>minimum</u> temperature. All months demonstrated a statistically significant (P<0.05) increase in mean monthly minimum temperatures (i.e., nighttime). Feb demonstrated the greatest increase, ~3.6°C since 1870.



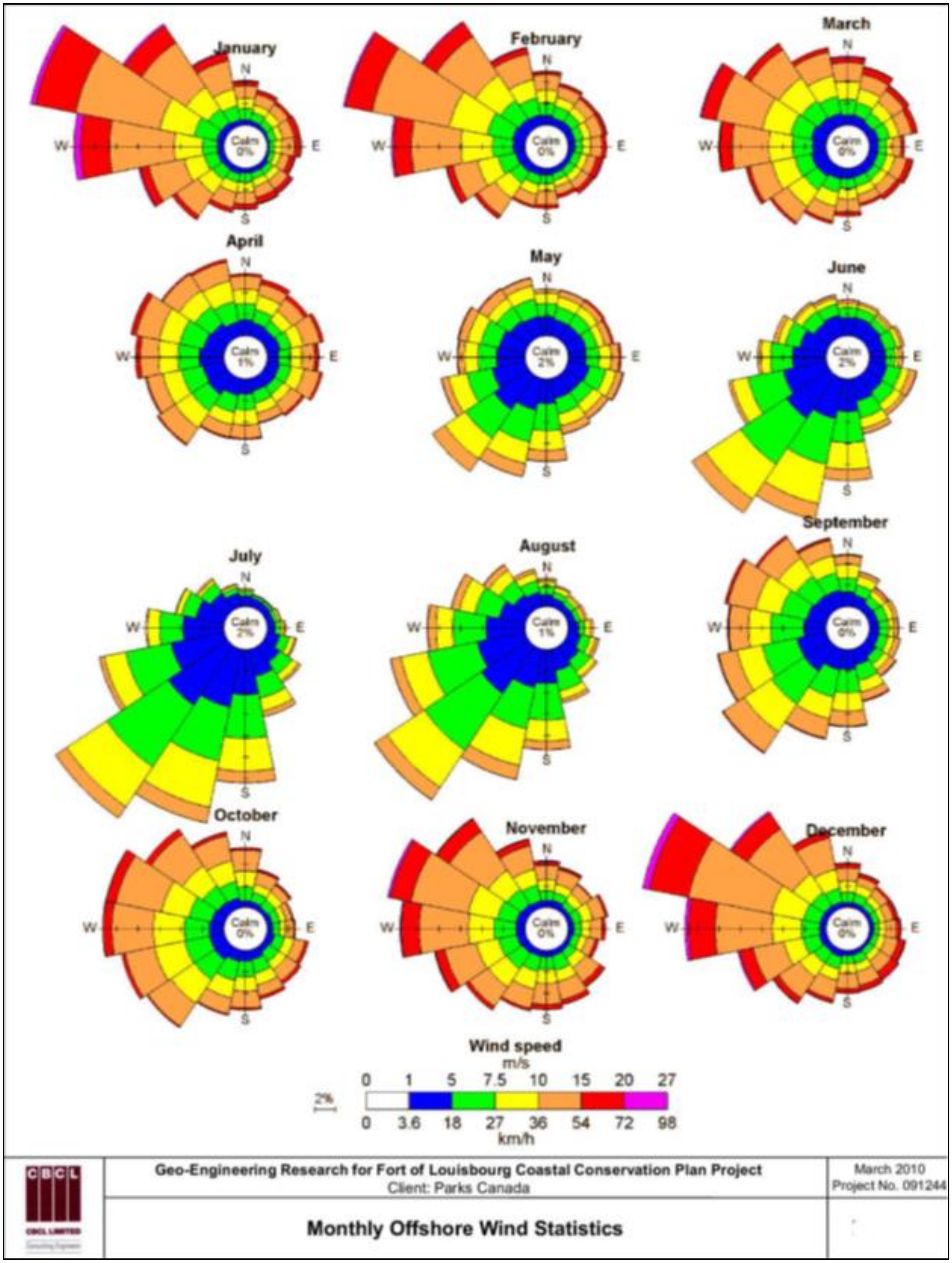
Sydney mean monthly <u>maximum</u> temperature. All months demonstrated a statistically significant ($P<0.05$) increase in mean monthly maximum temperatures (i.e., daytime). Feb demonstrated the greatest increase, ~3.6°C since 1870.



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%).

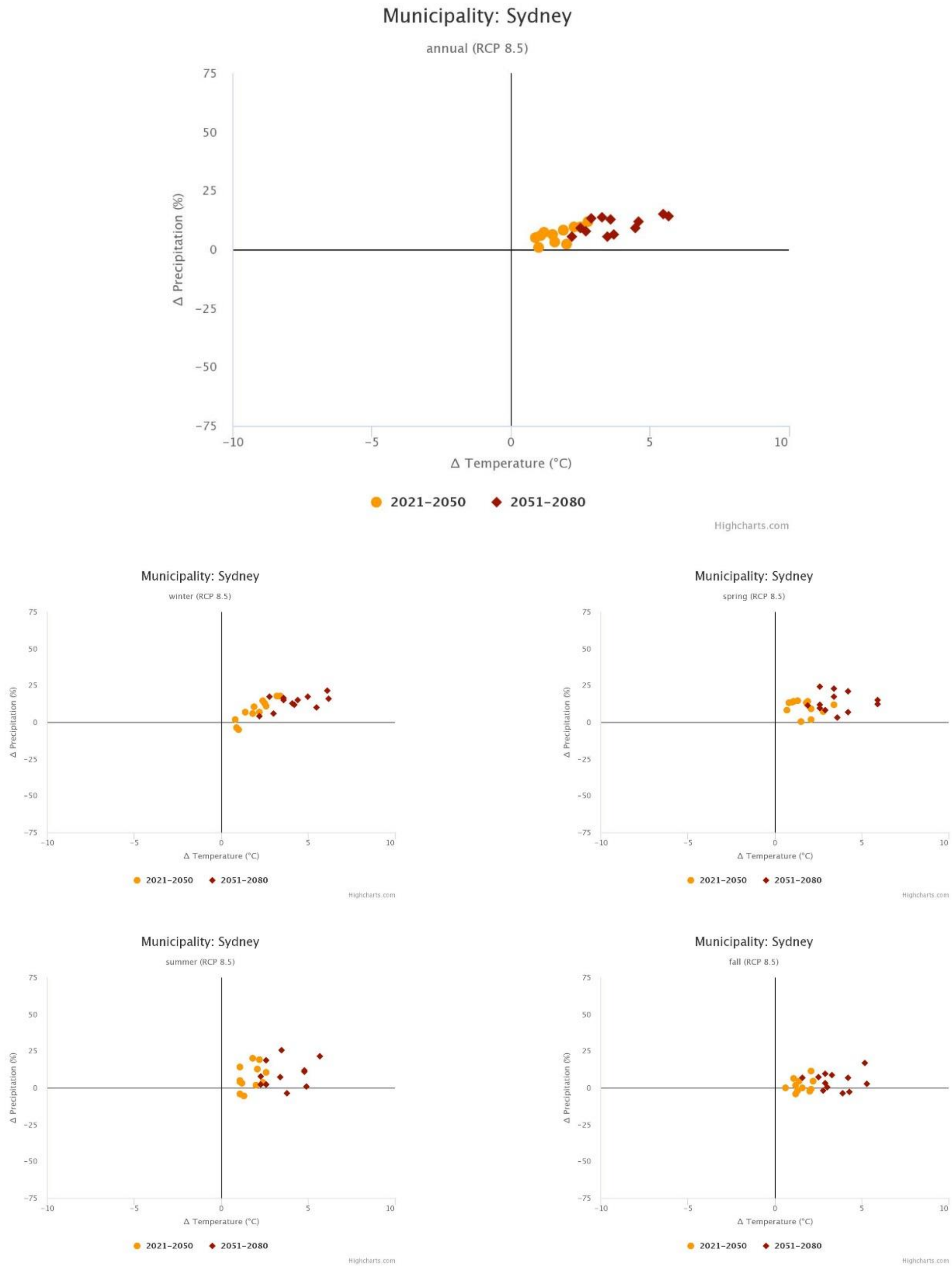


Sydney mean monthly wind speeds. All mean monthly wind speeds have demonstrated a statistically significant (P<0.05) decrease since 1953.



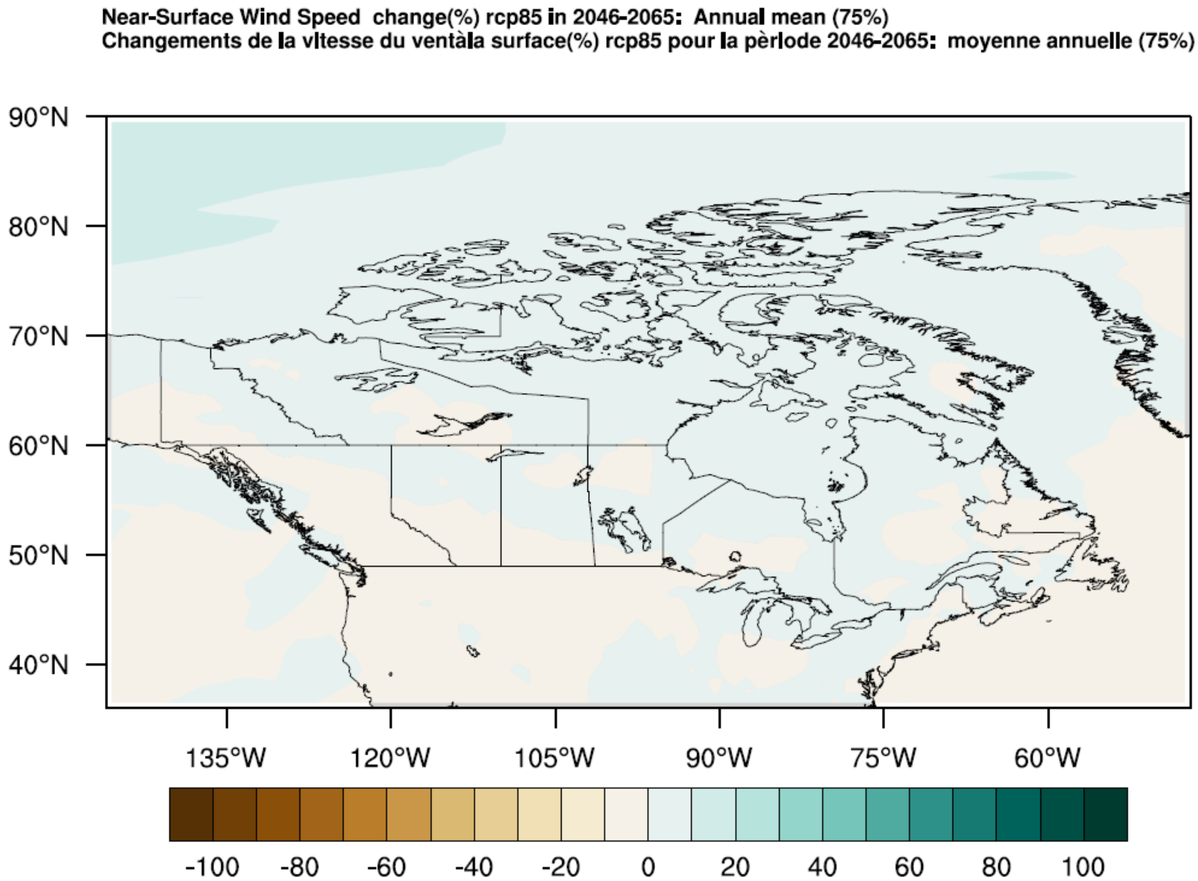
Monthly wind roses for the Fortress of Louisbourg. Summer winds are generally below 30 km/h and from the southwest. Winter winds are much stronger and predominantly from the west-northwest (Duggan, 2014).

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).