Ontario
Climate Change Data Portal

Technical Report

Development of High-Resolution Climate Change Projections under RCP 8.5 Emissions Scenario for the Province of Ontario

Xiuquan Wang & **Gordon Huang**

Institute for Energy, Environment and Sustainable Communities
University of Regina

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When referring to the climate data published on Ontario CCDP, the source must be clearly and prominently stated and cited. This report summarizes the development of high-resolution climate change projections under RCP 8.5 emissions scenario for the Province of Ontario, and should be referenced as:

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Copies for this report are available to download from: http://ontarioccdp.ca

The Ontario CCDP is developed and maintained by Xiuquan Wang at the University of Regina. For any questions or comments, please contact Xiuquan Wang at: xander.wang@ontarioccdp.ca

Executive Summary

Currently, climate adaptation practitioners have identified a need to refine climate change impacts modeling down to a regional/community level in order to understand the direct and long-term impacts on Ontario's communities. It is important for the Province of Ontario to promote the enhancement of knowledge and scientific expertise on the effects of climate change, and the acquisition and dissemination of the best information to support the development of sound, responsible and effective climate change adaptation strategies.

To this end, the Ministry has been building the Province of Ontario's modeling, monitoring and research capacity related to potential climate change at finder resolution over Ontario, by funding projects on high-resolution climate projections over the entire Province. Over the past four years, the Recipient has produced a series of high resolution climate change projections for the Province of Ontario using the PRECIS model developed at UK Met Office Hadley Centre in order to help climate adaptation practitioners understand the direct and long-term impacts of climate change on Ontario's communities. However, these previous projections were all based on IPCC AR4 model outputs published almost 7 years ago.

Along with the release of IPCC AR5, a large number of global climate projections based on the state-of-the-art global climate models (GCMs) and new earth systems models (ESMs) under the representative concentration pathways (RCPs) have been made available to the public. Therefore, it is necessary to update the previously-developed climate change scenarios for the Province of Ontario by using the newly published up-to-date AR data sets.

As the first step of such an initiative, this project is focused on the development of high-resolution climate change projections for the Province of Ontario with consideration of the RCP 8.5 emissions scenario only. Other RCP scenarios (i.e., RCP 2.6, RCP 4.5, and RCP 6.0) will be taken into account in the subsequent projects. The regional model used in this project to perform dynamical downscaling to the AR5 data sets is the Regional Climate Model system (RegCM).

As one of the deliverables of this project, this report summarizes:

- downscaling of AR5 data sets using the RegCM model;
- validation of the high-resolution climate projections of the RegCM model;
- projected changes in main climate variables under RCP 8.5 emissions scenario; and
- updates of the public data portal – Ontario Climate Change Data Portal (Ontario CCDP).

In this project, we carry out four RegCM runs driven by boundary conditions of CanESM2, HadGEM2-ES, GFDL-ESM2M, and IPSL-CM5A-LA under RCP 8.5 emissions scenario for historical period (i.e., 1986-2005) and future period (i.e., 2006-2100). Instead of providing probabilistic projections like the previous release of A1B projections (usually derived as percentiles, such as 10%, 20%, …, 90%), here we offer the direct outputs of these four runs without any post-processing. This is because we have received a large number of comments and suggestions from the current users of Ontario CCDP. It appears that the majority of the users would like to use the direct outputs of the model simulations to drive their impact models. Therefore, in the release of RCP 8.5 projections, we only provide the original outputs from our RegCM ensemble simulations. Thus, the users can use the data to drive their impact studies directly; meanwhile, they may apply different methods for probabilistic projections (e.g., Wang et al., 2014a) and bias corrections to the direct model outputs to obtain expected results.

Acknowledgements

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1. Introduction

During 2012-2013, the World Climate Research Program (WCRP) released the latest global climate projections from its Coupled Model Inter-comparison Project phase 5 (CMIP5), which will inform the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5, expected in 2014). The projections were generated using a set of new global climate models that collectively reflect varying degrees of advancement in climate science and modeling since CMIP phase 3 (CMIP3) which informed the IPCC Fourth Assessment Report (AR4). Besides, the CMIP5 climate projections were developed using a new set of climate forcing scenarios (i.e., representative concentration pathways, RCPs). These new scenarios reflect recent advancements in integrated assessment models to characterize future developments in global greenhouse gas (GHG) emissions since the release of the predecessor scenarios, known as the Special Report on Emissions Scenarios (SRES).

A recent comparison of downscaled CMIP5 and CMIP3 climate projections over the western U.S. (Brekke et al., 2013) shows notable differences in some regions. It is considered that these differences are generally related to (a) the updates and differences in the climate models as used for CMIP5 and (b) the new set of climate forcing emission scenarios. As the CMIP5 modeling projections have been available to the wide research community only very recently, understanding how and why CMIP5 results differ from those in CMIP3 is still at its early stage.

Over the past four years, the Recipient has produced a series of high resolution climate change projections across the entire Province of Ontario using PRECIS in order to help climate adaptation practitioners understand the direct and long-term impacts of climate change on Ontario's communities. However, the previous projections were all based on CMIP3 outputs. With the release of CMIP5, it is important to recognize that more work is required to better understand what CMIP5 means for local impact assessments as well as its differences from CMIP3.

Along with the release of IPCC AR5, a large number of global climate projections based on the state-of-the-art global climate models (GCMs) and new earth systems models (ESMs) under the representative concentration pathways (RCPs) have been made available to the public. Therefore, it is necessary to update the previously-developed climate change scenarios for the Province of Ontario by using the newly published up-to-date AR data sets.

As the first step of such an initiative, this project is focused on the development of high-resolution climate change projections for the Province of Ontario with consideration of the RCP 8.5 emissions scenario only. Other RCP scenarios (i.e., RCP 2.6, RCP 4.5, and RCP 6.0) will be taken into account in the subsequent projects. The regional model used in this project to perform dynamical downscaling to the AR5 data sets is the Regional Climate Model system (RegCM), which is originally developed at the National Center for Atmospheric Research (NCAR) and is now maintained in the Earth System Physics (ESP) section of the International Centre for Theoretical Physics (ICTP). The spatial resolution of the RegCM simulations in this project is 25 km.

Specifically, the boundary conditions from four CMIP5 global models (i.e., CanESM2, HadGEM2-ES, GFDL-ESM2M, and IPSL-CM5A-LA) for historical period (i.e., 1986-2005, referred to as baseline period hereinafter) and future period (i.e., 2006-2100) under RCP 8.5 emissions scenario will be used to drive our RegCM simulations over the Province of Ontario. The simulations for the baseline period will be first validated at twelve weather stations which are geographically distributed across the Province of Ontario. A brief analysis of the projected changes in main climate variables at these twelve weather stations are then presented in this report. The projected changes at grid point scales for the entire province can be viewed via Ontario CCDP. All related climate data generated from this project can be accessed and downloaded from Ontario CCDP.

2. Climate Downscaling with the RegCM Model

The RegCM has been the first limited area climate model developed for long term regional climate simulations. It has participated to numerous regional model intercomparison projects and it has been applied by a large community for a wide range of regional climate models, from process studies to paleo-climate and future climate projetions (Giorgi and Mearns, 1999; Giorgi et al., 2006). The RegCM system is a community model, and in particular it is designed for use by a varied community composed by scientists in industrialized countries as well as developing nations (Pal et al., 2007). The RegCM modeling system is originally developed at the National Center for Atmospheric Research (NCAR) and is now maintained in the Earth System Physics (ESP) section of the International Centre for Theoretical Physics (ICTP).

The RegCM model is a regional climate model developed throughout the years, with a wide base of model users. It has evolved from the first version developed in the late eighties (known as RegCM1), to the later versions in the early nineties (known as RegCM2), late nineties (known as RegCM2.5), and 2000s (known as RegCM3) (Dickinson et al., 1989; Giorgi, 1989, 1990; Giorgi et al., 1993a; Giorgi et al., 1993b; Giorgi et al., 1993c; Giorgi and Mearns, 1999; Pal et al., 2000). Since the release of RegCM3 (Pal et al., 2007), the model has undergone a substaintial evolution both in terms of sofrware code and physics representations, and this has lead to the development of a fourth version of the model, RegCM4, which was released by the ICTP in June 2010 as a prototype version (RegCM4.0) and in May 2011 as a first complete version (RegCM4.1).

Compared to previous versions, RegCM4 includes new land surface, planetary boundary layer and air-sea flux schemes, a mixed convection and tropical band configuration, modifications to the pre-existing radiative transfer and boundary layere schemes and a full upgrade of the model code towards improved flexibility, portability and user friendliness.

The current version of RegCM can be interactively coupled to a 1D lake model, a simplified aerosol scheme (including QC, BC, SO2, dust, and sea spray), and a gas phase chemistry module (CBM-Z). Overall, RegCM4 shows an improved performance in several respects compared to previous versions, although further testing by the user community is needed to fully explore its sensitivities and range of applications.

The RegCM modeling system consists of four components: Terrain, ICBC, RegCM, and Postprocessor. Terrain and ICBC are the two components of RegCM preprocessor. Terrestrial variables (including elevation, landuse, and sea surface temperature) and three-dimensinal isobaric meteorological data are horizontally interpolated from a latitude-longtitude mesh to a high-resolution domain on either a Rotated (and Normal) Mercator, Lambert Conformal, or Polar Stereographic projection. Vertical interpolation from pressure levels to the σ coordinate system of RegCM is also performed. The σ surfaces near the ground closely follow the terrain, and the higher-level σ surfaces tend to approximate isobaric surfaces. Since the vertical and horizontal resoluton and domain size can vary, the modeling package programs employ parameterized dimensions requiring a variable amount of core memory, and thus the requisite hard-disk storage amount is varied accordingly.

In this project, we use the latest version of RegCM (i.e., RegCM4.3) to perform regional climate simulations over the Province of Ontario. The spatial resolution of our RegCM simulations is 25 km. The boundary conditions from four CMIP5 global models (i.e., CanESM2, HadGEM2-ES, GFDL-ESM2M, and IPSL-CM5A-LA) for the baseline period (i.e., 1986-2005) and future period (i.e., 2006-2100) under RCP 8.5 emissions scenario are used to drive our RegCM simulations for the Province of Ontario.

3. Validation of the RegCM Simulations

To validate the performance of the RegCM simulations in reproducing the historical climatology of Ontario, we compare the model simulations of mean temperature and total precipitation for the baseline period with the observations at twelve weather stations. The twelve weather stations selected in this study are geographically distributed across the landmass of the Province of Ontario in order to reflect the spatial variability of its local climatology. The detailed information of these twelve weather stations is listed in Table 1, and their geographical locations are shown in Figure 1.

Table 1. Twelve weather stations selected in this study

No.	Name	Latitude	Longitude	Elevation (m)
1	Windsor	42.27°N	82.97°W	190
2	London	43.03°N	81.15°W	278
3	Toronto	43.67°N	79.40°W	113
4	Owen Sound	44.58°N	80.93°W	179
5	Ottawa	45.38°N	75.72°W	79
6	North Bay	46.37°N	79.42°W	370
7	Sault Ste Marie	46.48°N	84.52°W	192
8	Timmins	48.57°N	81.38°W	295
9	Geraldton	49.78°N	86.93°W	349
10	Kenora	49.78°N	94.37°W	406
11	Moosonee	51.27°N	80.65°W	10
12	Big Trout Lake	53.83°N	89.87°W	224

Figure 1. Geographical locations of the twelve weather stations

The observed annual and seasonal mean temperature and total precipitation for the twelve weather stations are obtained from the Adjusted and Homogenized Canadian Climate Data (AHCCD), Environment Canada (available at: http://www.ec.gc.ca/dccha-ahccd). The simulated annual and seasonal mean temperature and total precipitation for the baseline period by all RegCM model runs, which are driven by the boundary conditions from CanESM2, HadGEM2-ES, GFDL-ESM2M, and IPSL-CM5A-LA, are derived and compared to the observed values in order to help evaluate the performance of the RegCM simulations. For convenience, we use CanESM, HadGEM, GFDL, and IPSL hereinafter to represent the four RegCM model runs driven by CanESM2, HadGEM2-ES, GFDL-ESM2M, and IPSL-CM5A-LA, respectively.

3.1 Mean Temperature

This section presents the validation results for annual and seasonal mean temperature at twelve weather stations. Comparison of observed and simulated annual mean temperature is shown in Figure 2, and the comparisons of observed and simulated seasonal mean temperature are presented in Figures 3-6, respectively.

It seems that the HadGEM and GFDL runs demonstrates reasonable capability in capturing the historical annual mean temperature at the selected stations, while the other two runs (i.e., CanESM and IPSL) tends to overestimate the observed annual mean temperature at all stations. For example, the average of observed annual mean temperature in the City of Toronto is about 9.5 °C. In comparison, the simulated values by the HadGEM and GFDL runs are about 9.5 °C and 8.5 °C, respectively; while the simulated ones by the CanESM and IPSL runs can be as high as 16.9 °C and 14.1 °C, respectively.

The performance of the four RegCM runs in reproducing the observed seasonal mean temperature appears to be similar with that for annual mean temperature. For example, the observed mean temperature in winter in the City of Toronto is about -2.2 °C. In comparison, the simulated values by the HadGEM and GFDL runs are about -3.1 °C and -2.4 °C, respectively; while the simulated ones by the CanESM and IPSL runs can be as high as 3 °C and -0.1 °C, respectively.

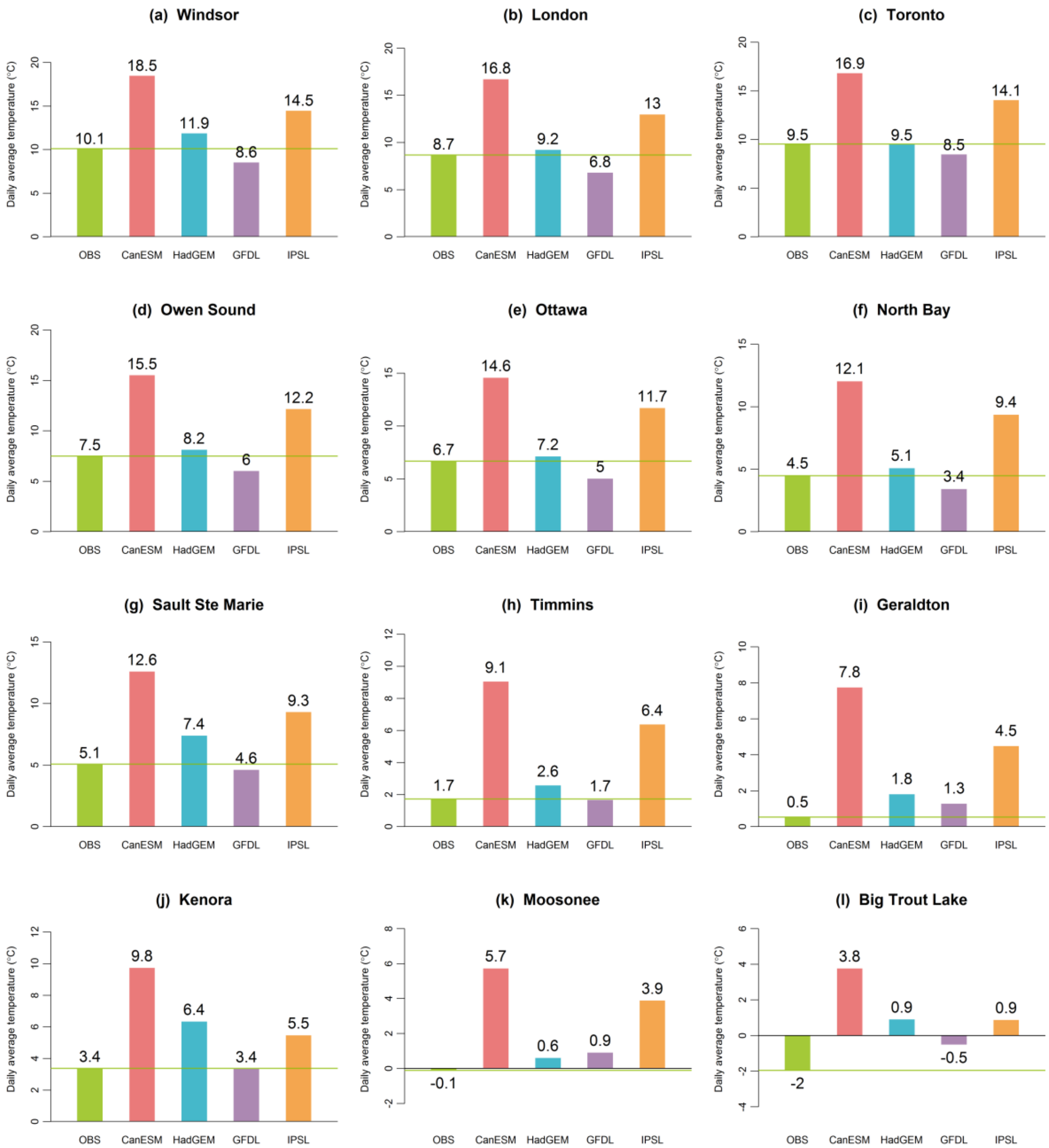

Figure 2. Comparison of observed and simulated annual mean temperature

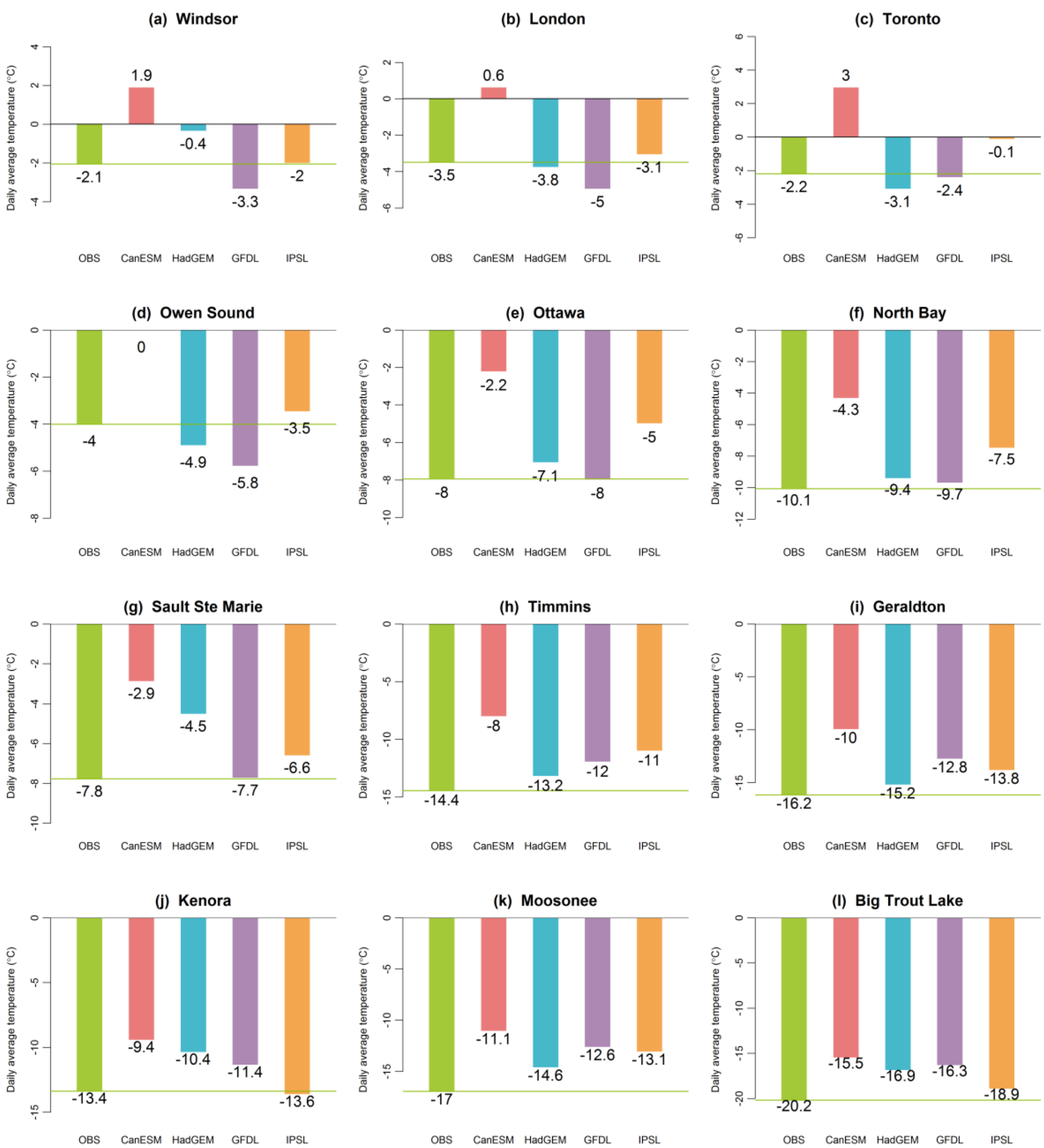

Figure 3. Comparison of observed and simulated winter mean temperature

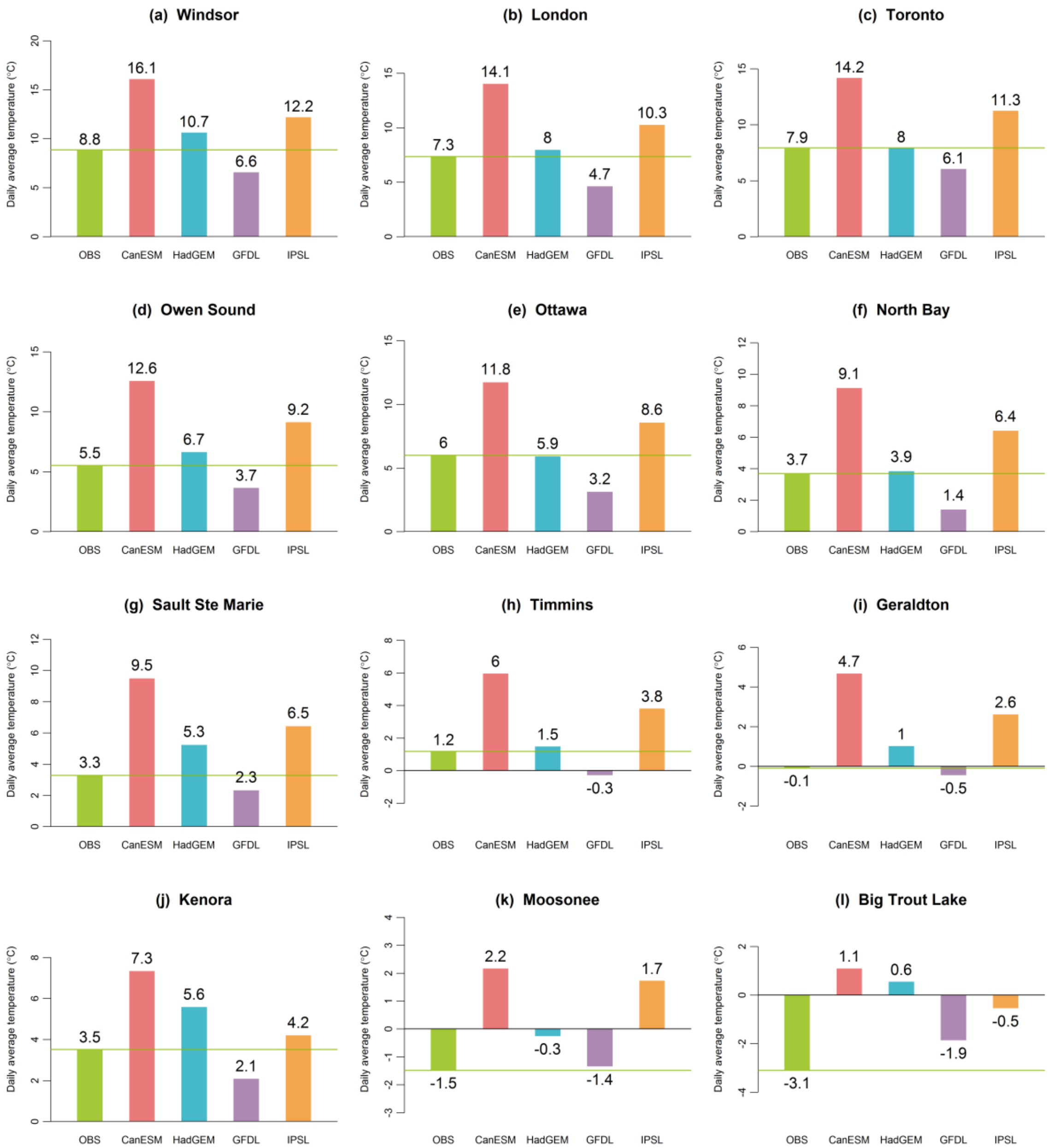

Figure 4. Comparison of observed and simulated spring mean temperature

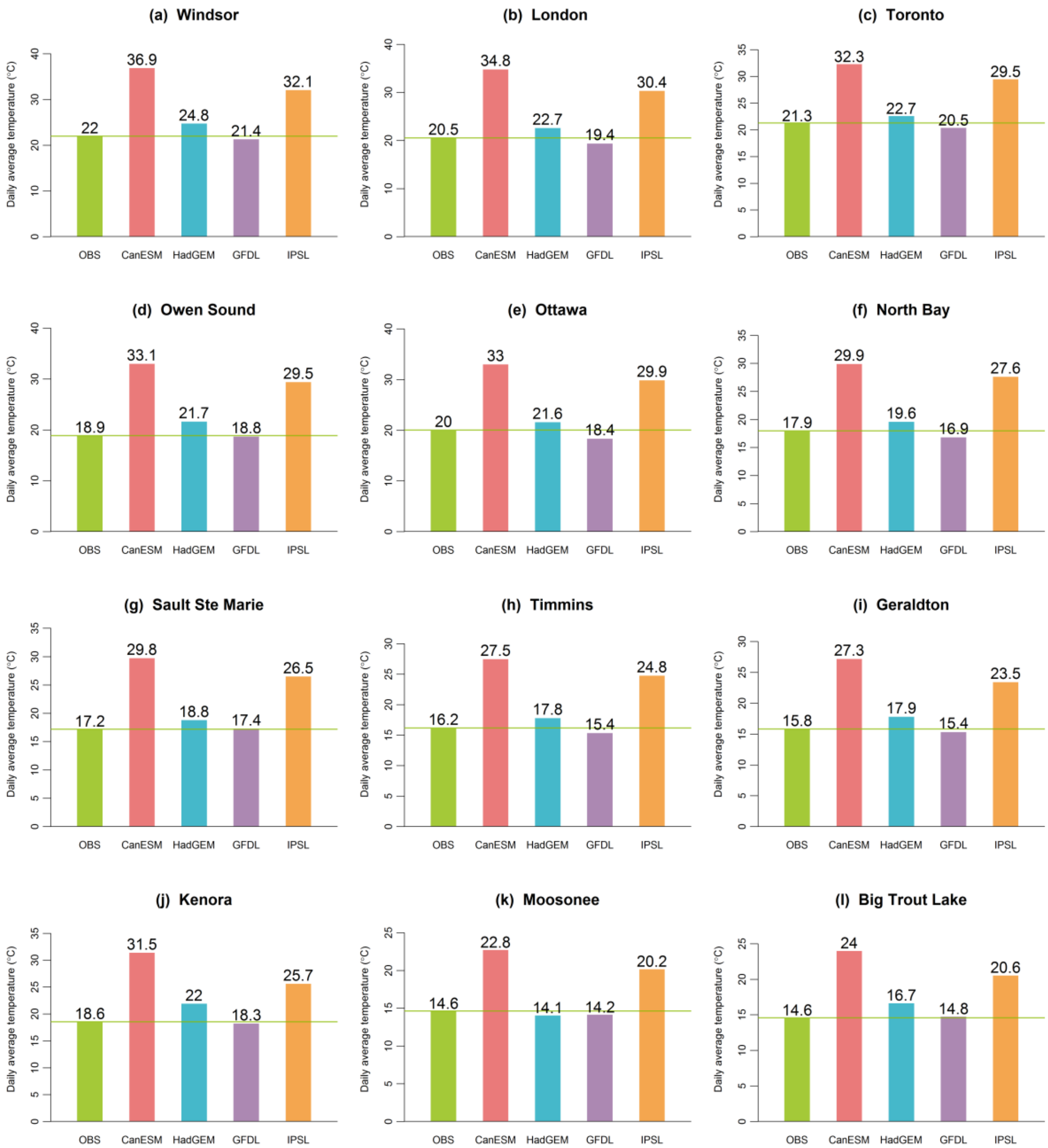

Figure 5. Comparison of observed and simulated summer mean temperature

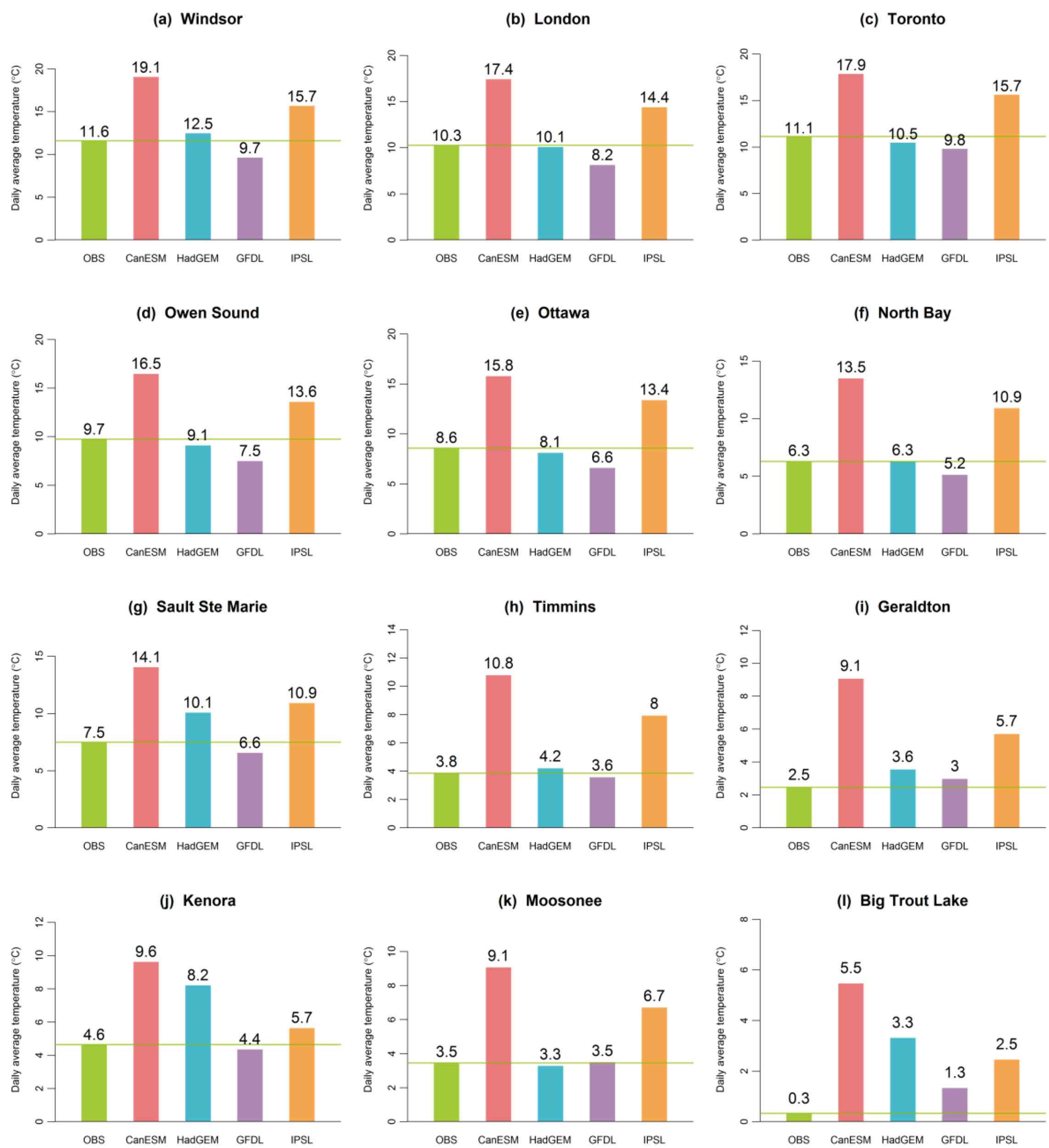

Figure 6. Comparison of observed and simulated autumn mean temperature

3.2 Total Precipitation

This section presents the validation results for annual and seasonal total precipitation at twelve weather stations. Comparison of observed and simulated annual total precipitation is shown in Figure 7, and the comparisons of observed and simulated seasonal total precipitation are presented in Figures 8-11, respectively.

It seems that the HadGEM and GFDL runs still demonstrates reasonable capability in capturing the historical annual total precipitation at the selected stations, while the other two runs (i.e., CanESM and IPSL) tends to consistently underestimate the observed annual total precipitation at all stations. Specifically, the HadGEM and GFDL runs tends to either slightly overestimate or slightly underestimate the observed annual total precipitation at all stations. But the spatial patterns of the annual total precipitation throughout these twelve stations are generally well captured by these two runs (i.e., HadGEM and GFDL). By contrast, the CanESM and IPSL runs show apparent underestimations of the observed annual total precipitation at all stations. For example, the observed annual total precipitation in the City of Windsor is about 1005 mm, while the simulated values by the CanESM and IPSL runs can be as low as 503 mm and 567 mm, respectively.

As for the seasonal total precipitation, it seems that the four RegCM runs show well performance in reproducing the observed winter and spring total precipitation at the selected stations. However, it is interesting to find that the CanESM and IPSL runs present significantly poor performance (i.e. underestimation) in simulating the observed summer and autumn total precipitation at all stations, while the performance of the other runs (i.e., HadGEM and GFDL) is reasonably acceptable.

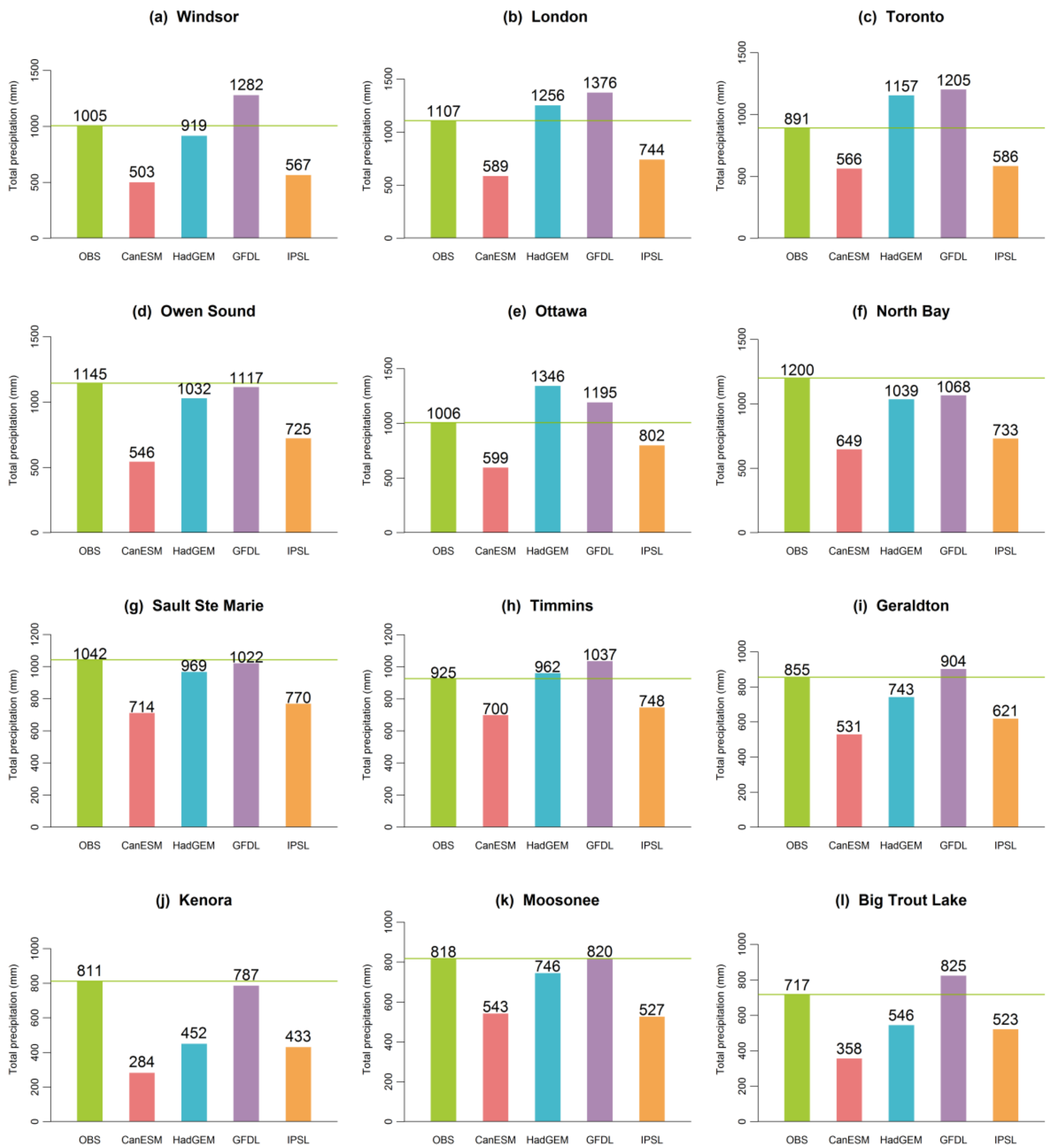

Figure 7. Comparison of observed and simulated annual total precipitation

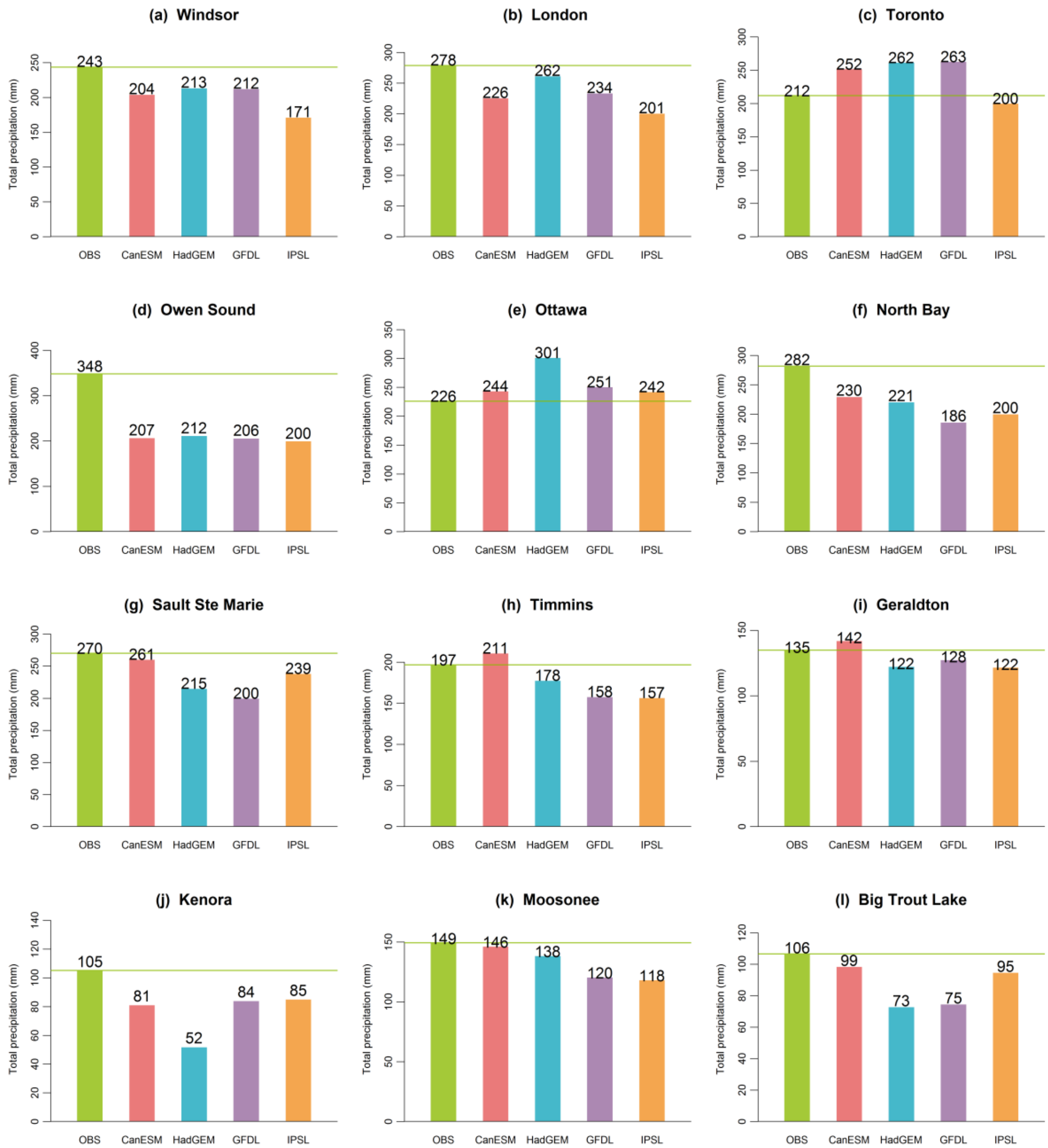

Figure 8. Comparison of observed and simulated winter total precipitation

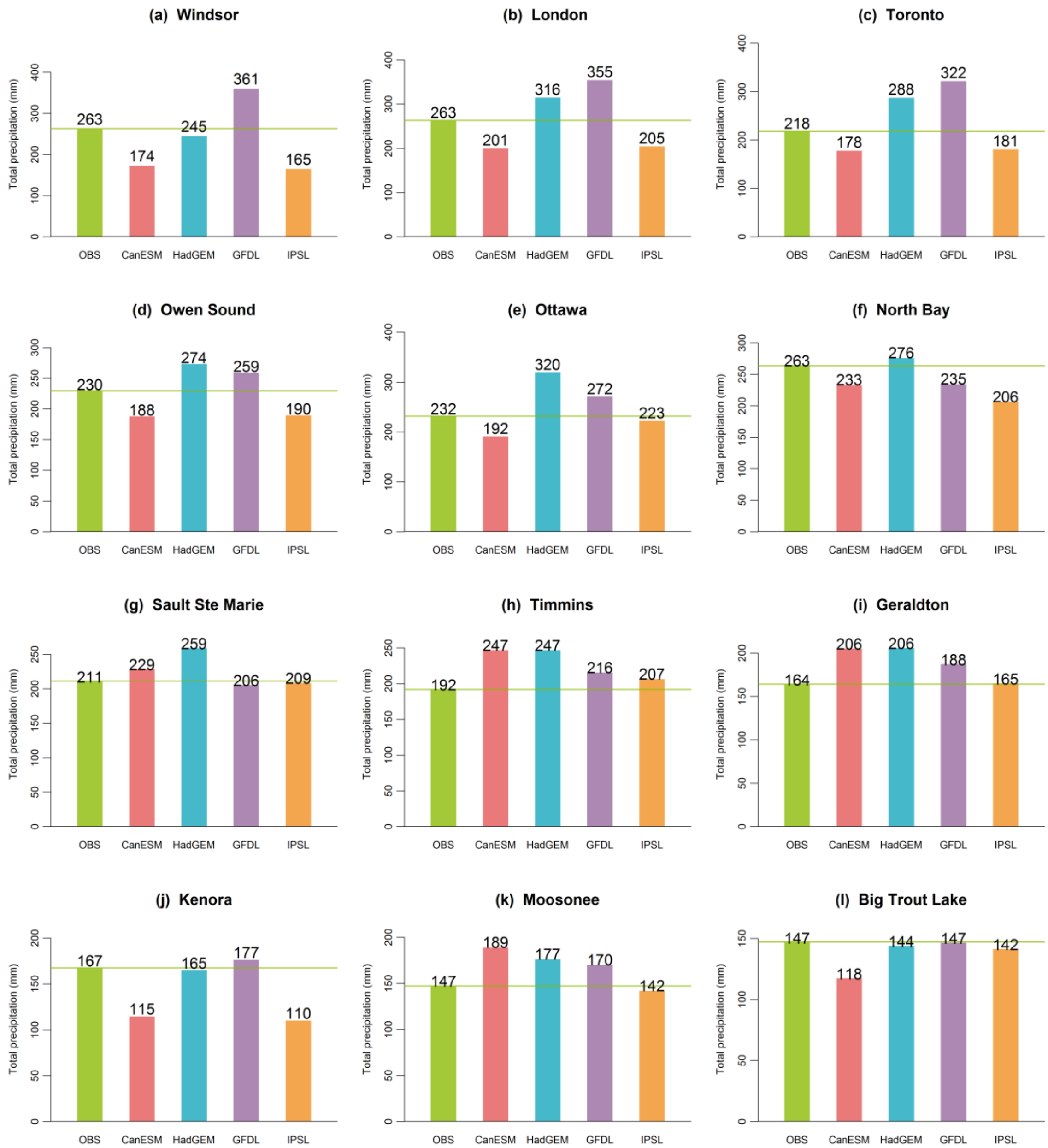

Figure 9. Comparison of observed and simulated spring total precipitation

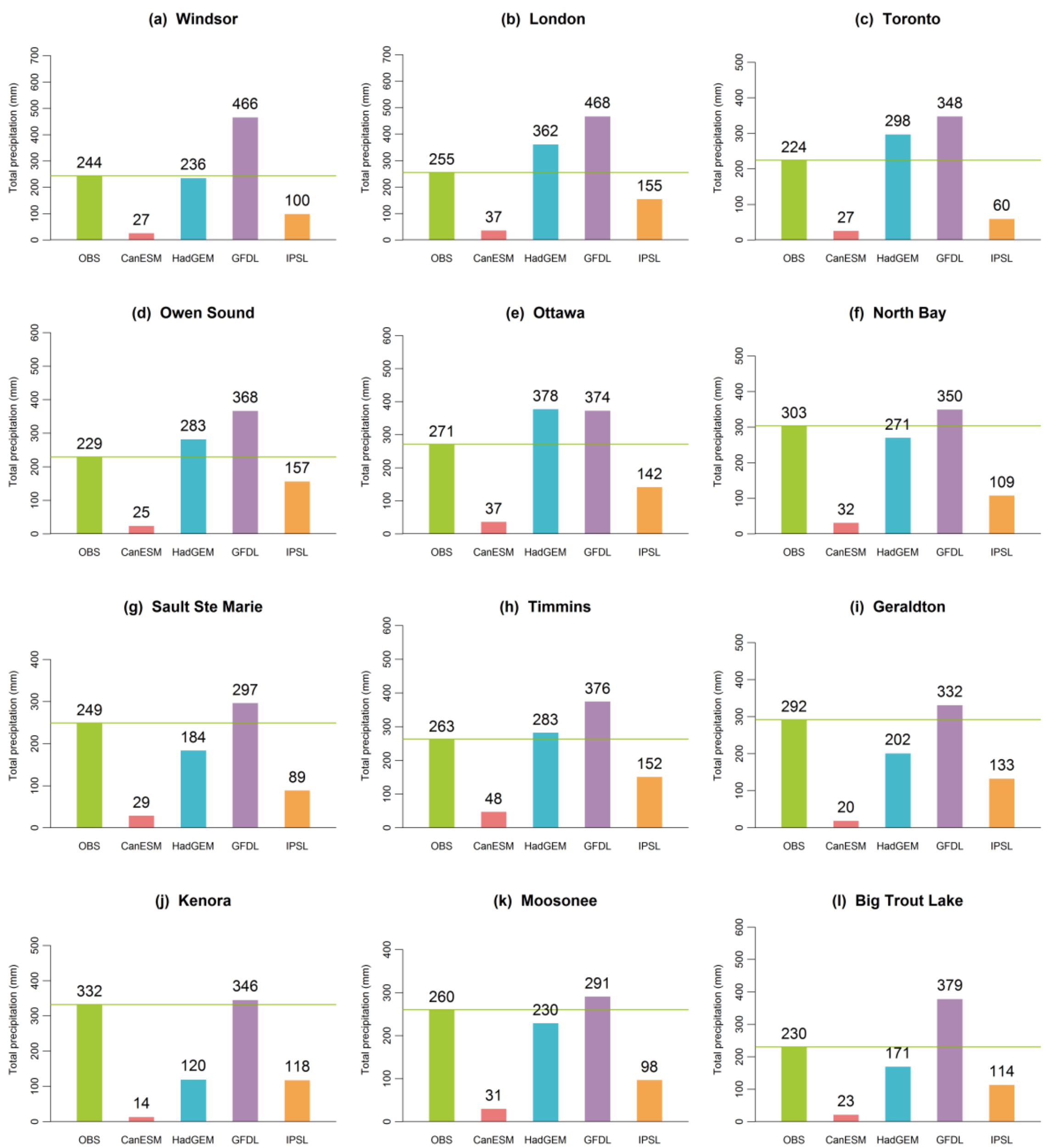

Figure 10. Comparison of observed and simulated summer mean temperature

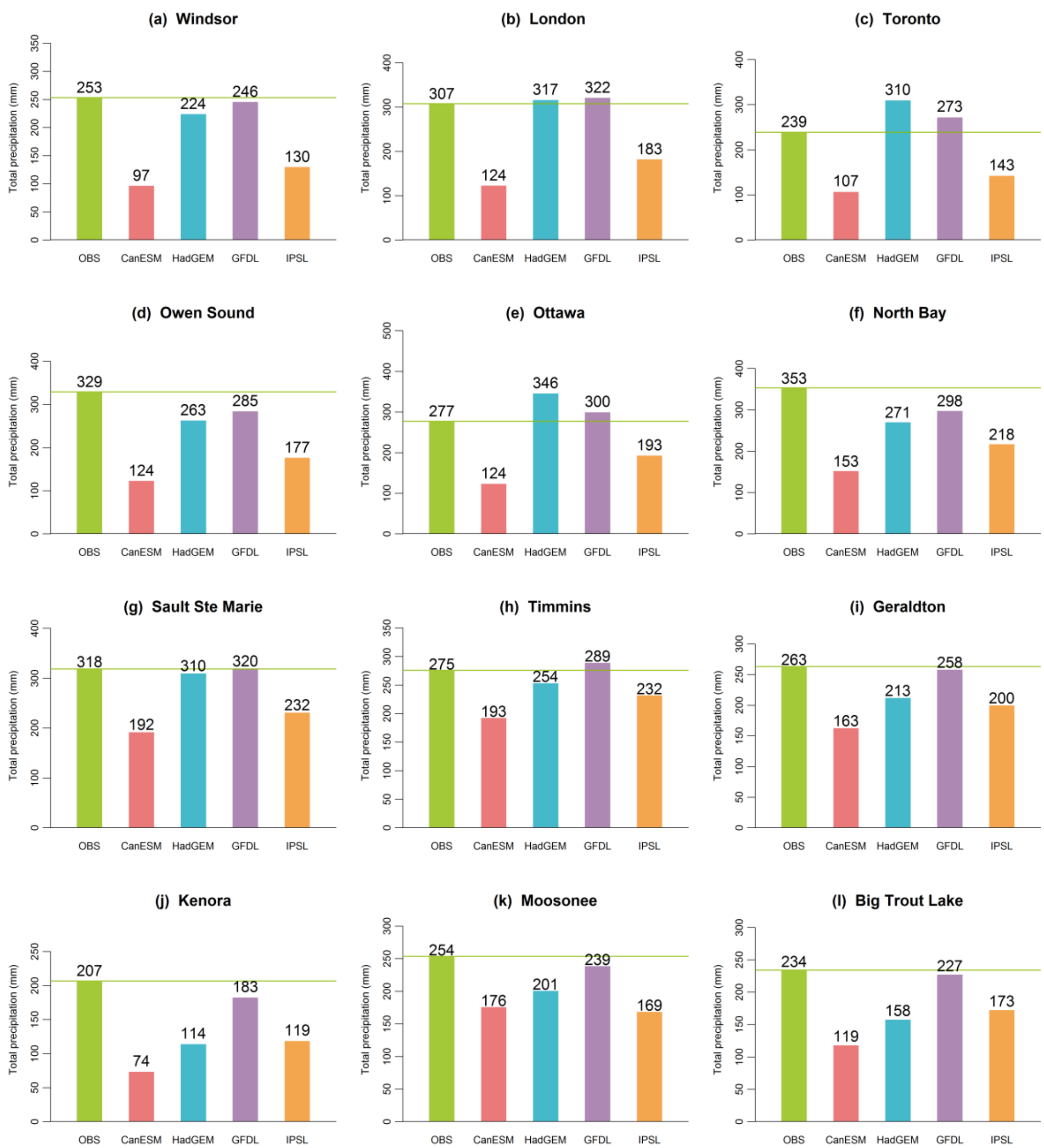

Figure 11. Comparison of observed and simulated autumn total precipitation

Note that the relatively-poor performance of CanESM and IPSL has already been reported by many previous studies (e.g., Bhattacharjee and Zaitchik, 2015; Chylek et al., 2011; Gillett et al., 2012; Gregory, 2013; McSweeney et al., 2014), readers may refer to them for more details. However, the projections of these two models are still valuable for providing a bigger range of potential climate change.

4. Projected Changes in Main Climate Variables

This chapter presents the projected changes in main climate variables, including mean temperature, maximum temperature, minimum temperature, and precipitation, by the four RegCM runs. Only the projected changes at the twelve weather stations are presented and analyzed in this report, the likely changes at each 25 km grid cells over the Province of Ontario can be accessed and downloaded from Ontario CCDP (http://ontarioccdp.ca). The simulations for future period (i.e., 2006-2100) at the twelve stations are first extracted and split into three time slices: 2020-2049 (or 2030s), 2040-2069 (or 2050s), and 2070-2099 (or 2080s). The changes in these three future periods (i.e., 2030s, 2050s, and 2080s) are calculated as the differences between the simulated values for future periods and the simulated ones for the baseline period.

We should note that the changes presented in this report and included in Ontario CCDP do not undergo bias-correction. Considering that a large number of methods can be used to performance bias-correction, we leave the selection of methods to the users' discretion. However, the validation results presented in the previous chapter can more or less provide useful reference information when applying any bias-correction measures to the RegCM simulations. We have already developed a Bayesian hierarchical model in our previous studies to help deal with the individual biases generated by each member of ensemble simulations, such that reliable probabilistic projections of future climatic changes can be derived. Users can refer to the papers of the authors for more details (Wang et al., 2014a; Wang et al., 2014b).

4.1 Changes in Mean Temperature

This section presents the projected changes in annual and seasonal mean temperature at twelve weather stations for three future periods: 2030s, 2050s, and 2080s. Figures 12-14 show the projected changes in annual mean temperature by the four RegCM runs. It is apparent that all runs consistently demonstrate continuous warming trends throughout the 21st century at all stations, although the magnitude of changes in annual mean temperature projected by each model run is completely different from others. The largest changes in annual mean temperature are reported by the CanESM run, and the smallest changes are projected by the GFDL run, while the changes projected by the other two runs (i.e., HadGEM and IPSL) are mostly in the middle. For example, the changes in annual mean temperature in 2030s, 2050s, and 2080s for the City of Windsor simulated by the CanESM run are likely to be 2.3 °C, 3.7 °C, and 6.2 °C, respectively, while the projected changes for the City of Windsor by the GFDL run are likely to be 0.9 °C in 2030s, 2 °C in 2050s, and 2.5 °C in 2080s, respectively. In comparison, the projected changes by the HadGEM and IPSL runs are relatively similar. For example, the projected changes for the City of Windsor by these two runs are likely to be the same (i.e., 1.2 °C) in 2030s, 2.6 °C and 3.1 °C in 2050s, and 5.1 °C and 5.6 °C in 2080s, respectively.

The projected changes in seasonal mean temperature by the four RegCM runs for three future periods (i.e., 2030s, 2050s, and 2080s) are shown in Figures 15-26. Similar patterns among these four runs are also reported for seasonal changes, although there are some slight variations for a few specific combinations of seasons and periods. Besides, the magnitude of changes in summer and autumn mean temperature projected by the four runs seems to be slightly greater than those in winter and spring at most of the stations.

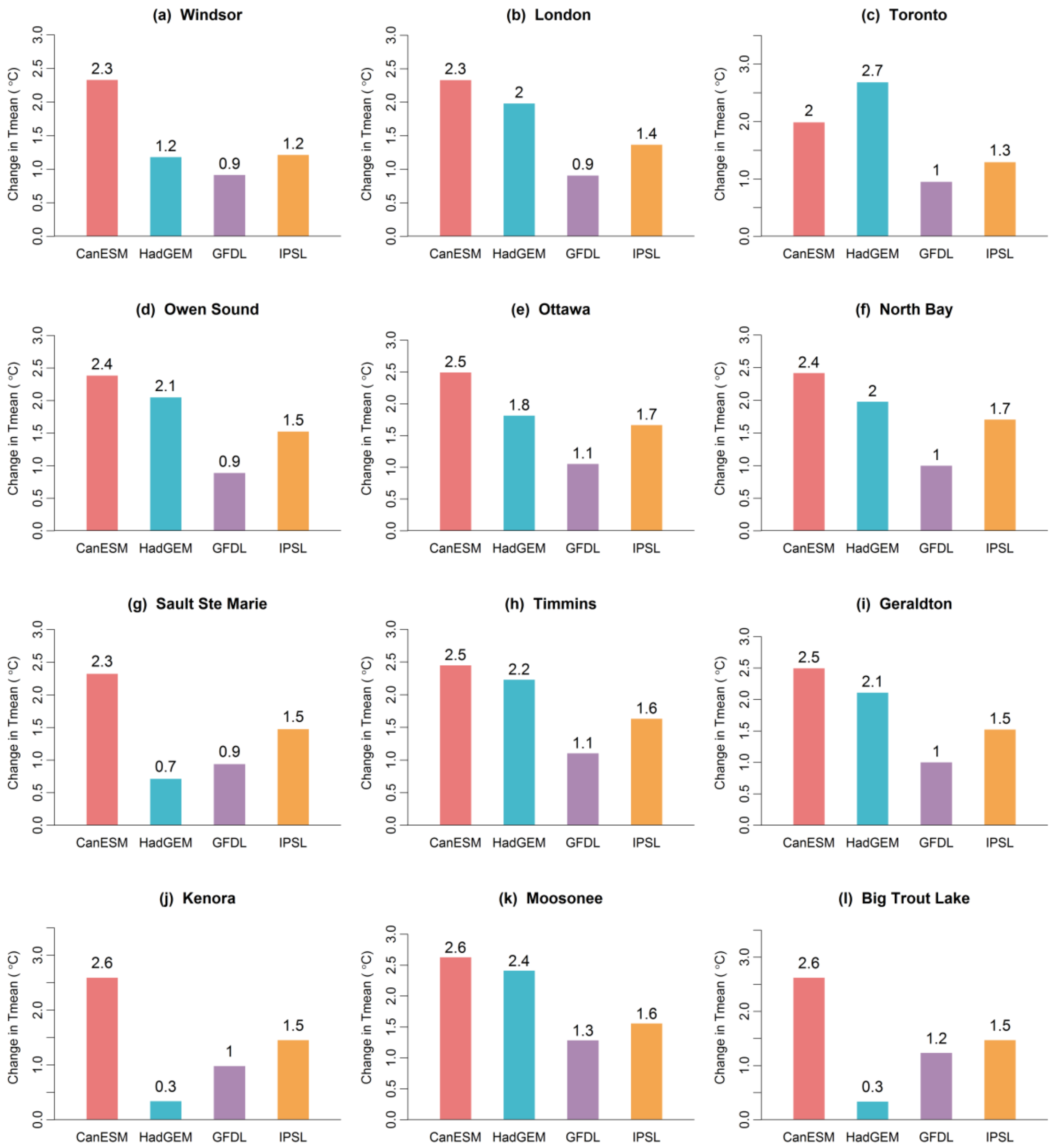

Figure 12. Changes in annual mean temperature in 2030s

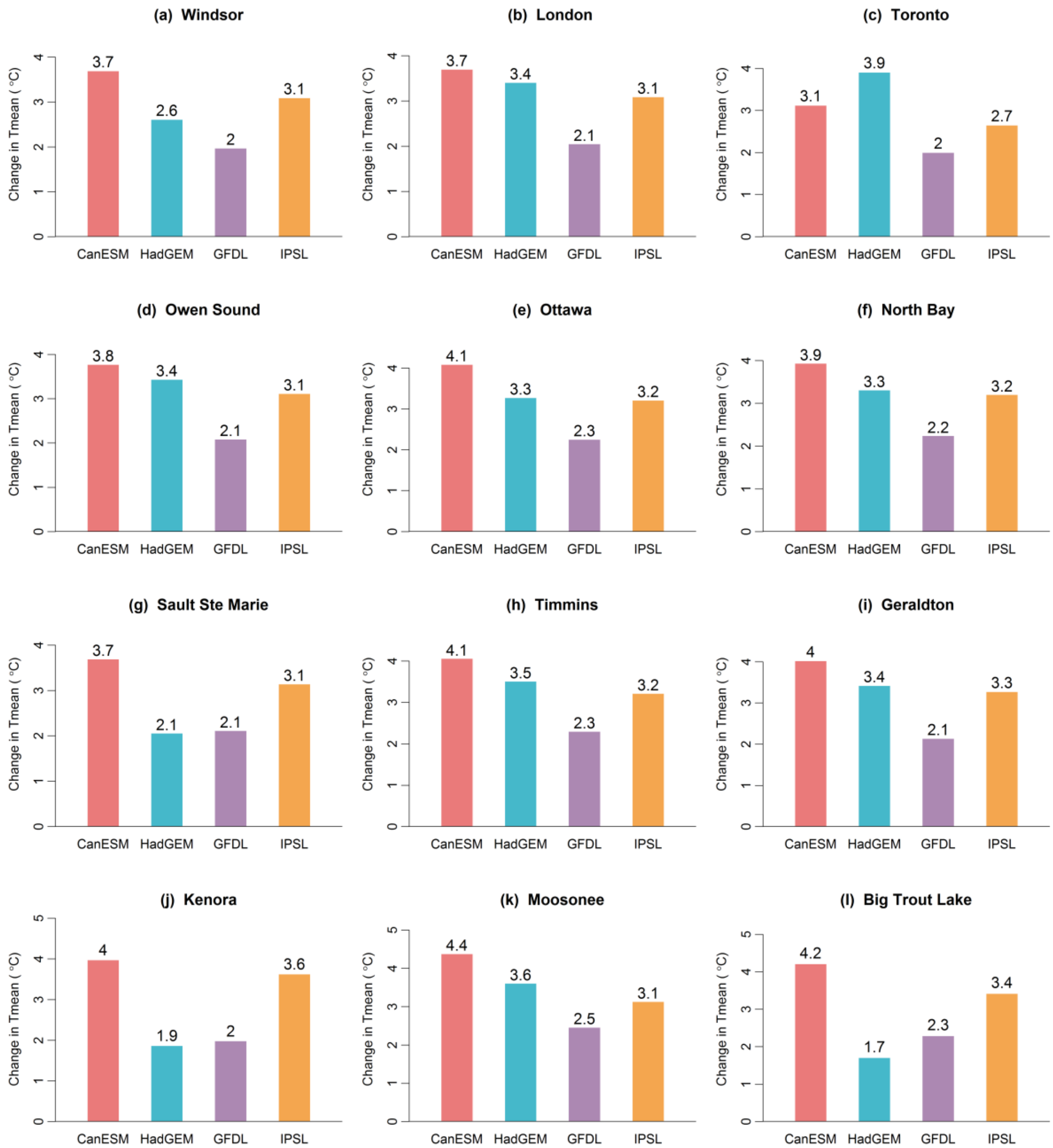

Figure 13. Changes in annual mean temperature in 2050s

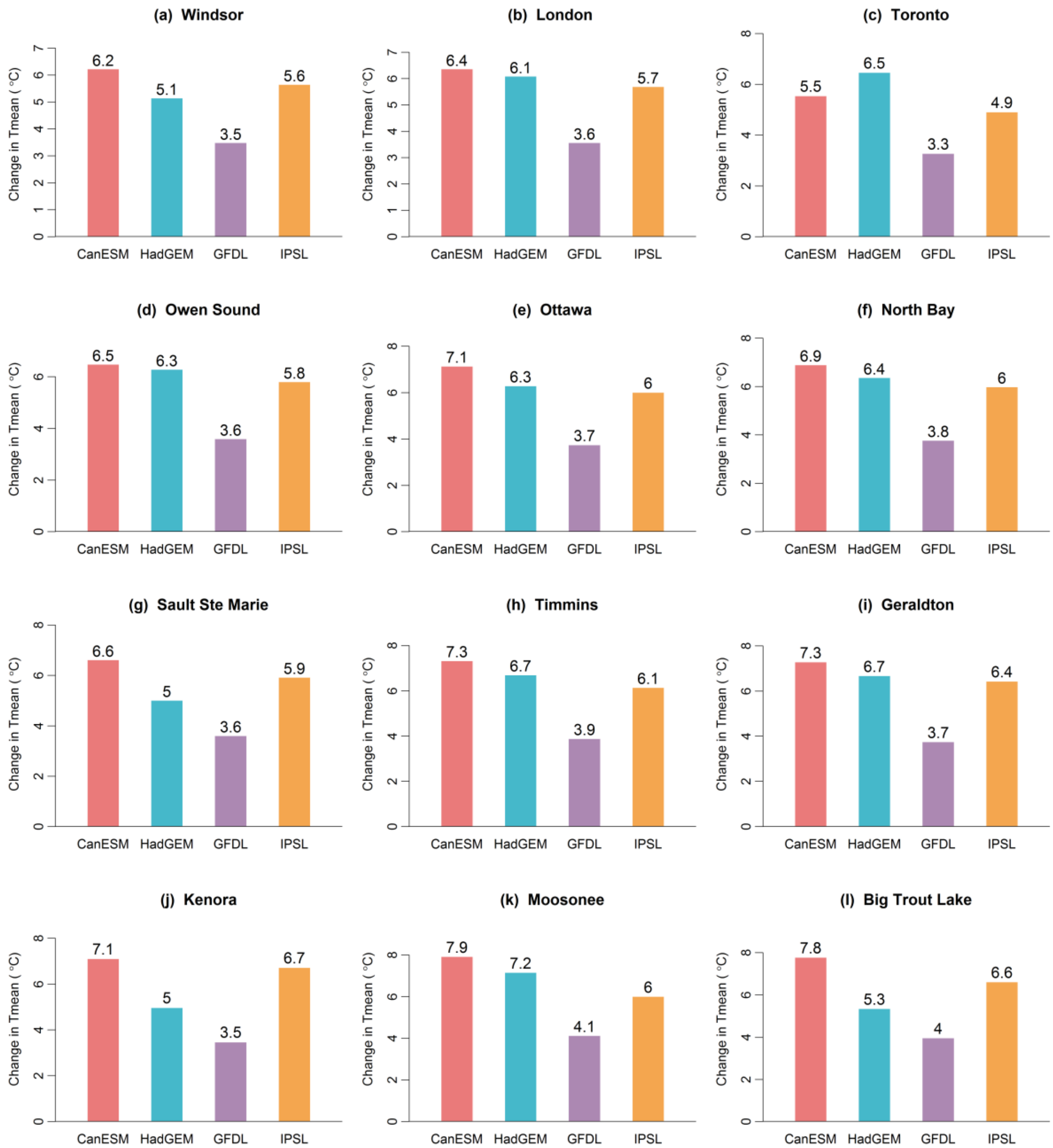

Figure 14. Changes in annual mean temperature in 2080s

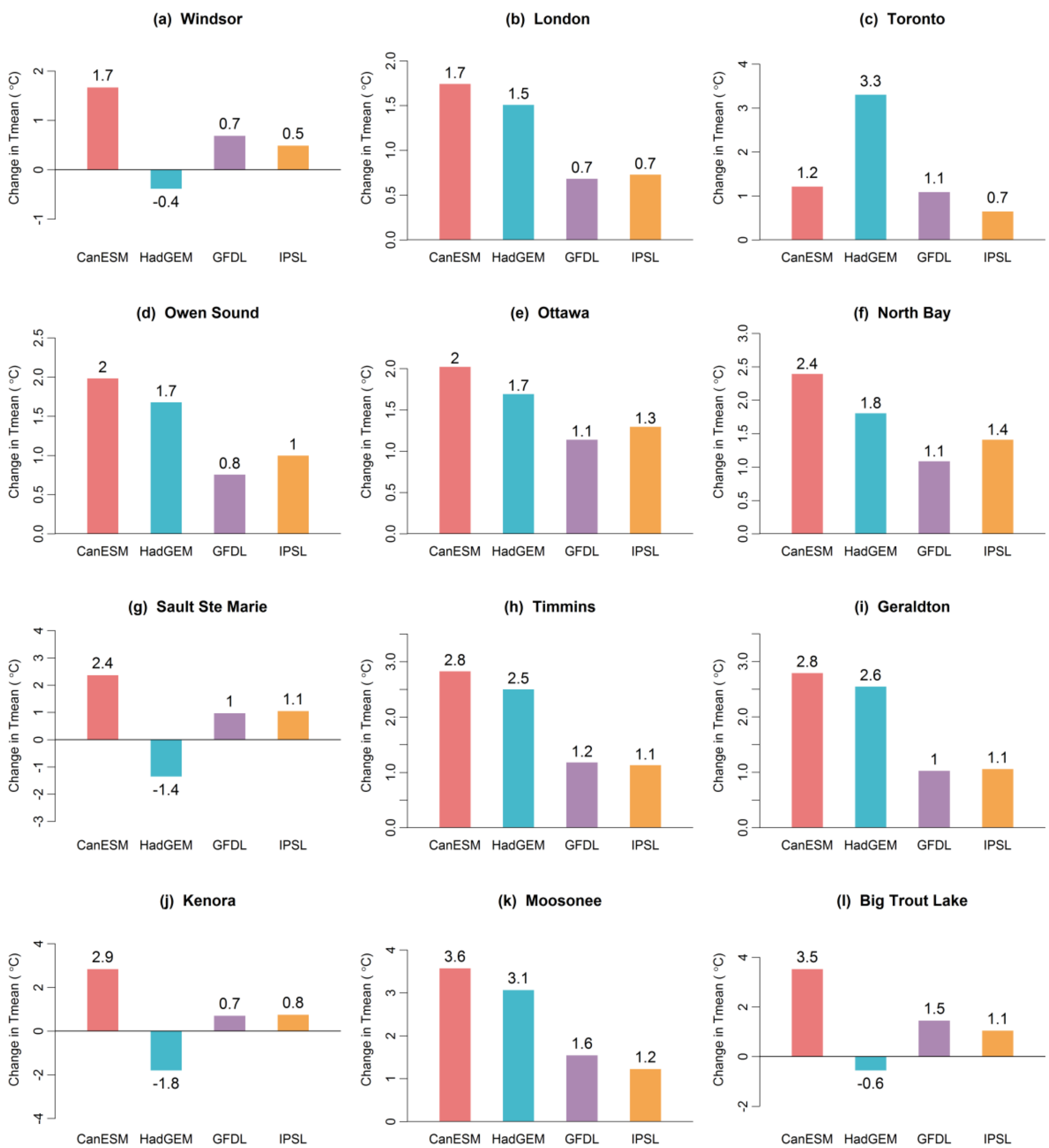

Figure 15. Changes in winter mean temperature in 2030s

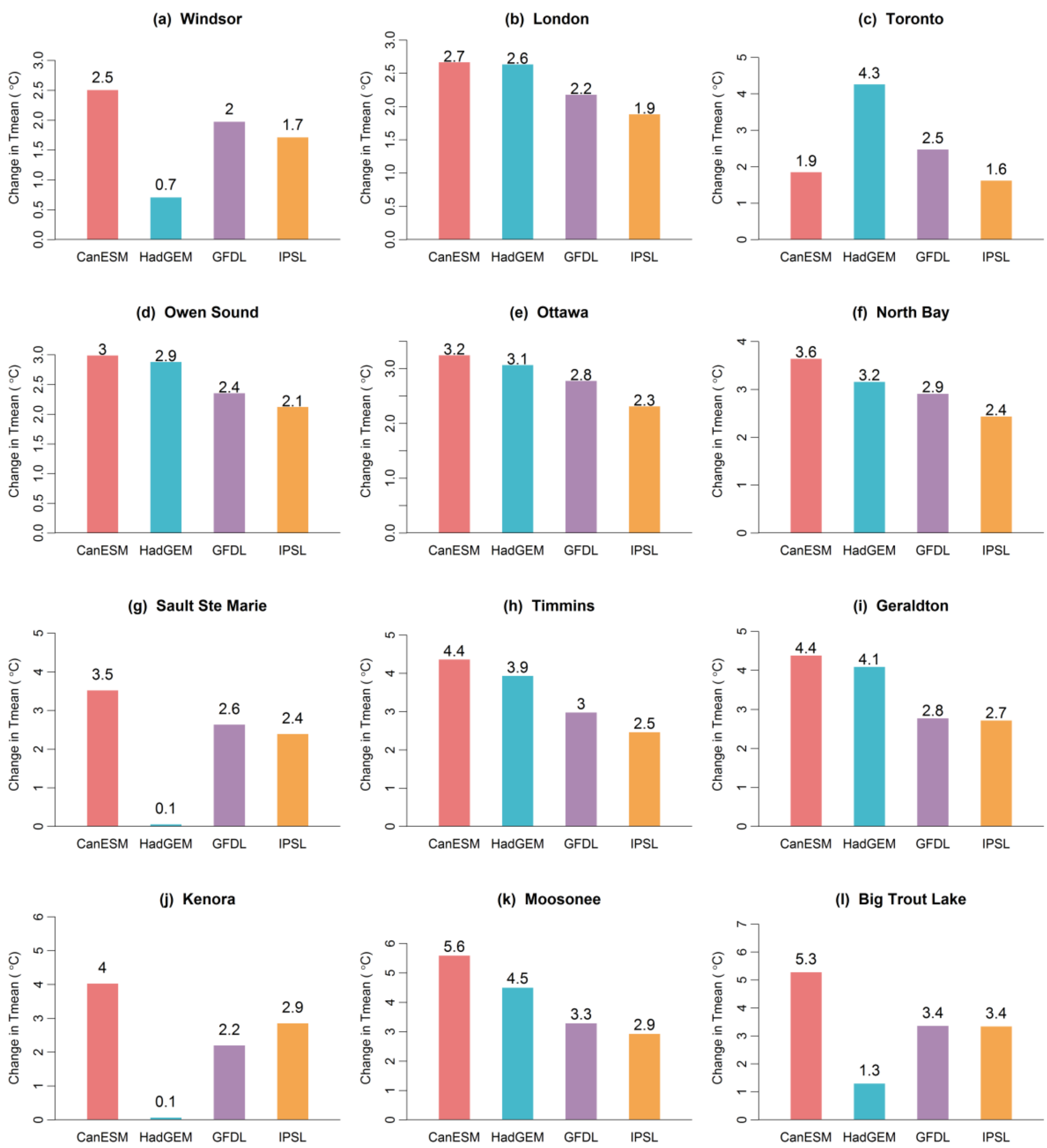

Figure 16. Changes in winter mean temperature in 2050s

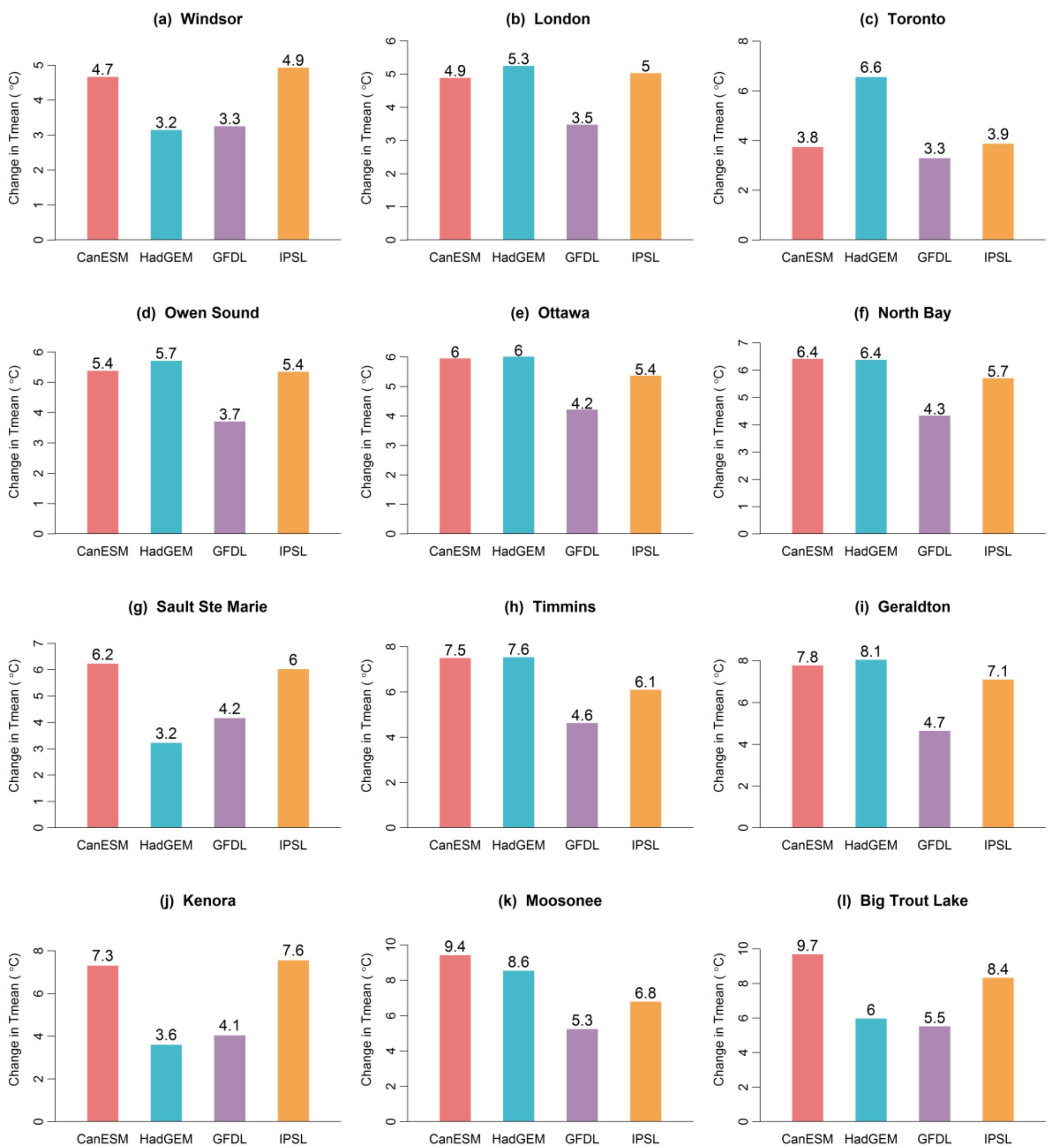

Figure 17. Changes in winter mean temperature in 2080s

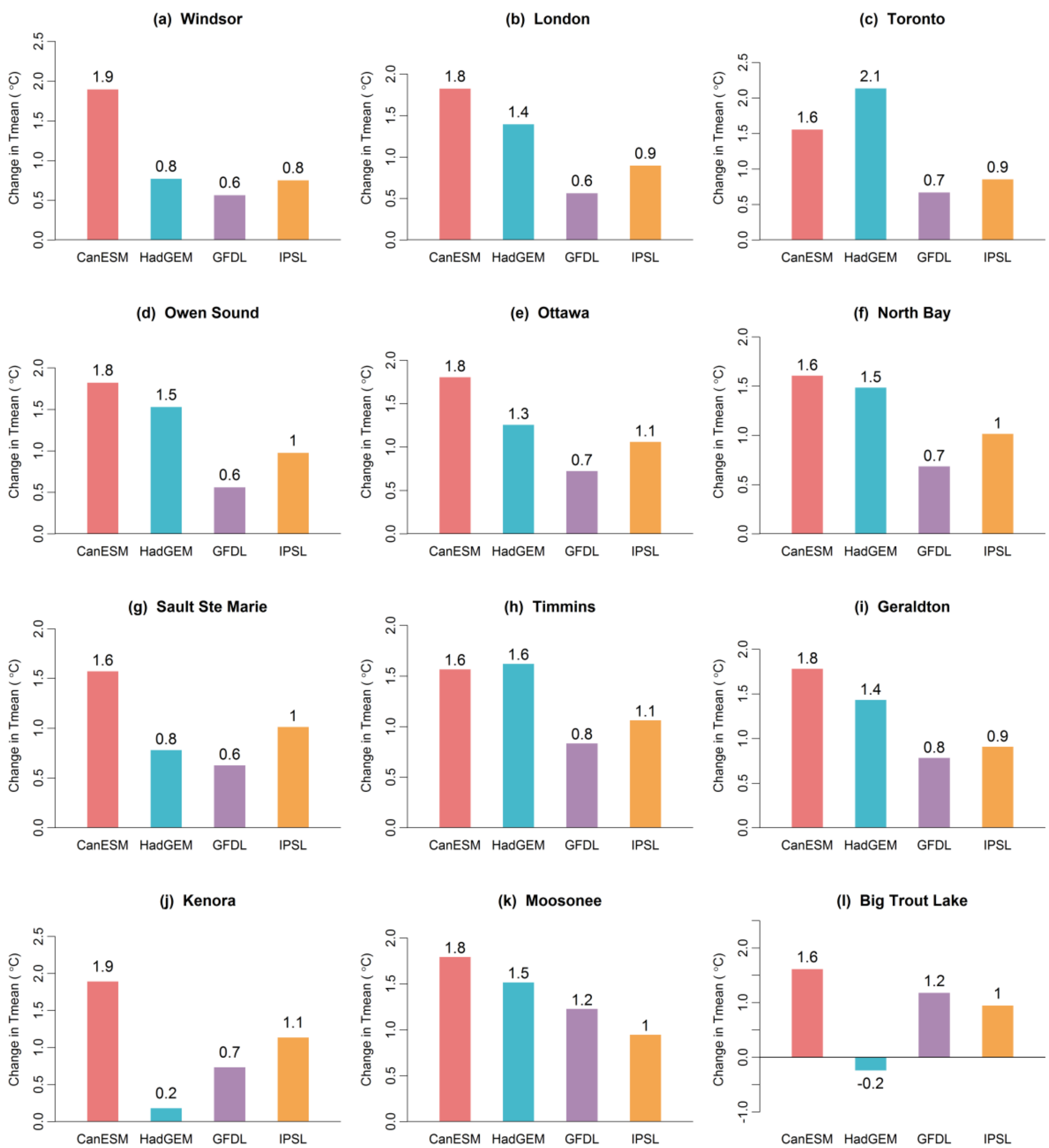

Figure 18. Changes in spring mean temperature in 2030s

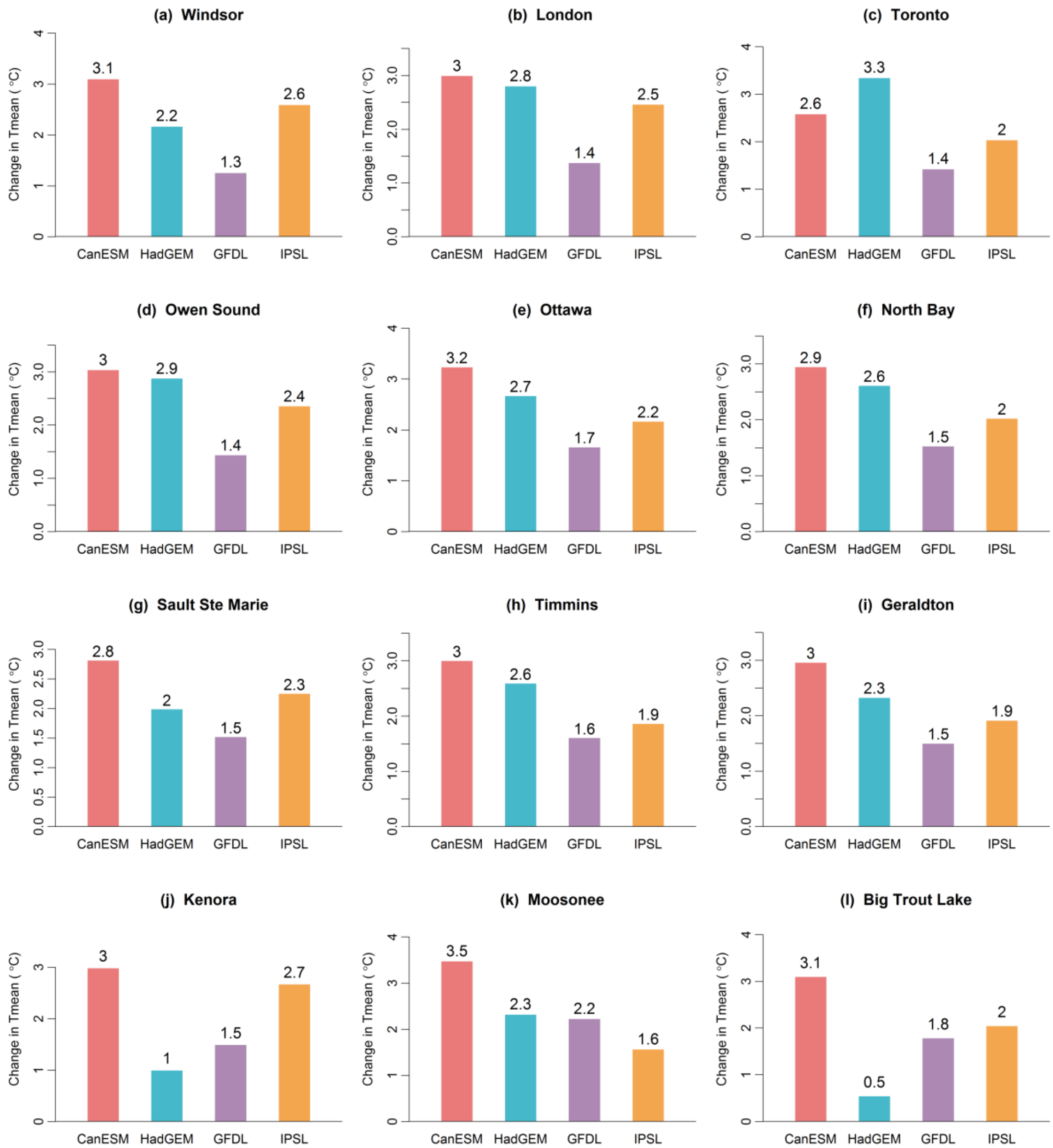

Figure 19. Changes in spring mean temperature in 2050s

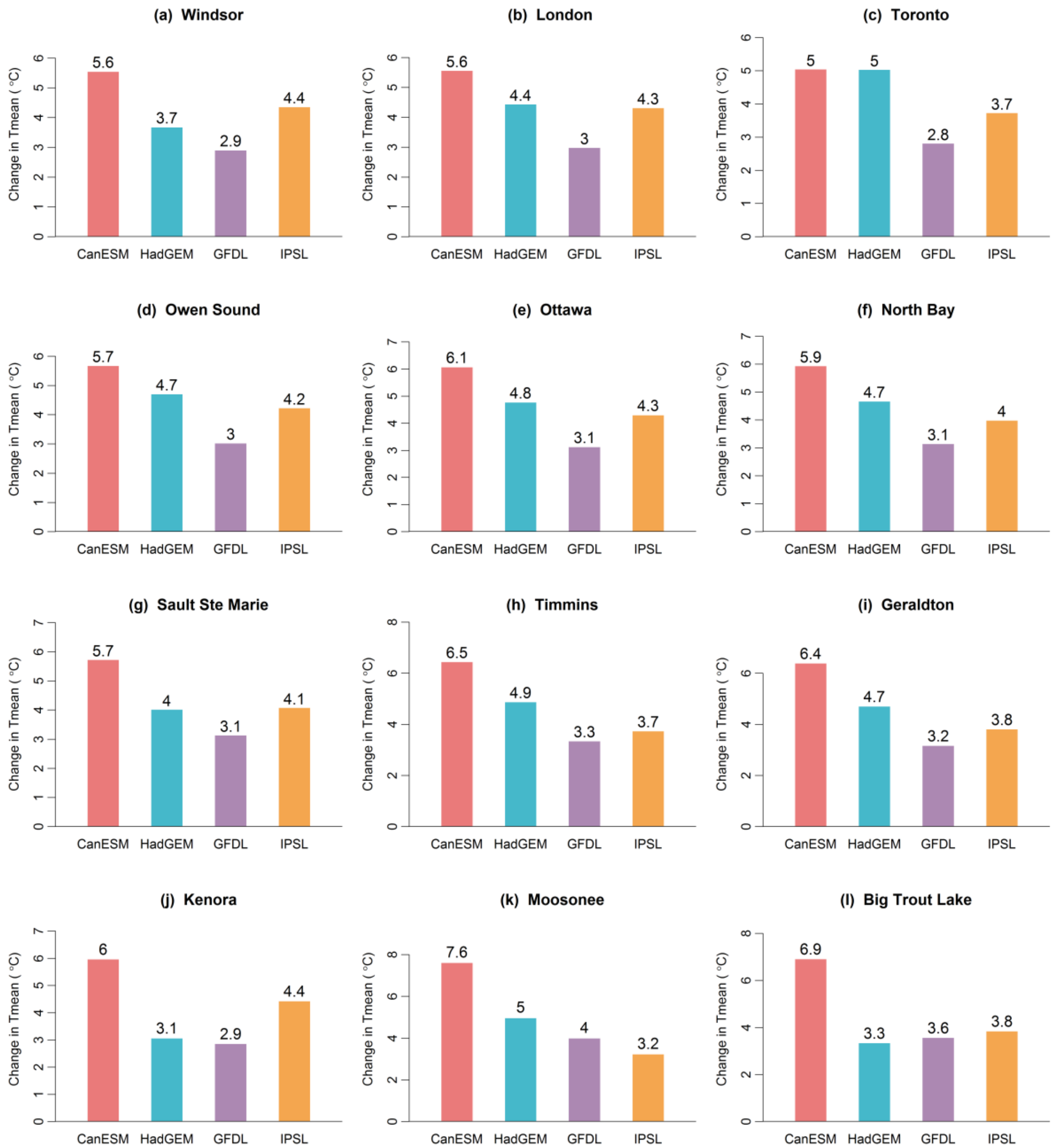

Figure 20. Changes in spring mean temperature in 2080s

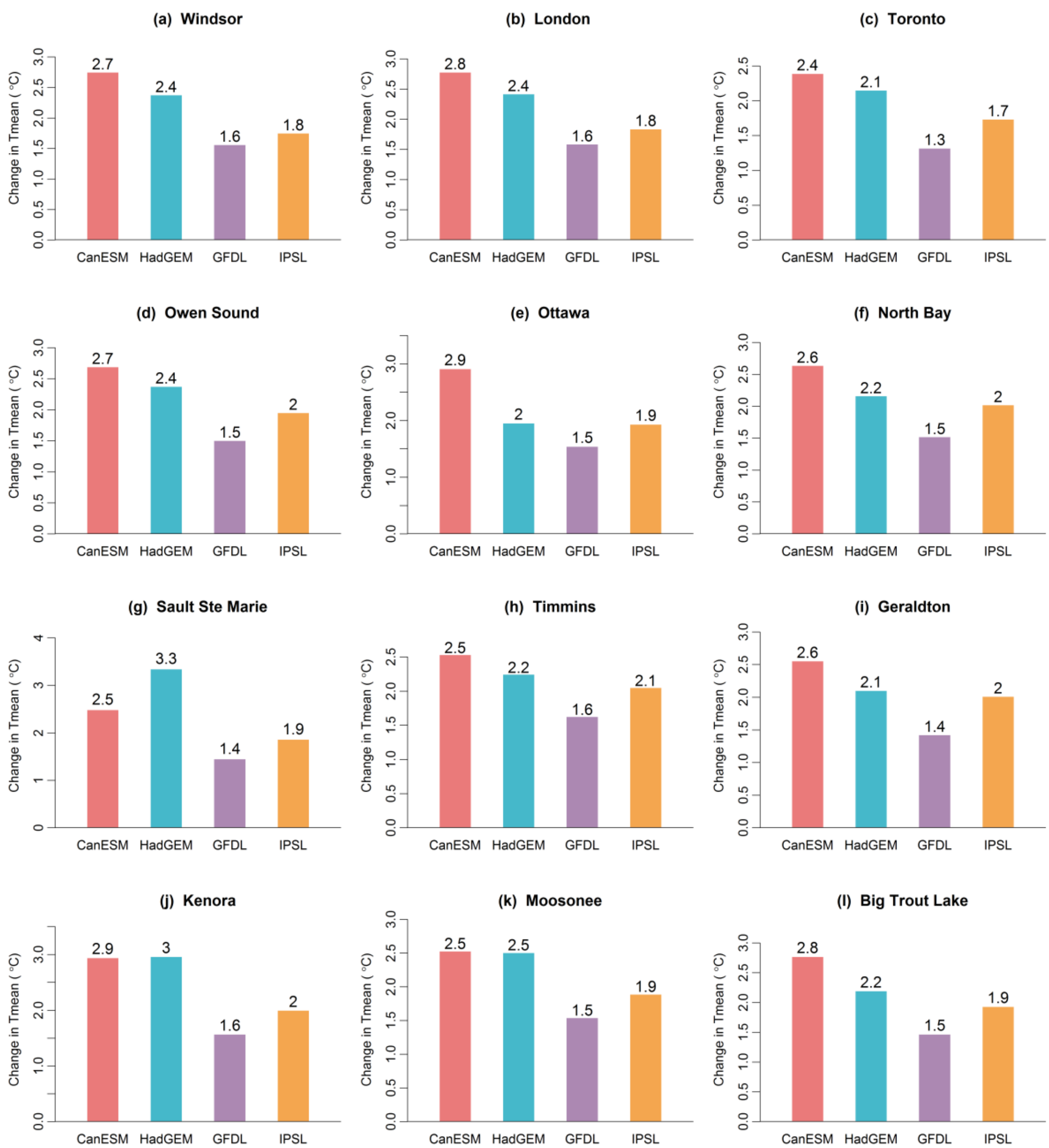

Figure 21. Changes in summer mean temperature in 2030s

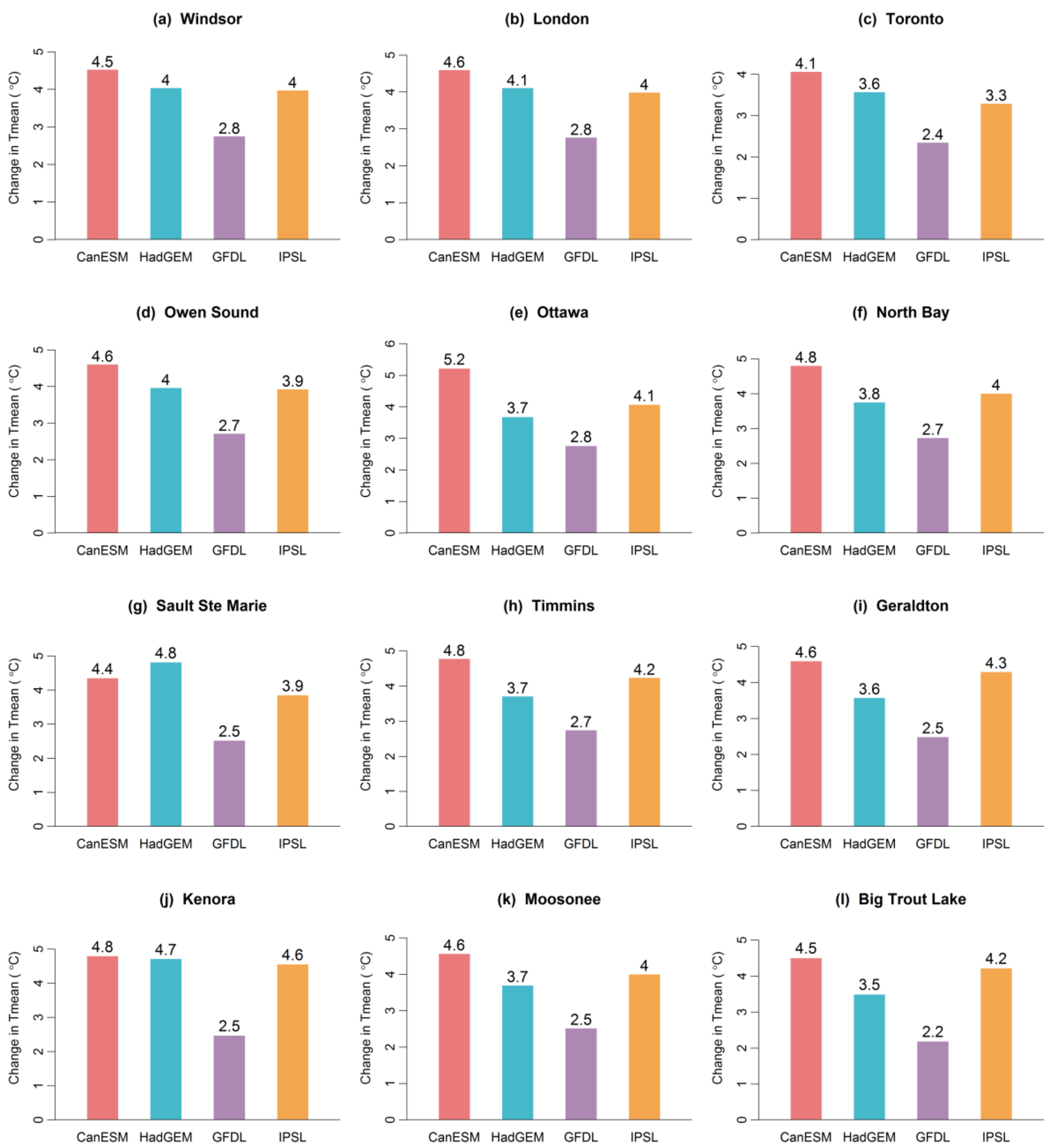

Figure 22. Changes in summer mean temperature in 2050s

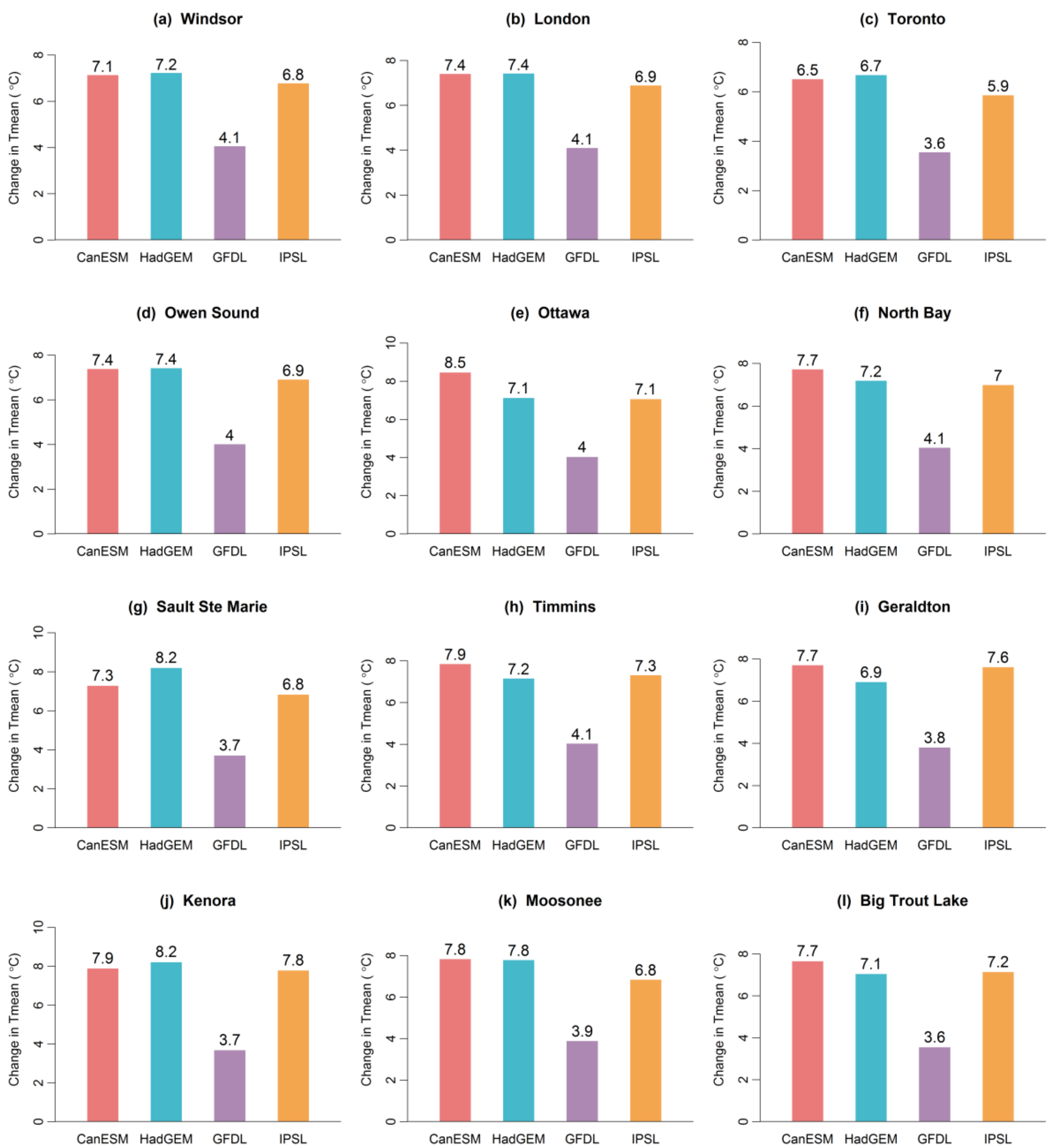

Figure 23. Changes in summer mean temperature in 2080s

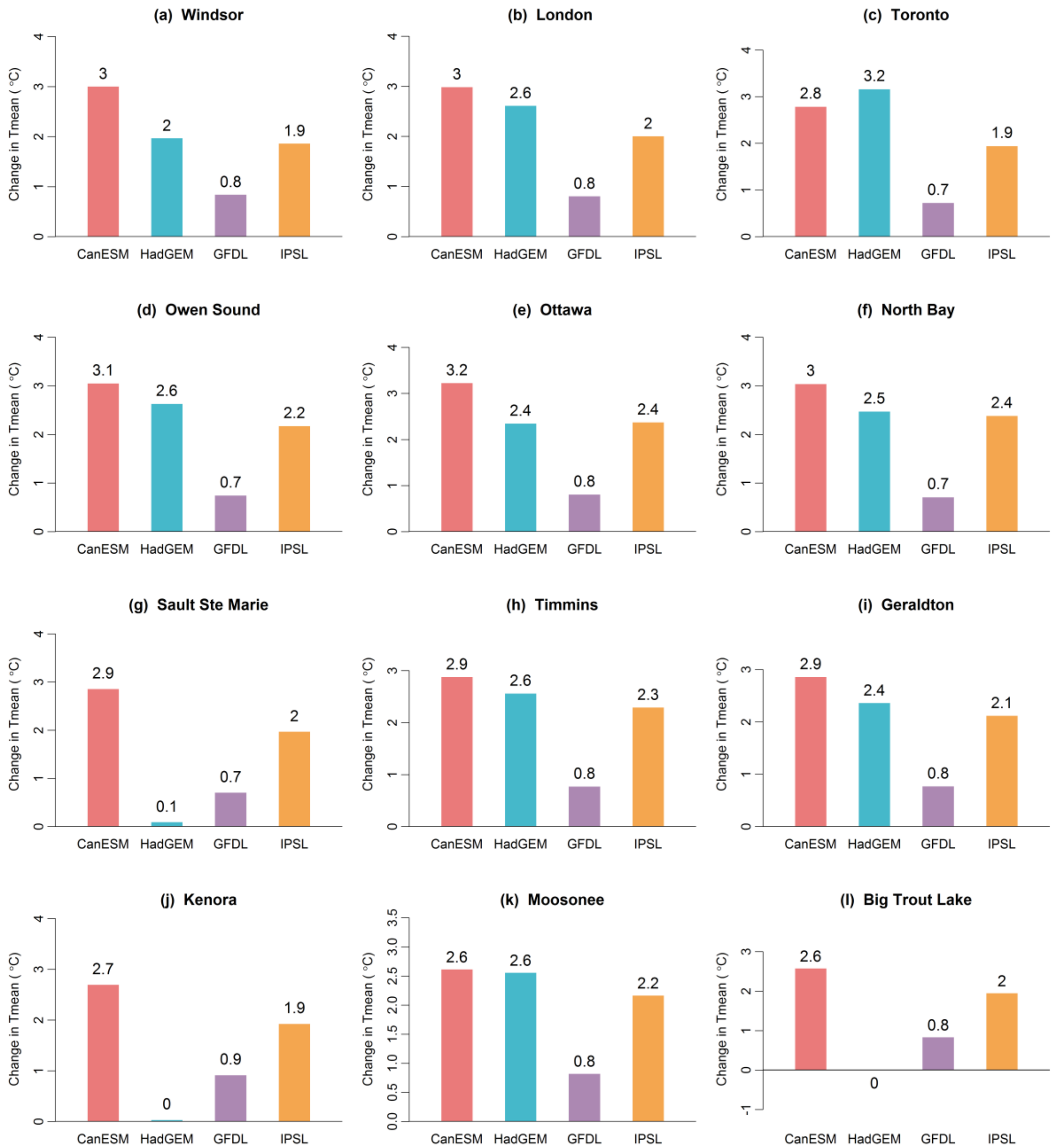

Figure 24. Changes in autumn mean temperature in 2030s

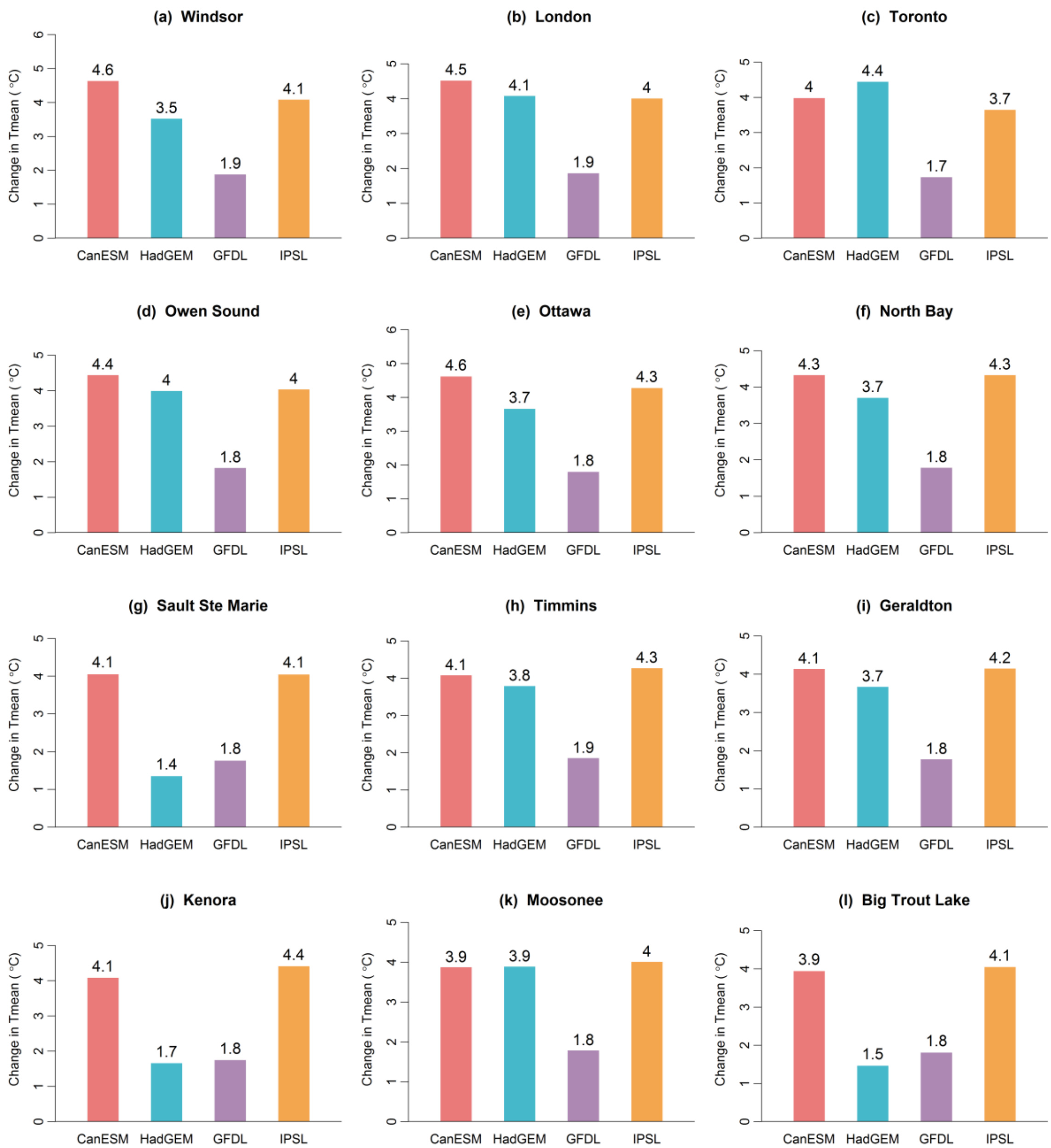

Figure 25. Changes in autumn mean temperature in 2050s

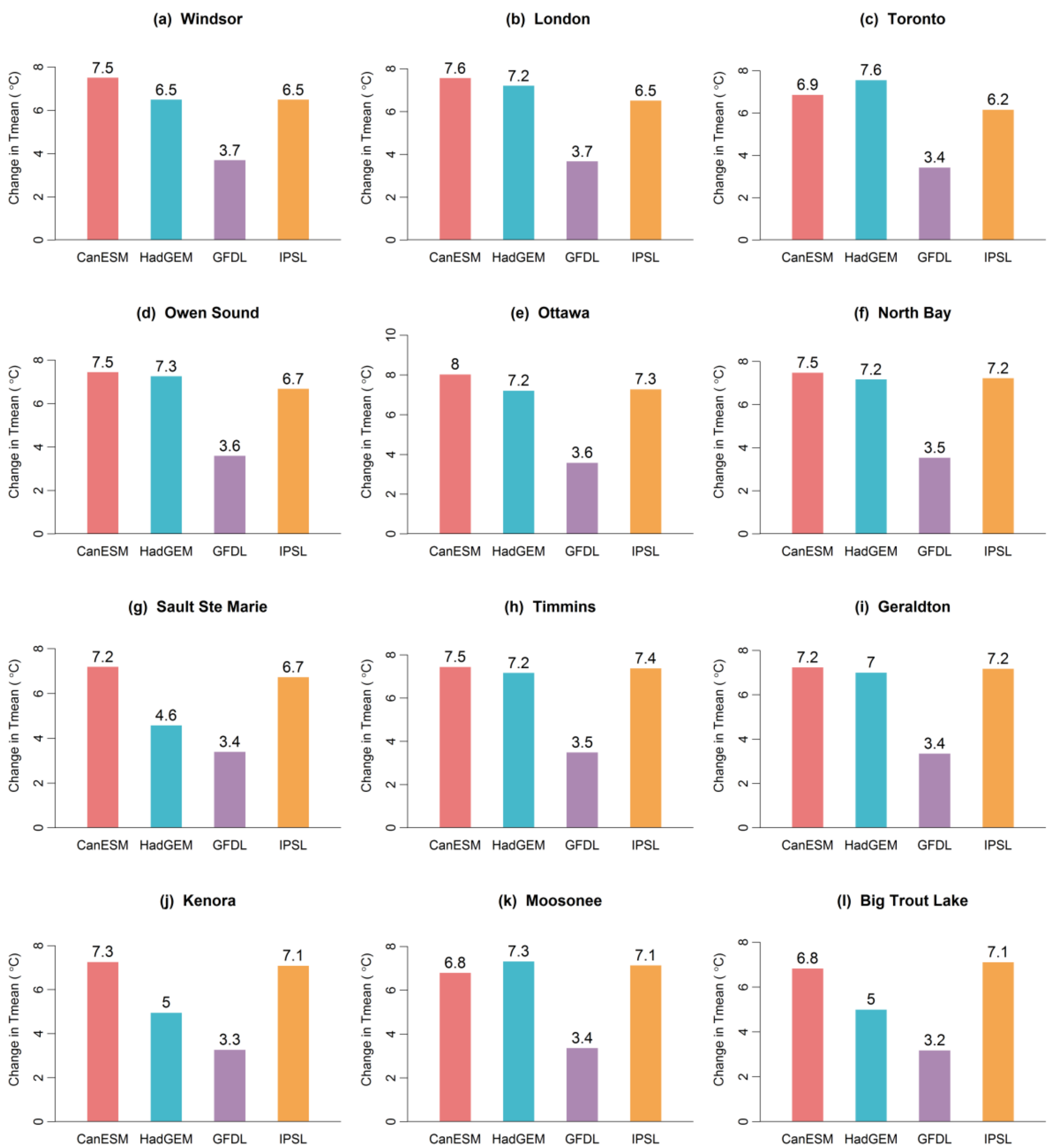

Figure 26. Changes in autumn mean temperature in 2080s

4.2 Changes in Maximum Temperature

This section presents the projected changes in annual and seasonal maximum temperature at twelve weather stations for three future periods: 2030s, 2050s, and 2080s. Figures 27-29 show the projected changes in annual maximum temperature by the four RegCM runs. It is apparent that all runs consistently demonstrate continuous increasing trends in annual maximum temperature throughout the 21^{st} century at all stations, although the magnitude of changes in annual maximum temperature projected by each model run is slightly different from others. Generally speaking, the greatest changes in annual maximum temperature are reported by the CanESM run, and the smallest changes are projected by the GFDL run, while the changes projected by the other two runs (i.e., HadGEM and IPSL) are slightly less than the changes projected by the CanESM run. For example, the change in annual maximum temperature in 2080s for the City of London simulated by the CanESM run is likely to be 6.4 °C, while the projected changes for the City of London in the same period by the HadGEM and IPSL runs are likely to be 6 °C and 5.5 °C, respectively. In comparison, the projected changes in annual maximum temperature at all stations by the GFDL run are relatively small. For example, the projected change in annual maximum temperature for the City of London in 2080s by the GFDL run is likely to be the 3.5 °C.

The projected changes in seasonal maximum temperature by the four RegCM runs for three future periods (i.e., 2030s, 2050s, and 2080s) are shown in Figures 30-41. Similar patterns among these four runs are also found for seasonal changes, although there are some slight variations for a few specific combinations of seasons and periods. Besides, the magnitude of changes in summer and autumn maximum temperature projected by the four runs seems to be slightly greater than those in winter and spring at most of the stations.

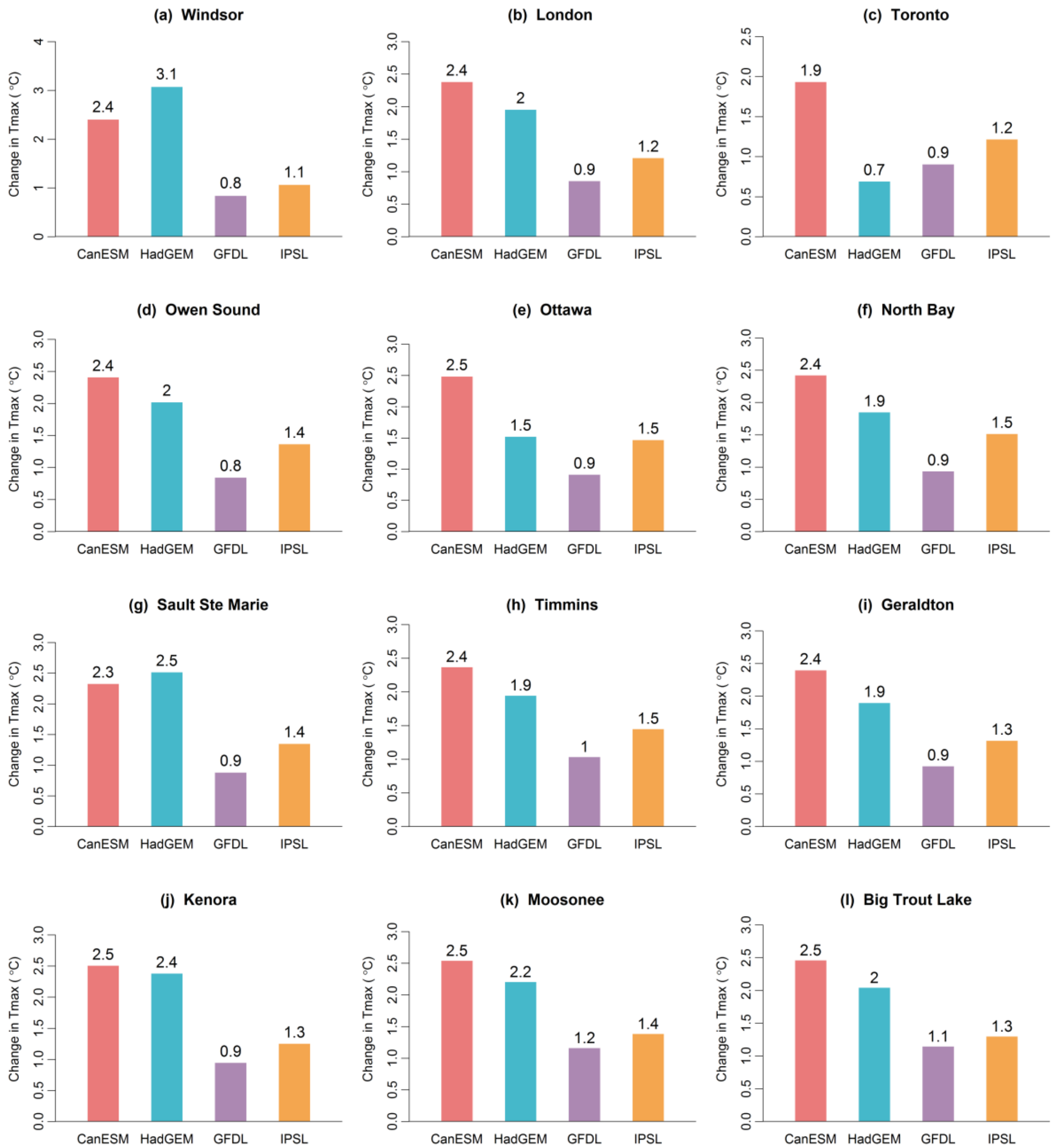

Figure 27. Changes in annual maximum temperature in 2030s

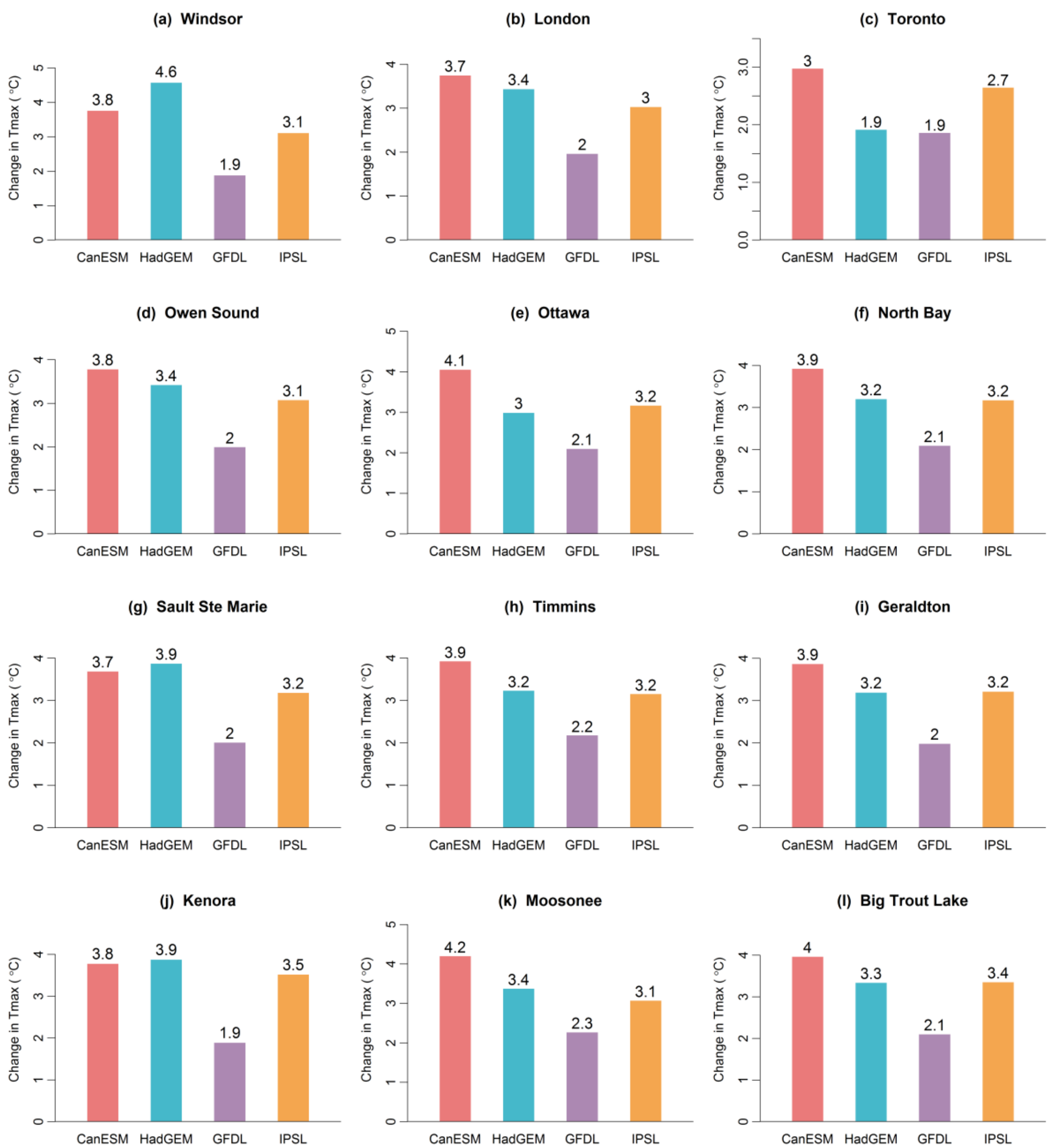

Figure 28. Changes in annual maximum temperature in 2050s

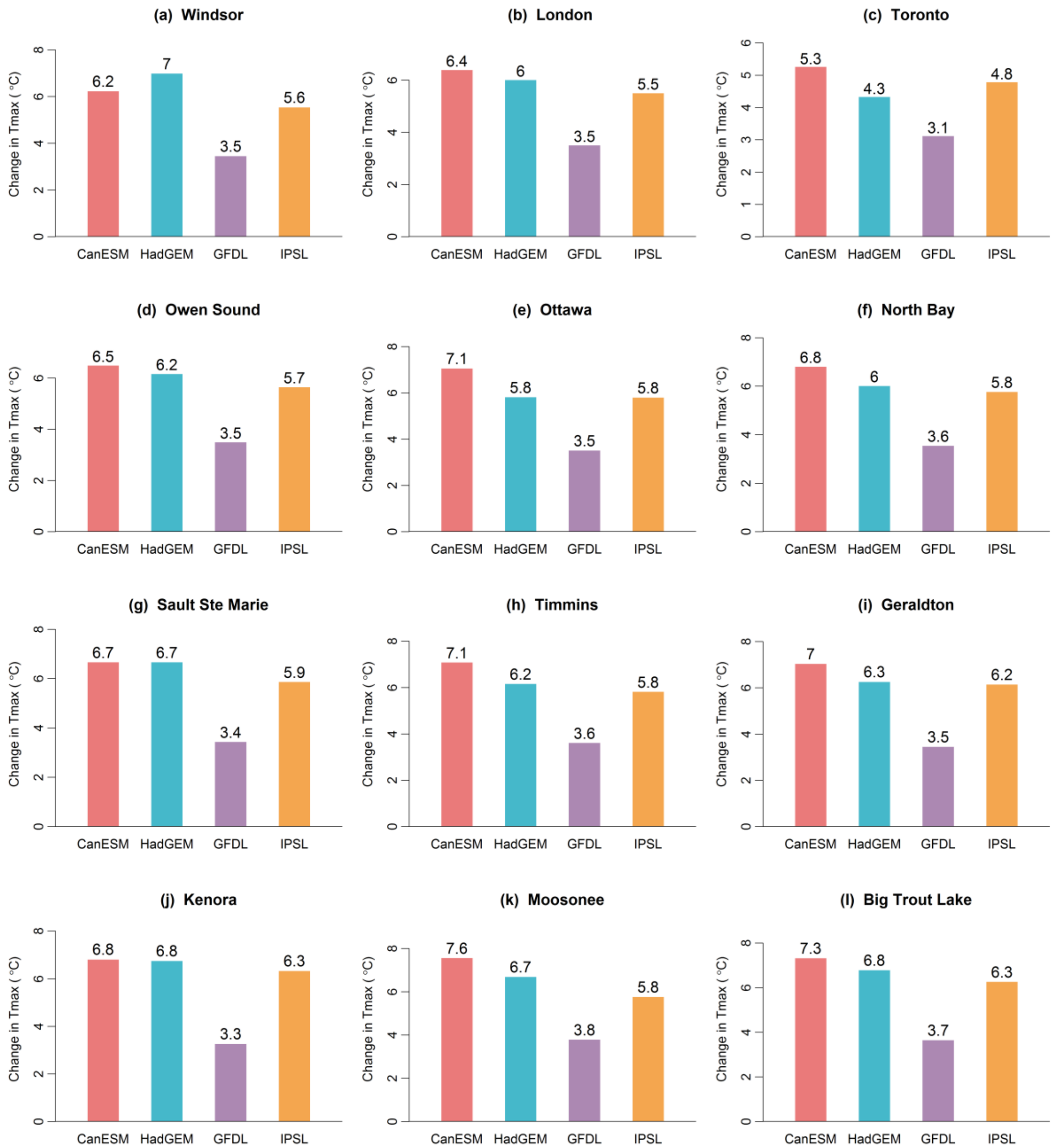

Figure 29. Changes in annual maximum temperature in 2080s

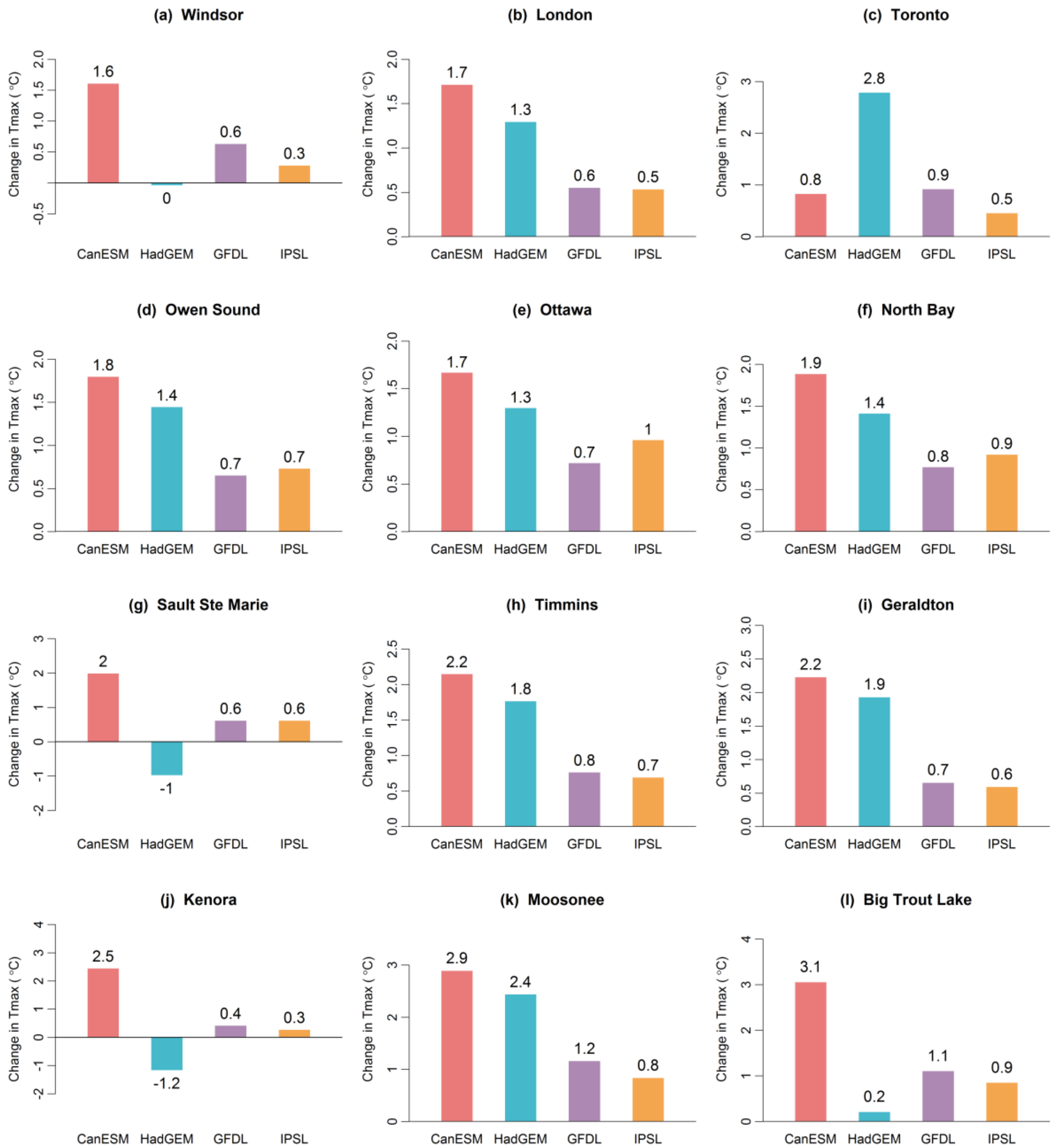

Figure 30. Changes in winter maximum temperature in 2030s

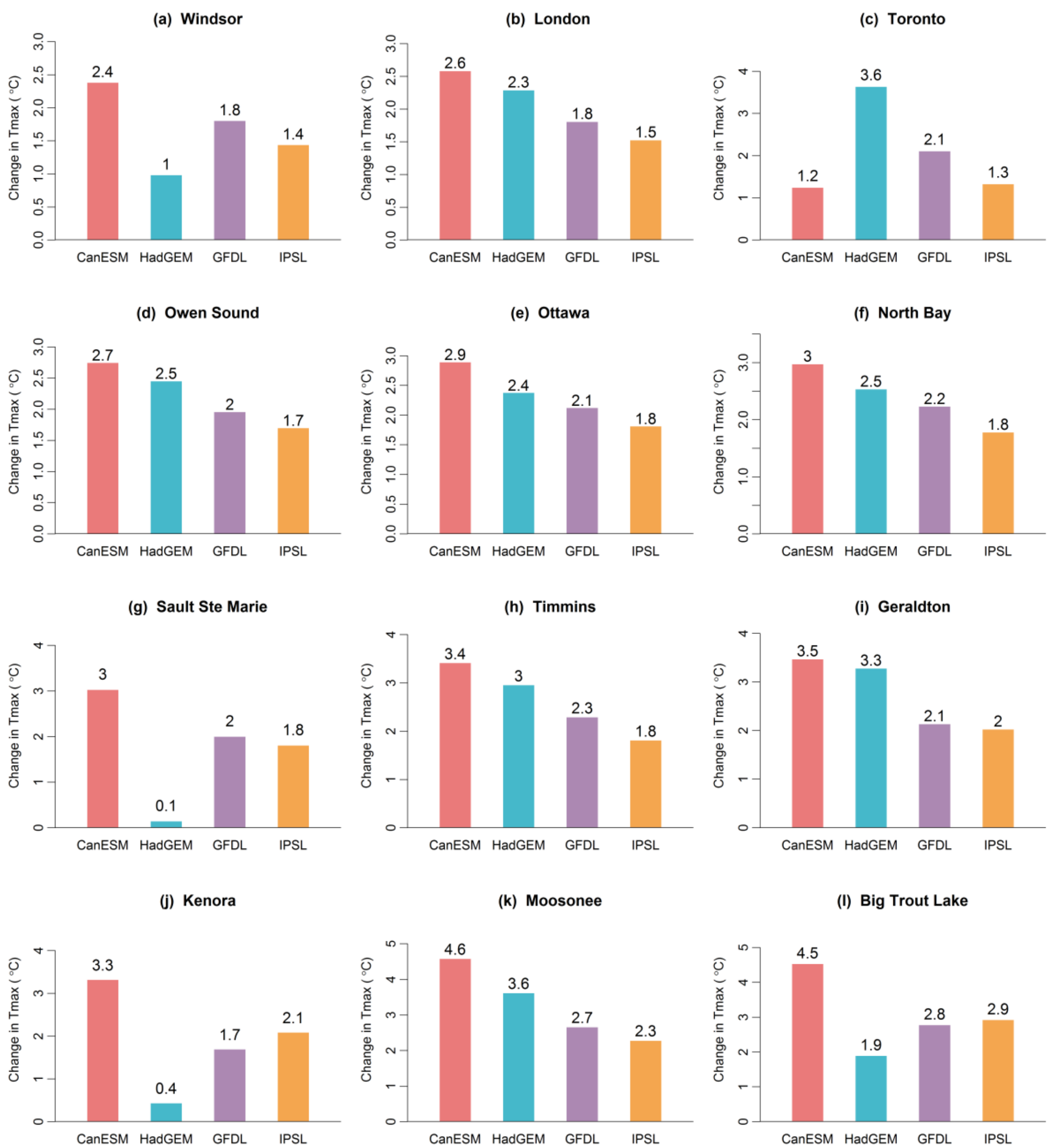

Figure 31. Changes in winter maximum temperature in 2050s

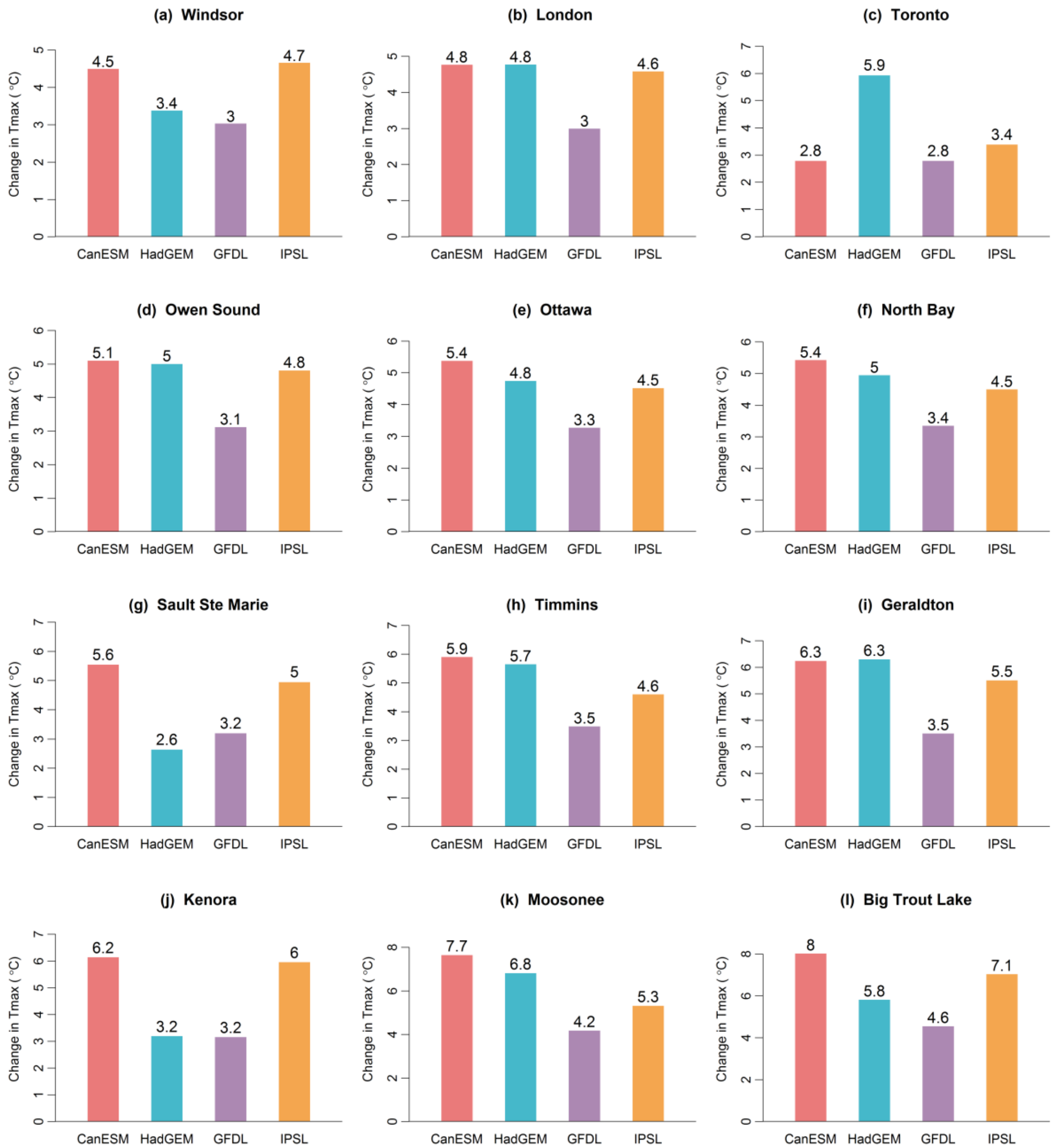

Figure 32. Changes in winter maximum temperature in 2080s

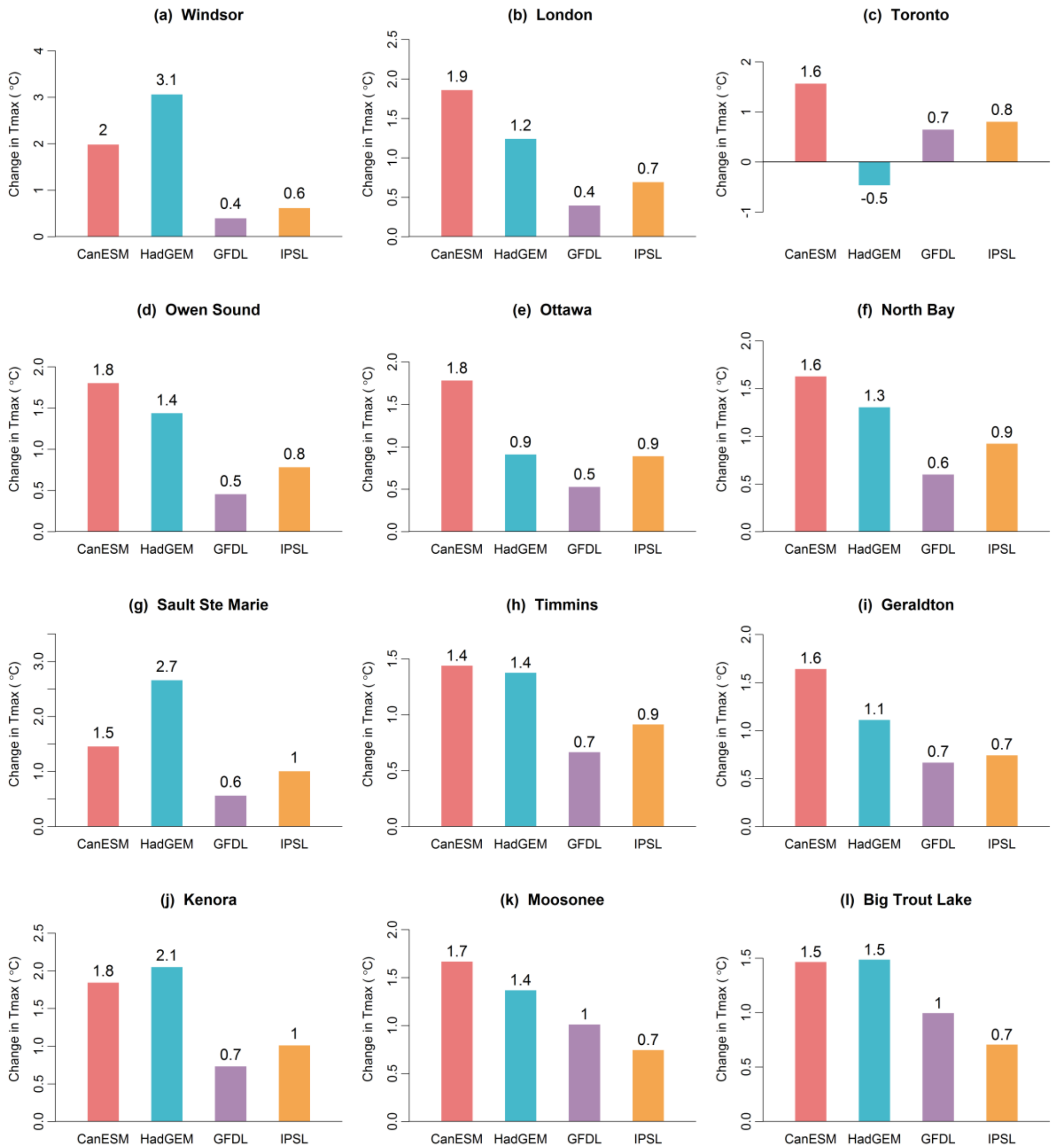

Figure 33. Changes in spring maximum temperature in 2030s

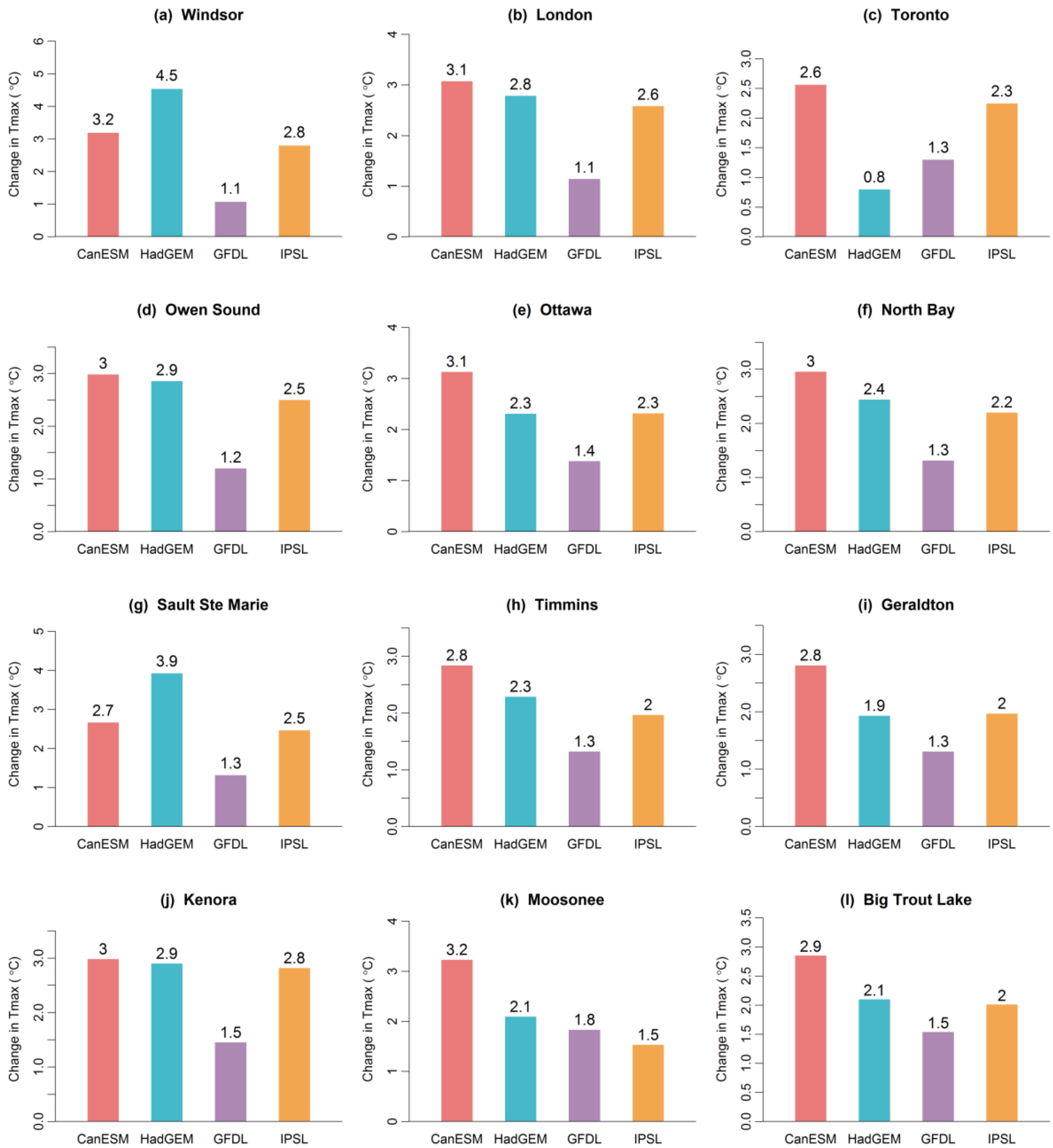

Figure 34. Changes in spring maximum temperature in 2050s

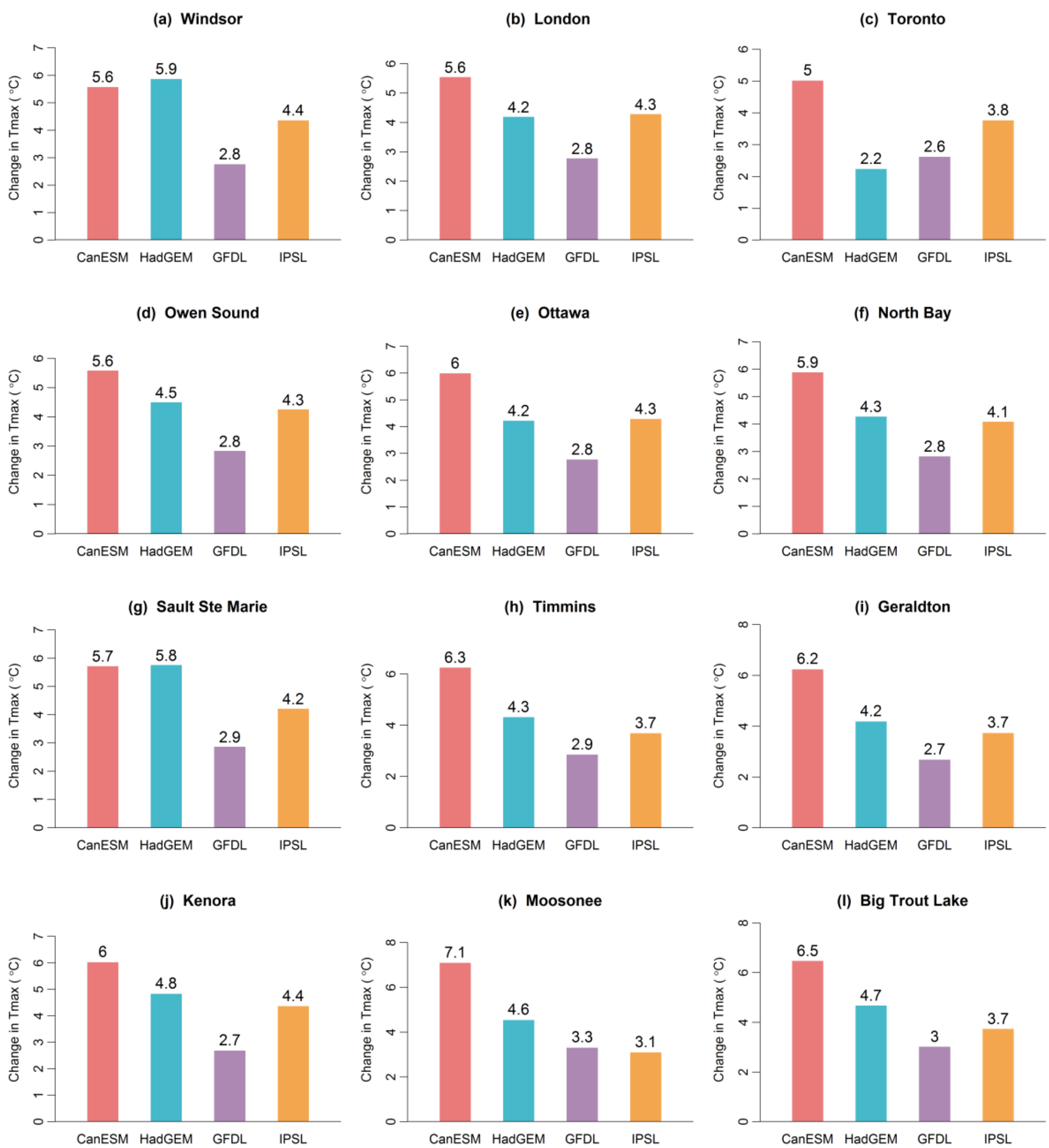

Figure 35. Changes in spring maximum temperature in 2080s

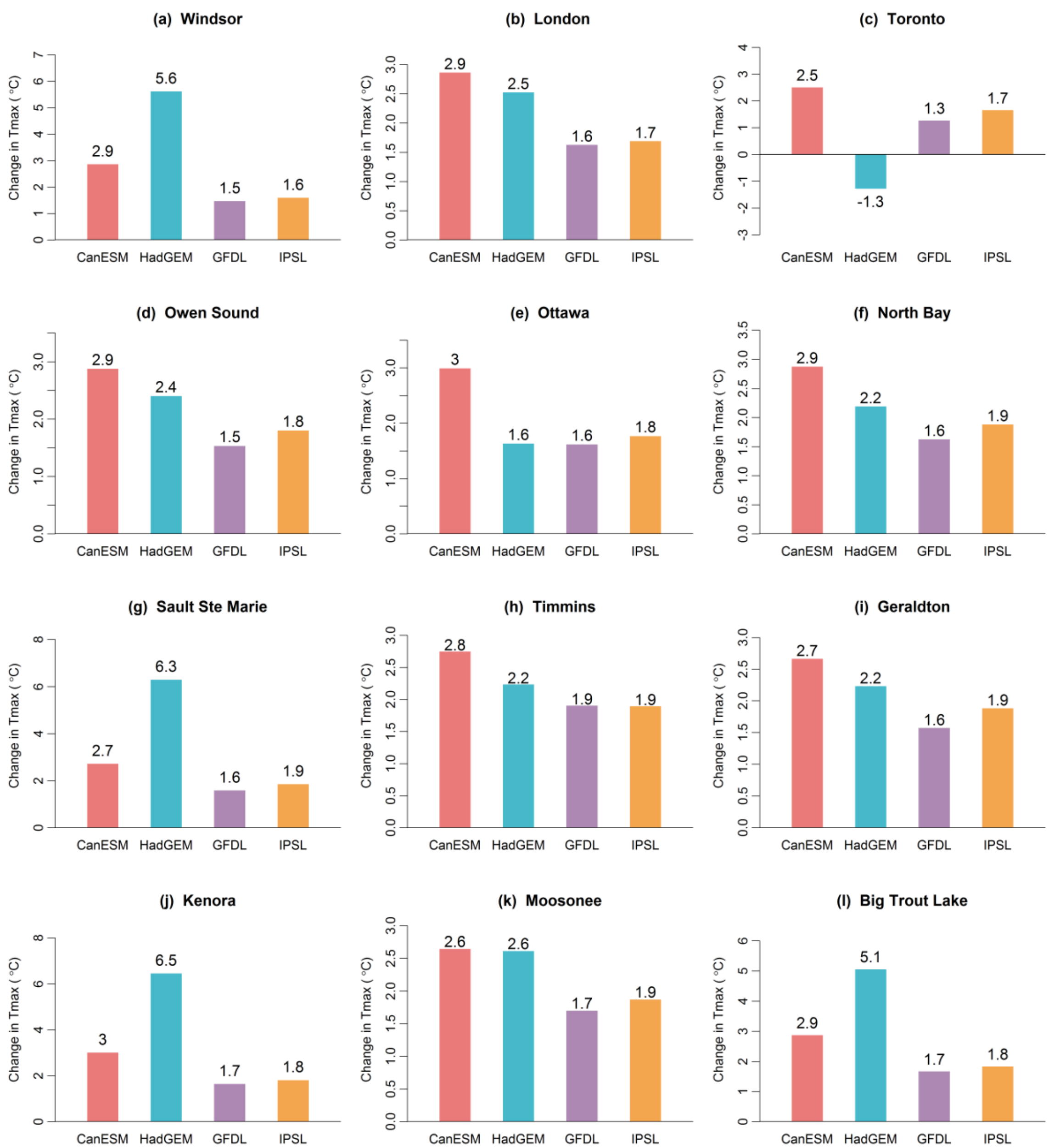

Figure 36. Changes in summer maximum temperature in 2030s

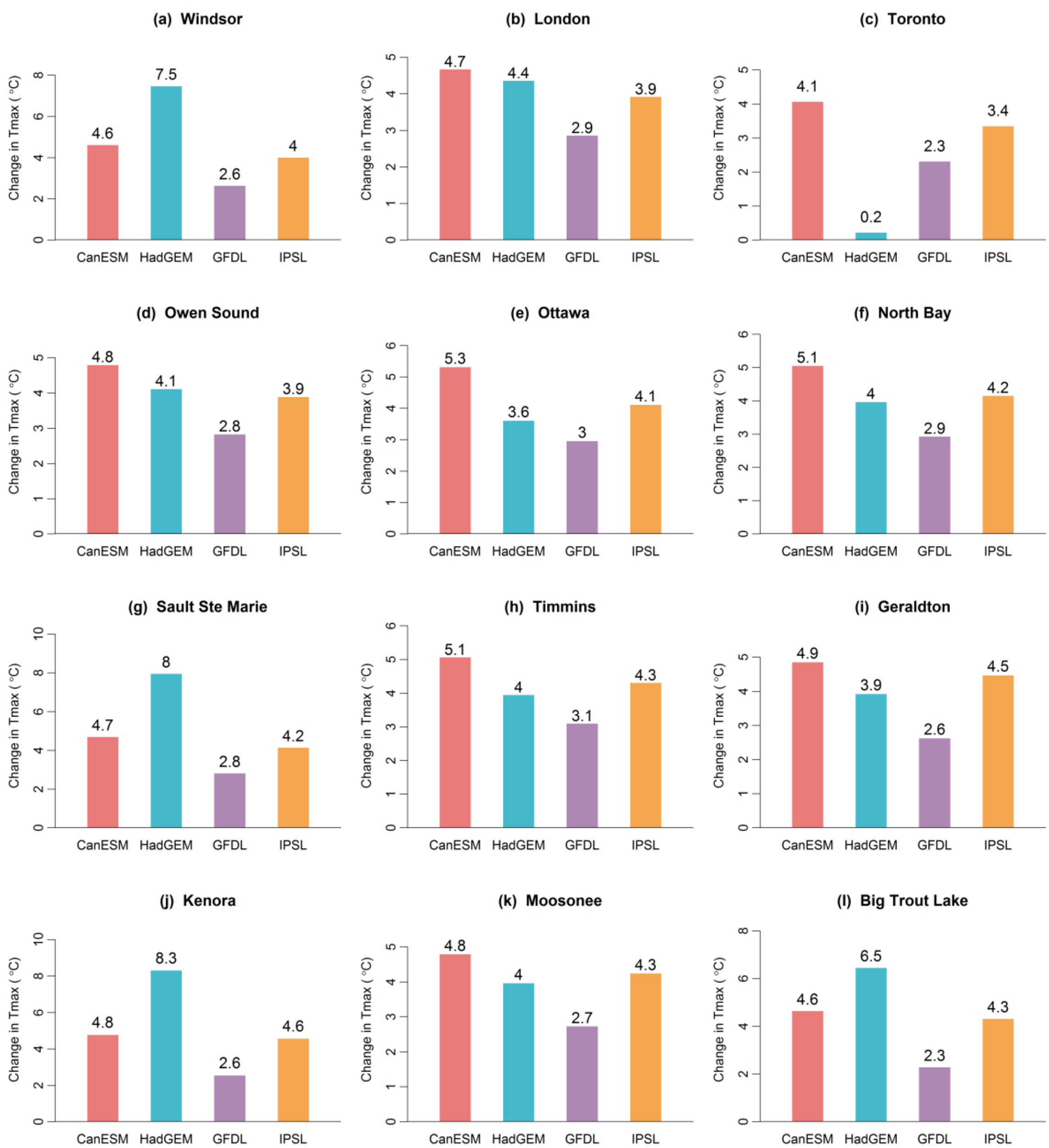

Figure 37. Changes in summer maximum temperature in 2050s

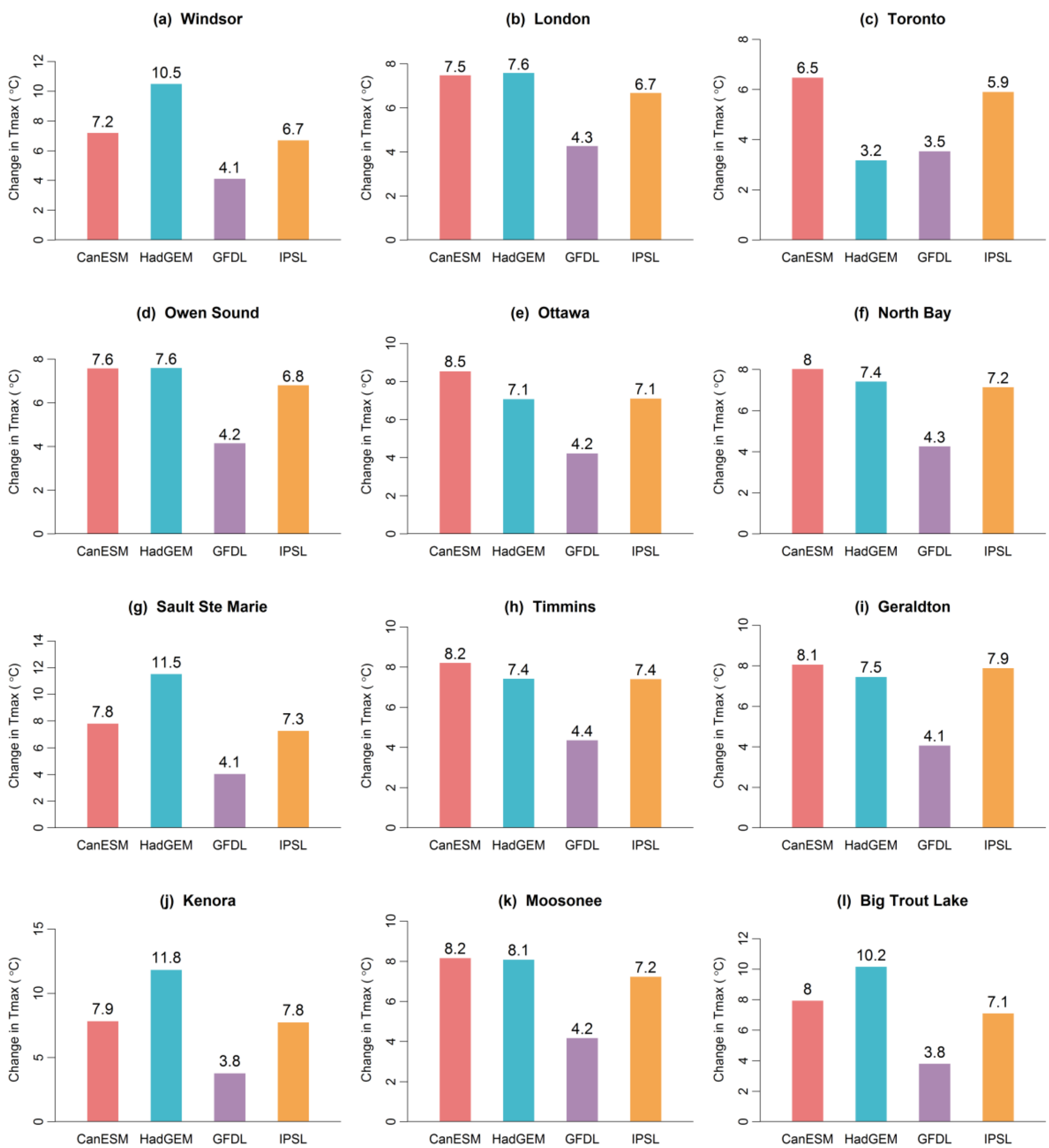

Figure 38. Changes in summer maximum temperature in 2080s

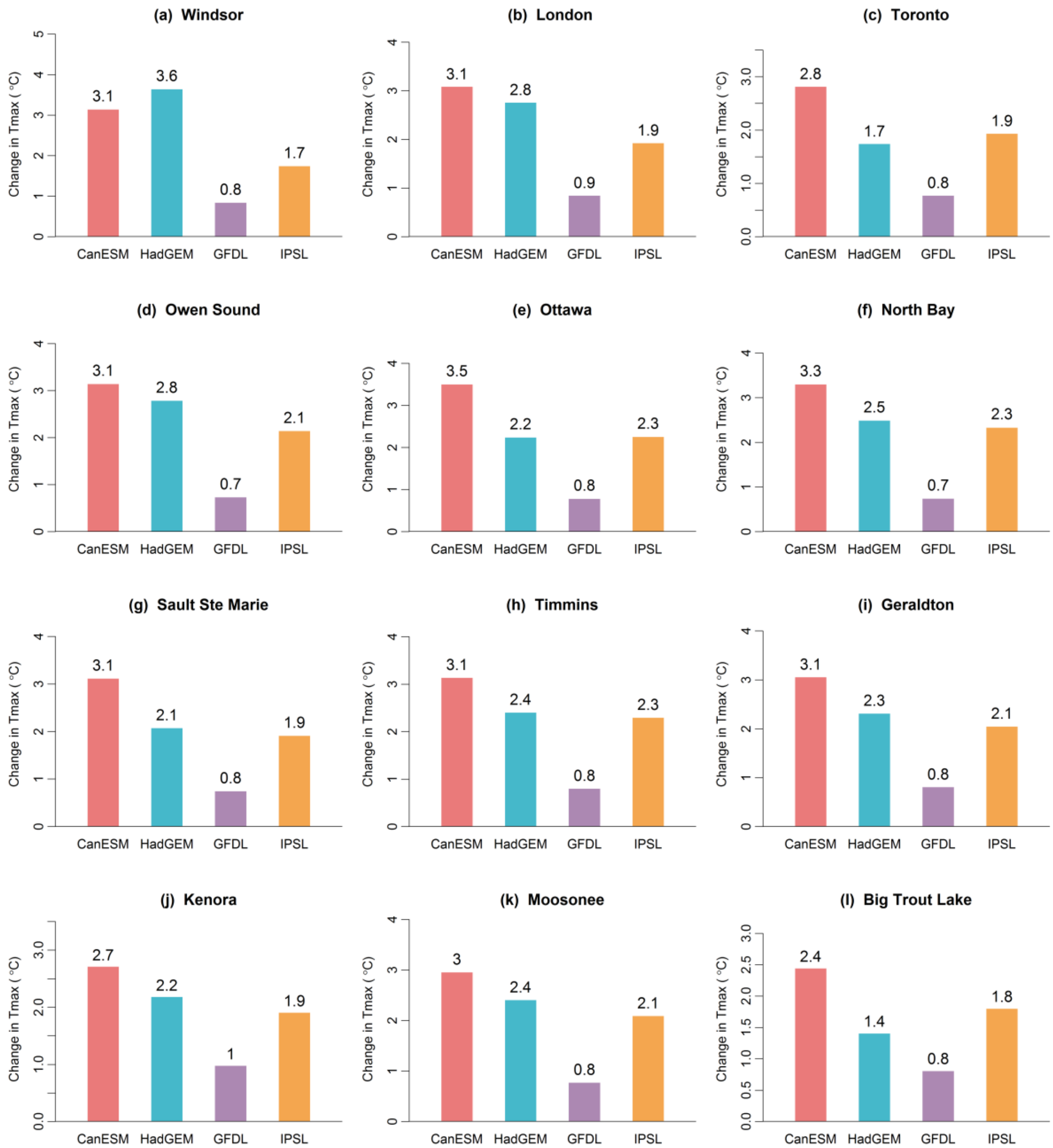

Figure 39. Changes in autumn maximum temperature in 2030s

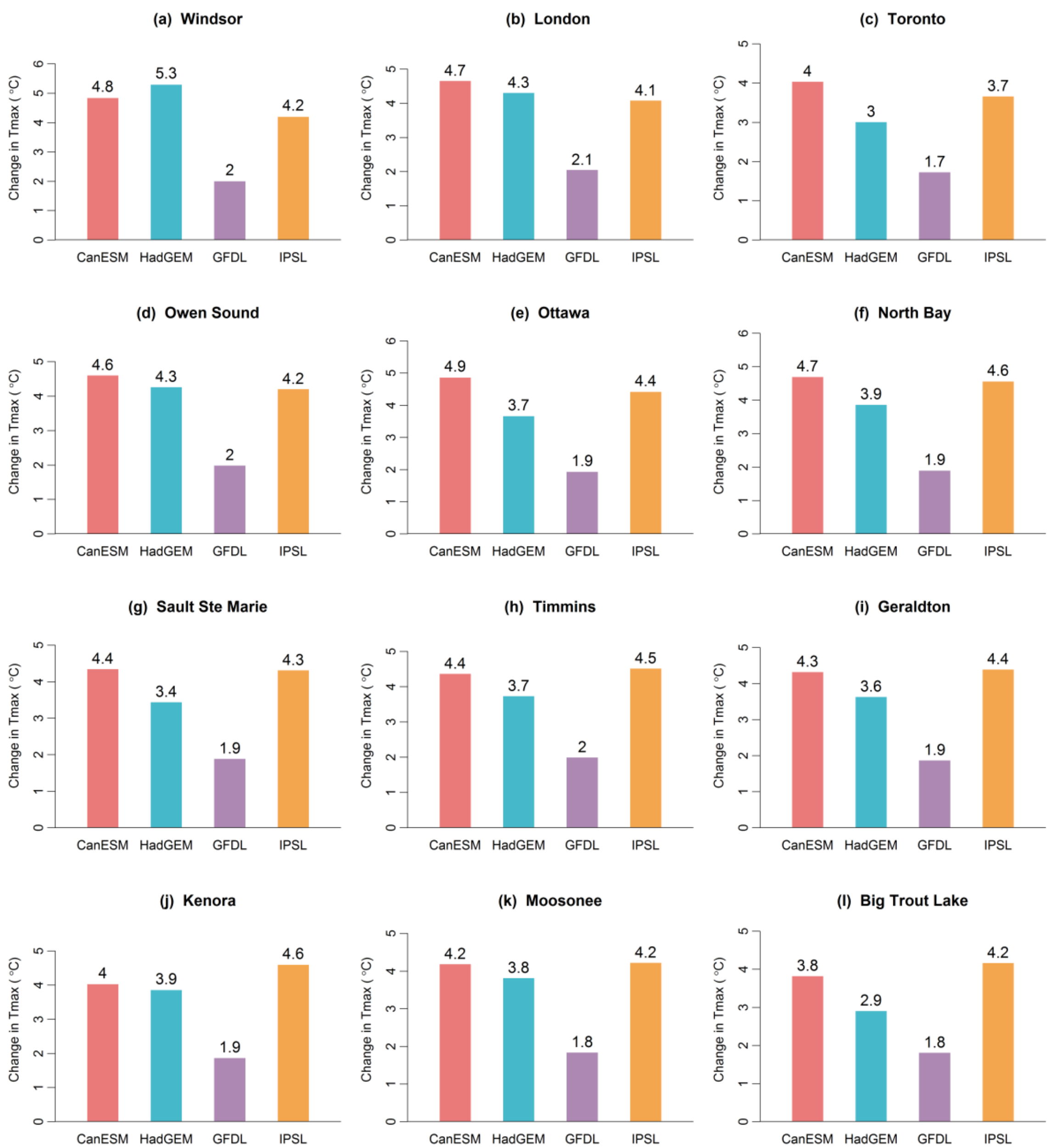

Figure 40. Changes in autumn maximum temperature in 2050s

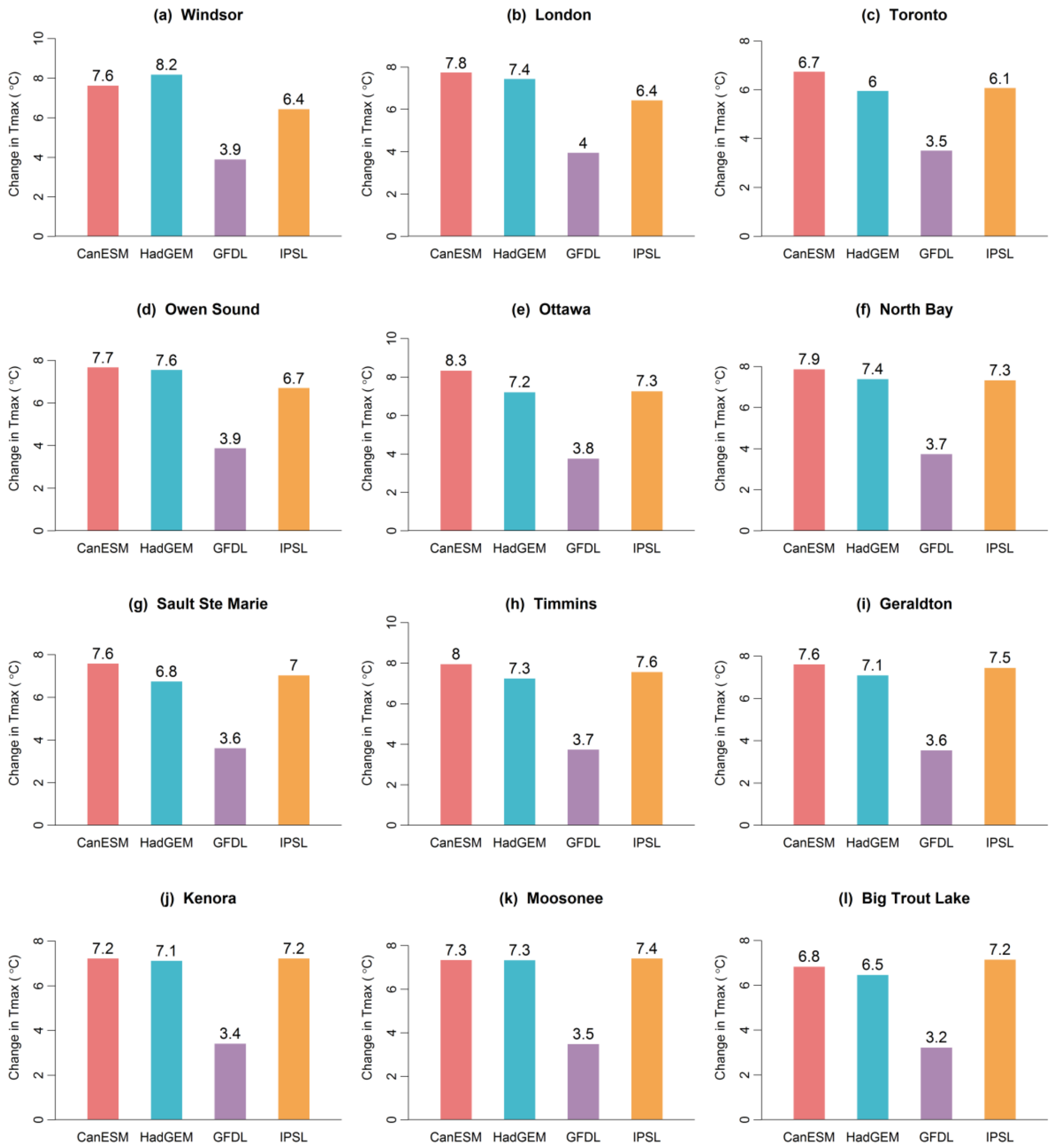

Figure 41. Changes in autumn maximum temperature in 2080s

4.3 Changes in Minimum Temperature

This section presents the projected changes in annual and seasonal minimum temperature at twelve weather stations for three future periods: 2030s, 2050s, and 2080s. Figures 42-44 show the projected changes in annual minimum temperature by the four RegCM runs. It is apparent that all runs consistently demonstrate continuous increasing trends in annual minimum temperature throughout the 21st century at all stations, although the magnitude of changes in annual minimum temperature projected by each model run is slightly different from others. Generally speaking, the greatest changes in annual minimum temperature are reported by the CanESM run, and the smallest changes are projected by the GFDL run, while the changes projected by the other two runs (i.e., HadGEM and IPSL) are slightly less than the changes projected by the CanESM run. For example, the change in annual minimum temperature in 2080s for the City of London simulated by the CanESM run is likely to be 6.4 °C, while the projected changes for the City of London in the same period by the HadGEM and IPSL runs are likely to be 6.2 °C and 5.9 °C, respectively. In comparison, the projected changes in annual minimum temperature at all stations by the GFDL run are relatively small. For example, the projected change in annual minimum temperature for the City of London in 2080s by the GFDL run is likely to be the 3.7 °C.

The projected changes in seasonal minimum temperature by the four RegCM runs for three future periods (i.e., 2030s, 2050s, and 2080s) are shown in Figures 30-41. Similar patterns among these four runs are also found for seasonal changes, although there are some slight variations for a few specific combinations of seasons and periods. Besides, the magnitude of changes in winter minimum temperature projected by the four runs seems to be apparently greater than those in other seasons (i.e., spring, summer, and autumn) at most of the stations.

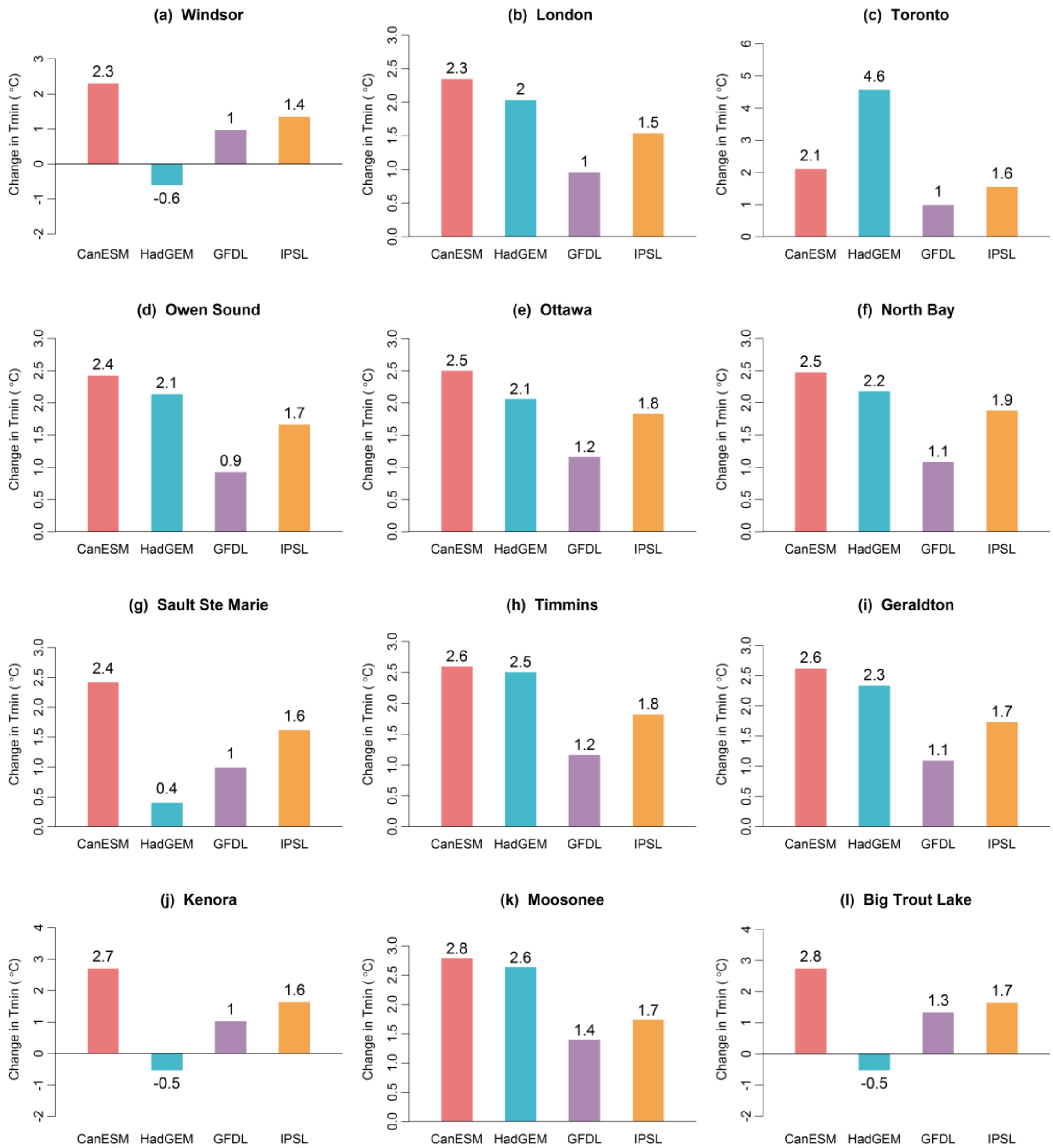

Figure 42. Changes in annual minimum temperature in 2030s

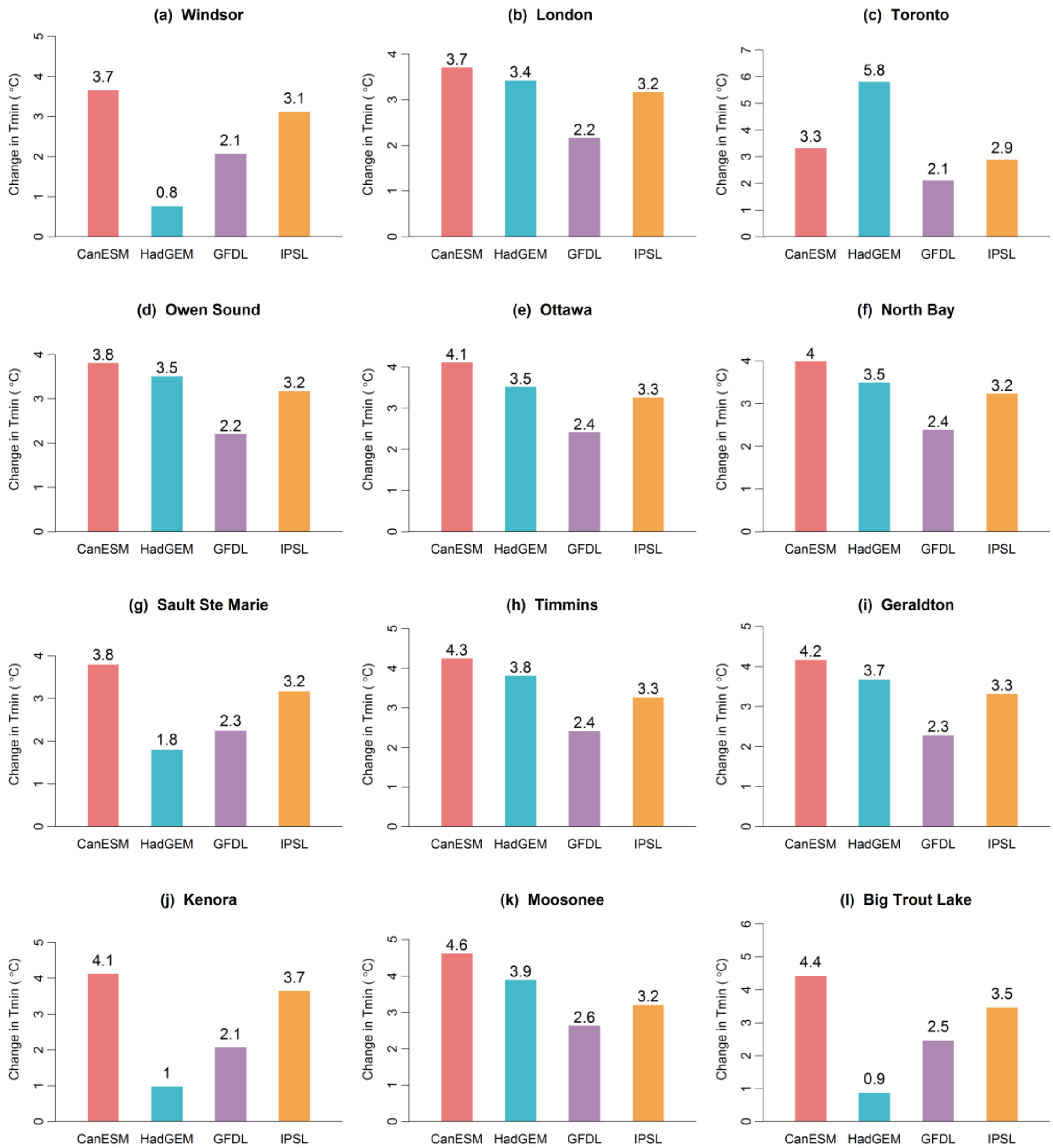

Figure 43. Changes in annual minimum temperature in 2050s

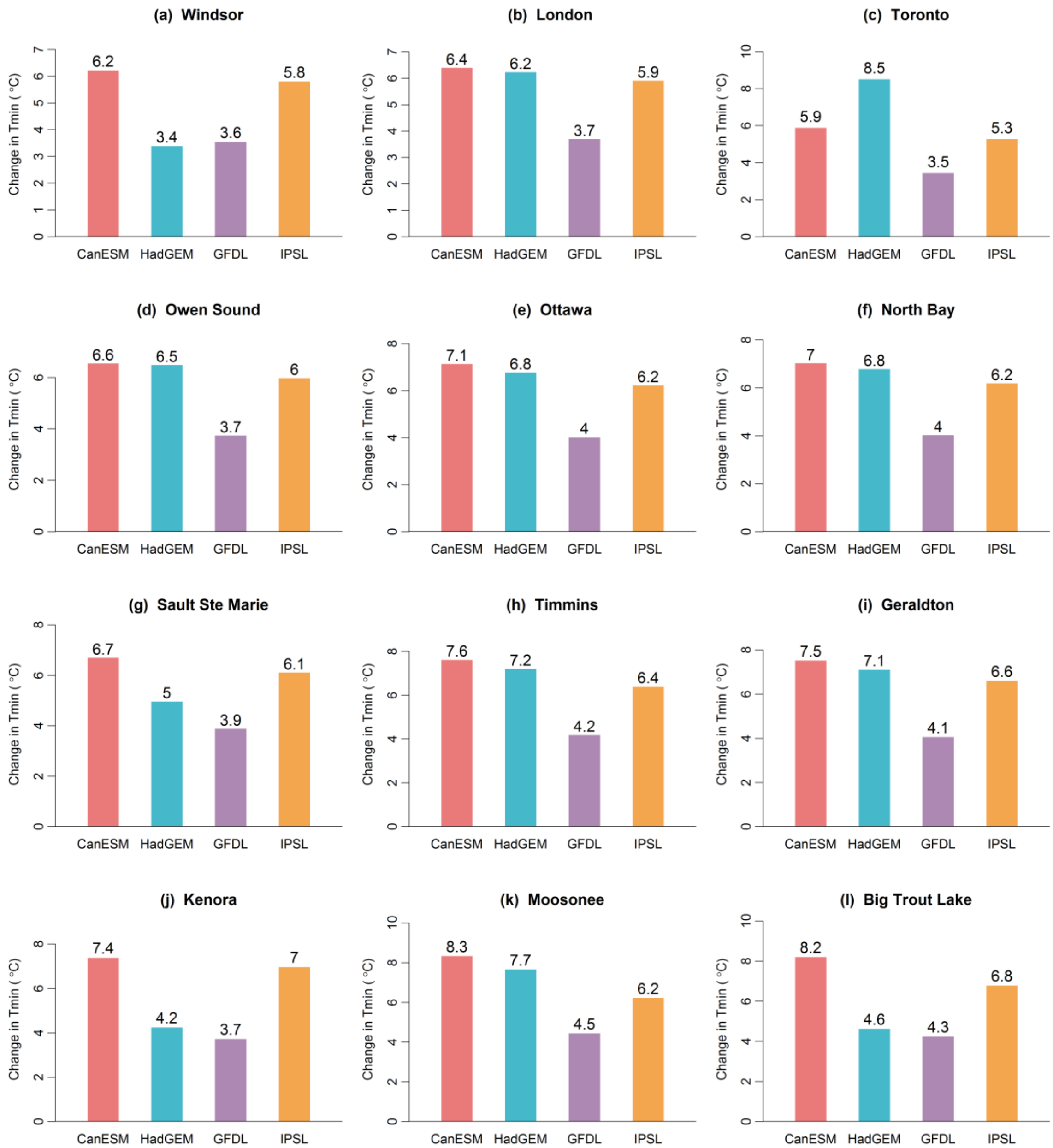

Figure 44. Changes in annual minimum temperature in 2080s

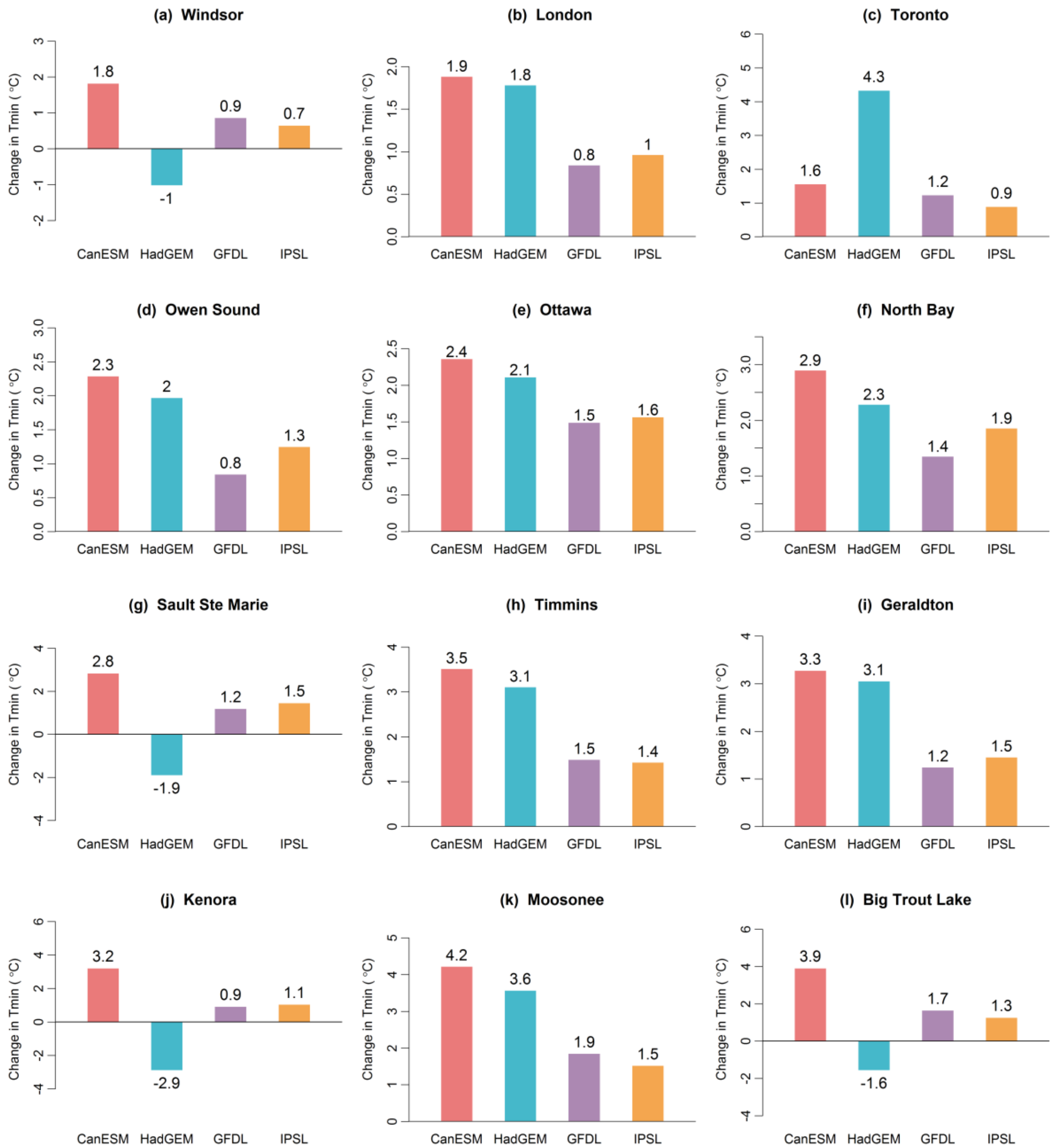

Figure 45. Changes in winter minimum temperature in 2030s

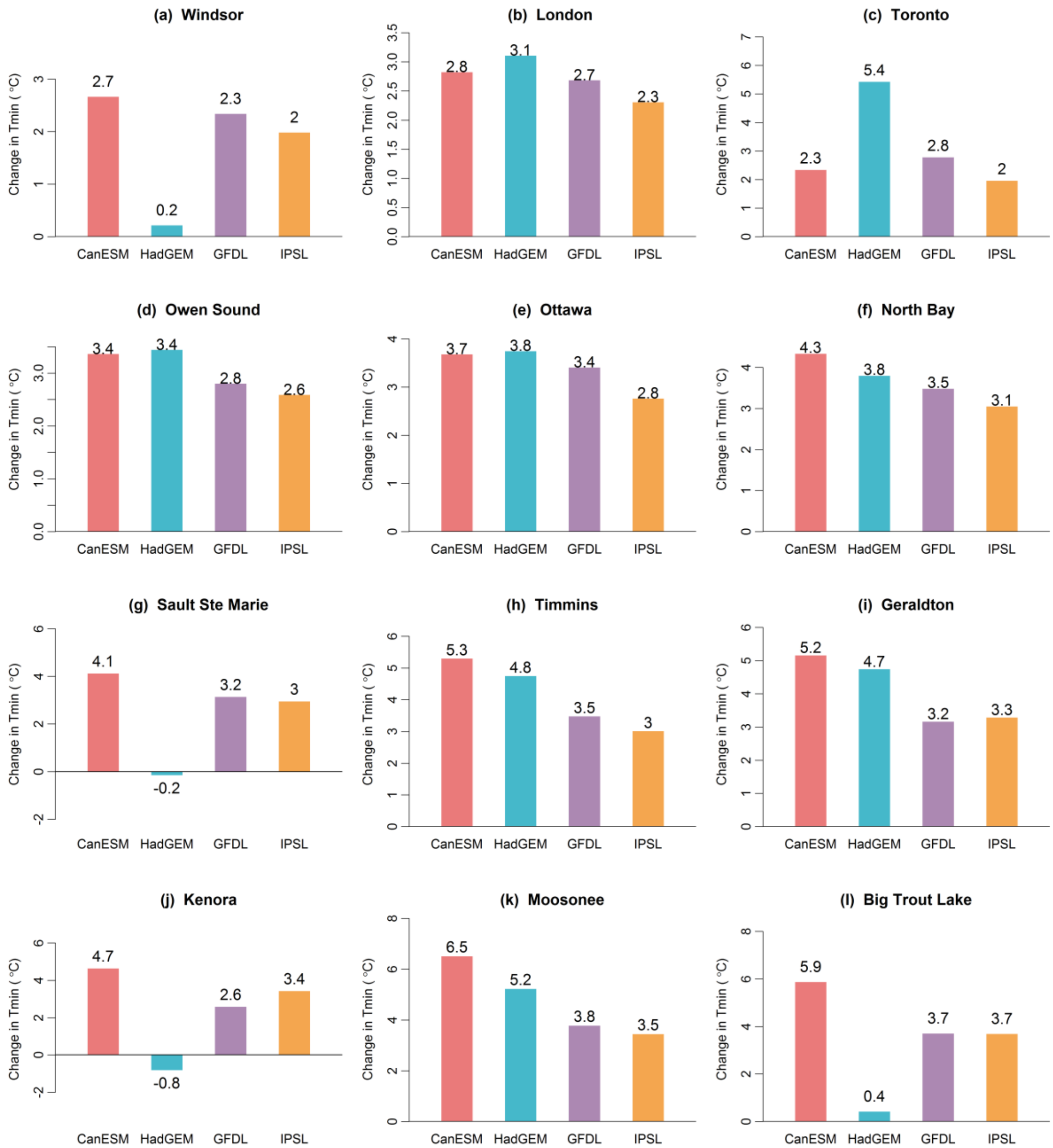

Figure 46. Changes in winter minimum temperature in 2050s

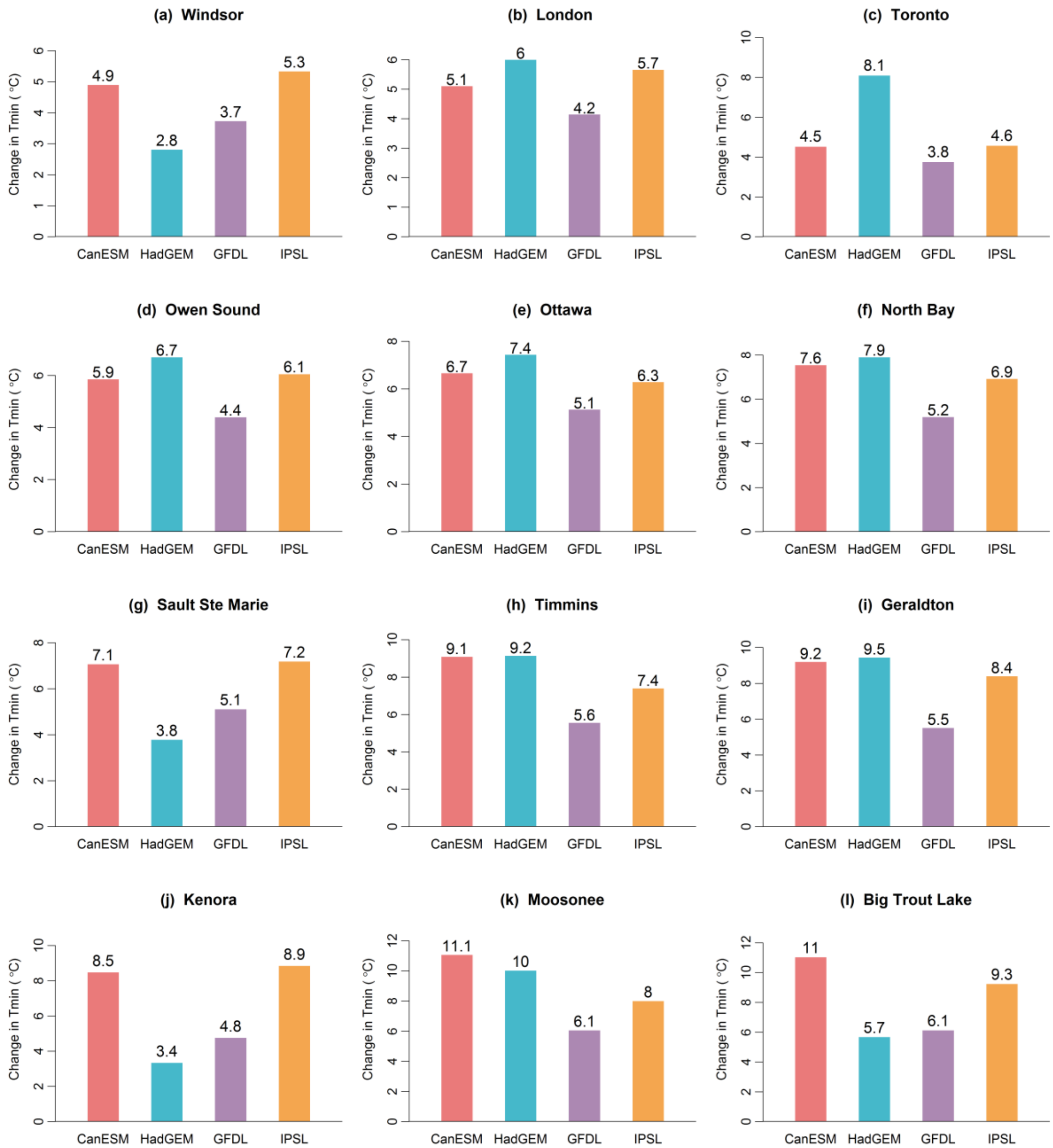

Figure 47. Changes in winter minimum temperature in 2080s

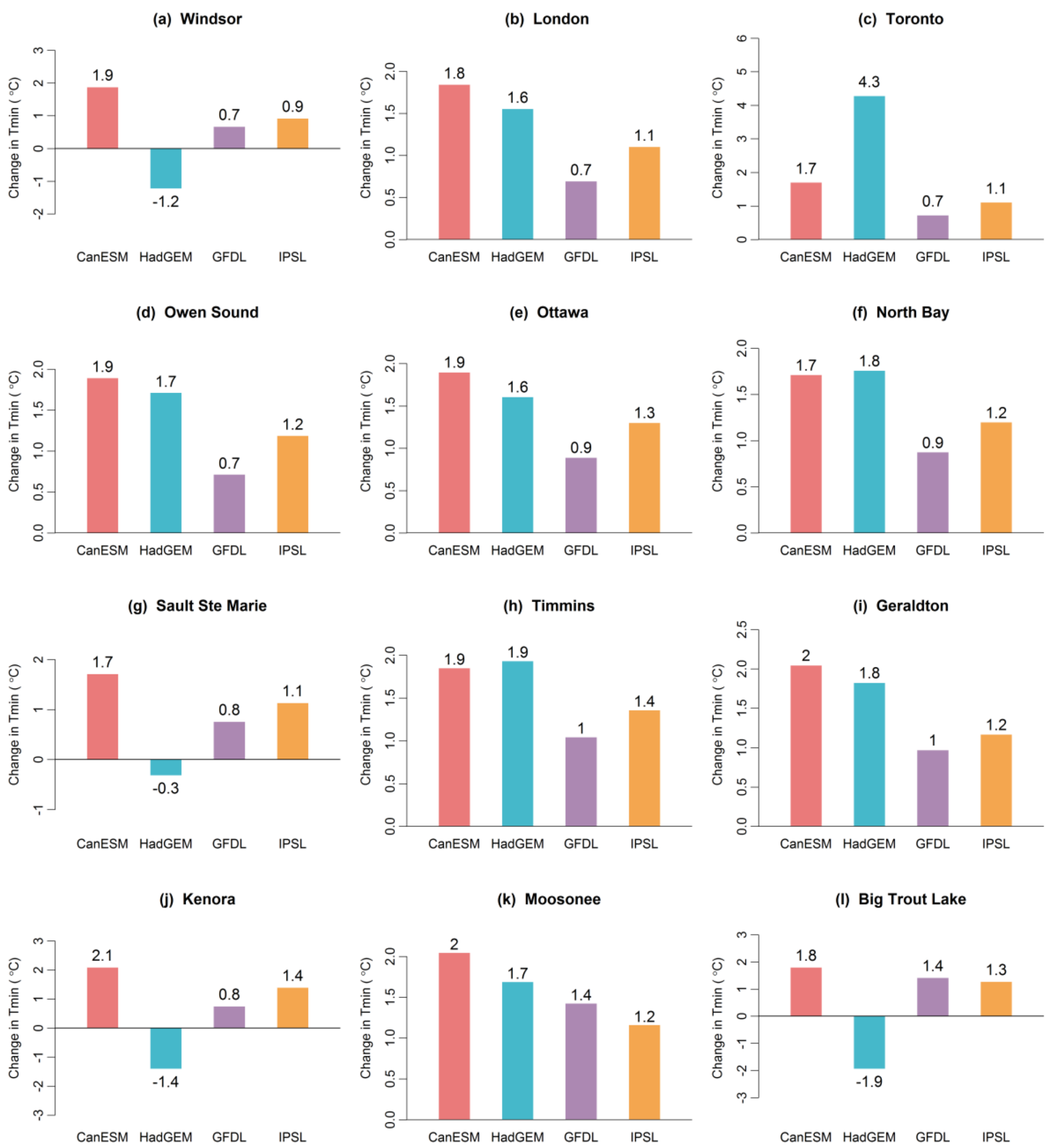

Figure 48. Changes in spring minimum temperature in 2030s

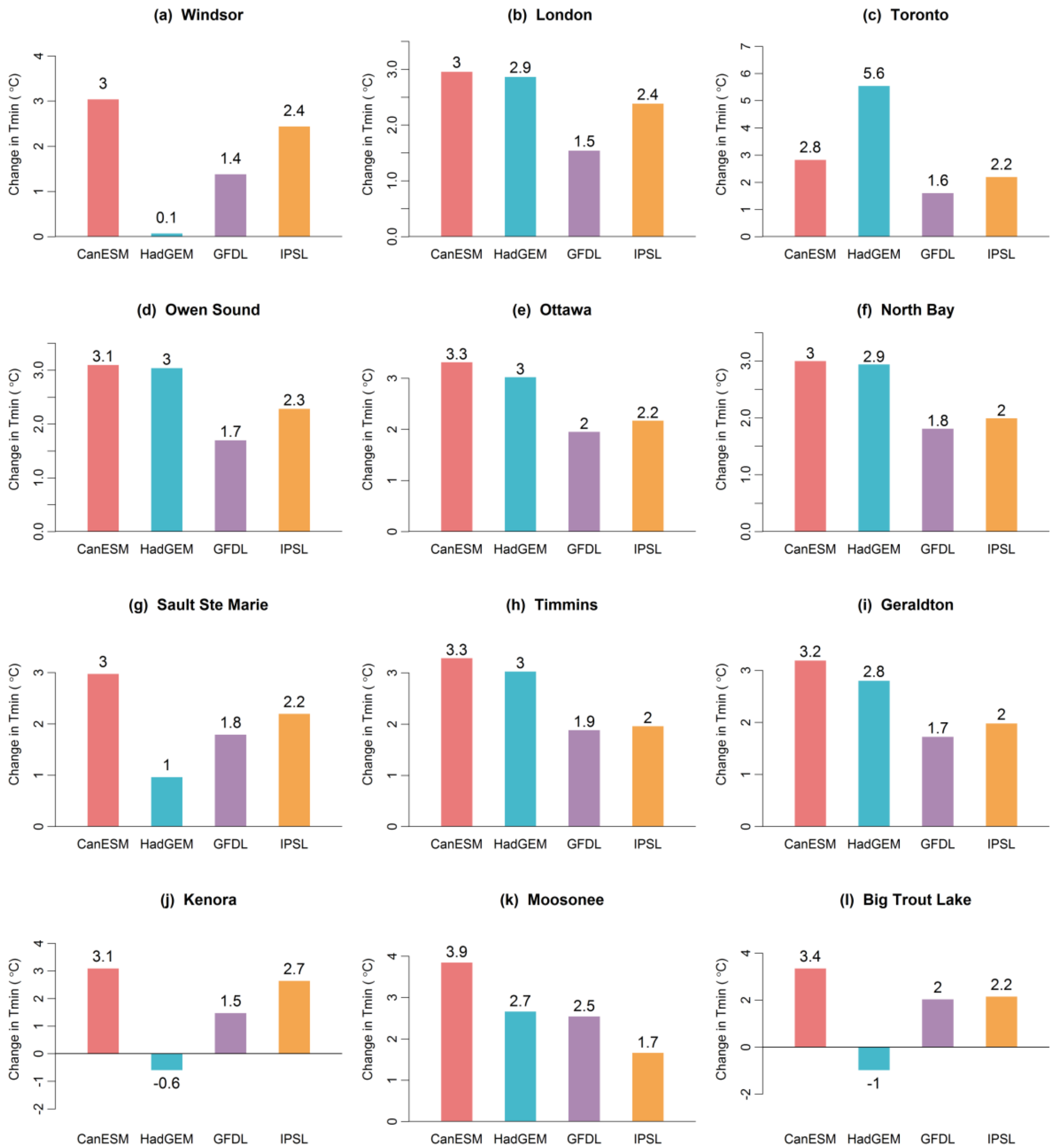

Figure 49. Changes in spring minimum temperature in 2050s

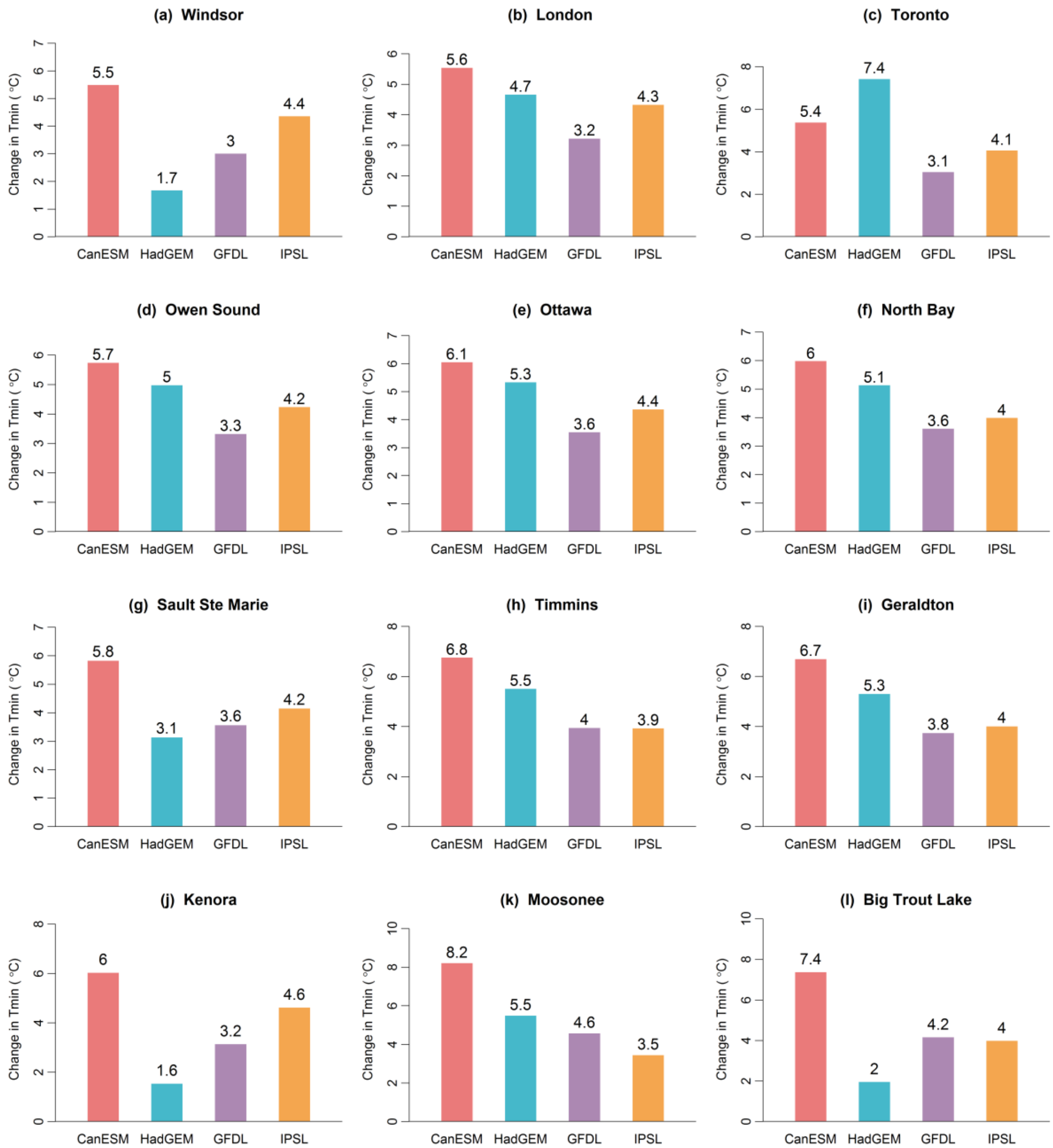

Figure 50. Changes in spring minimum temperature in 2080s

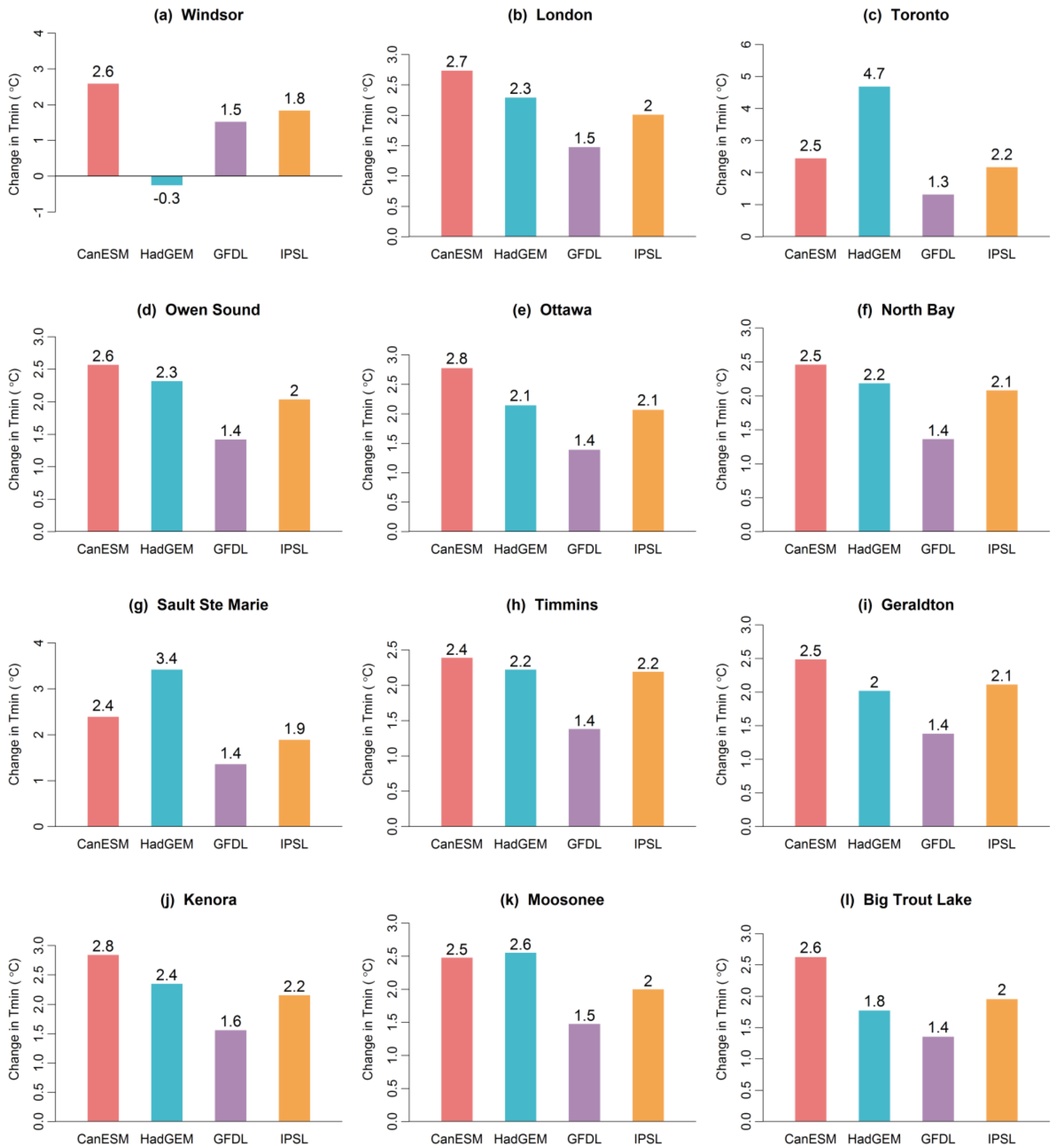

Figure 51. Changes in summer minimum temperature in 2030s

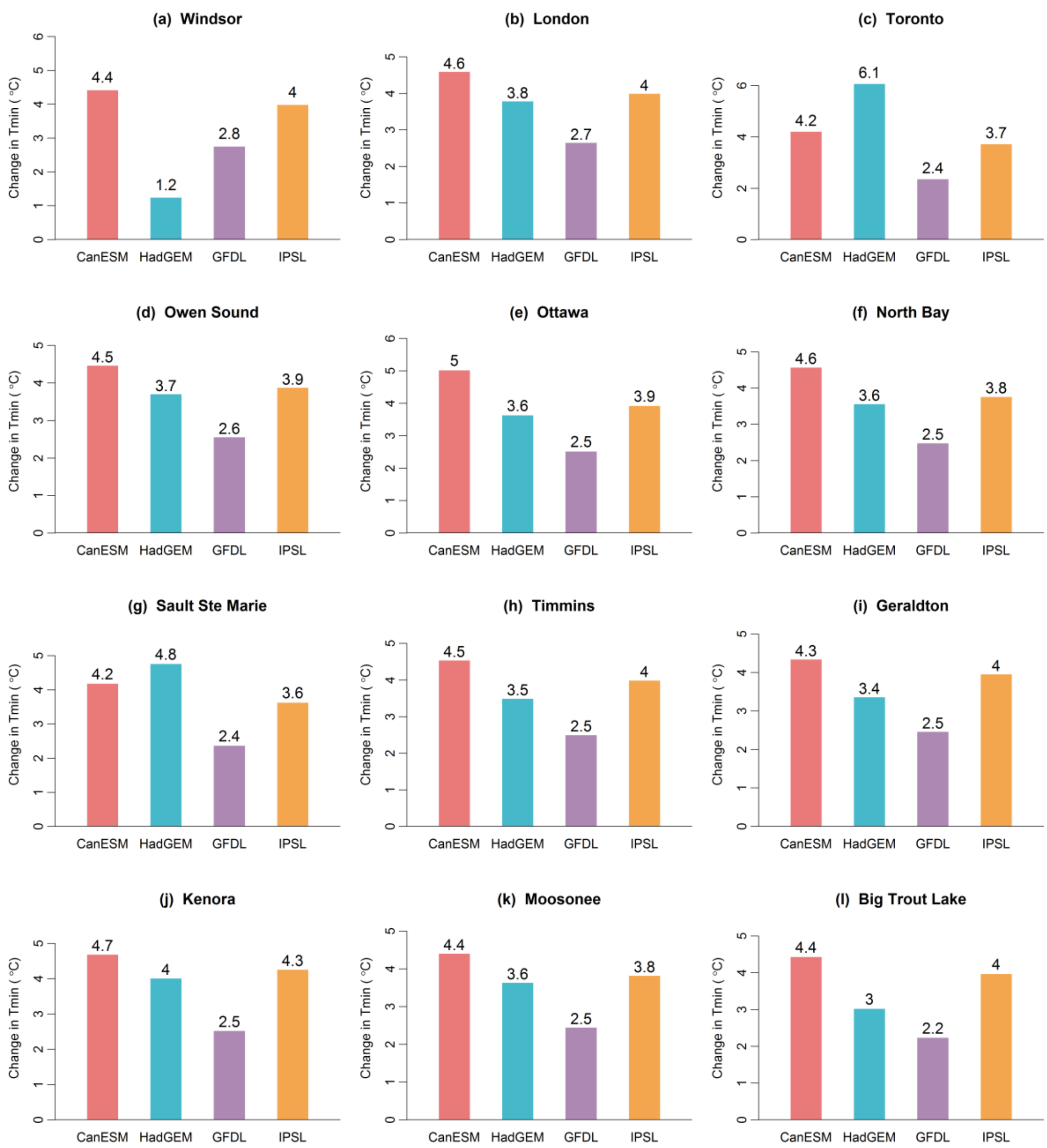

Figure 52. Changes in summer minimum temperature in 2050s

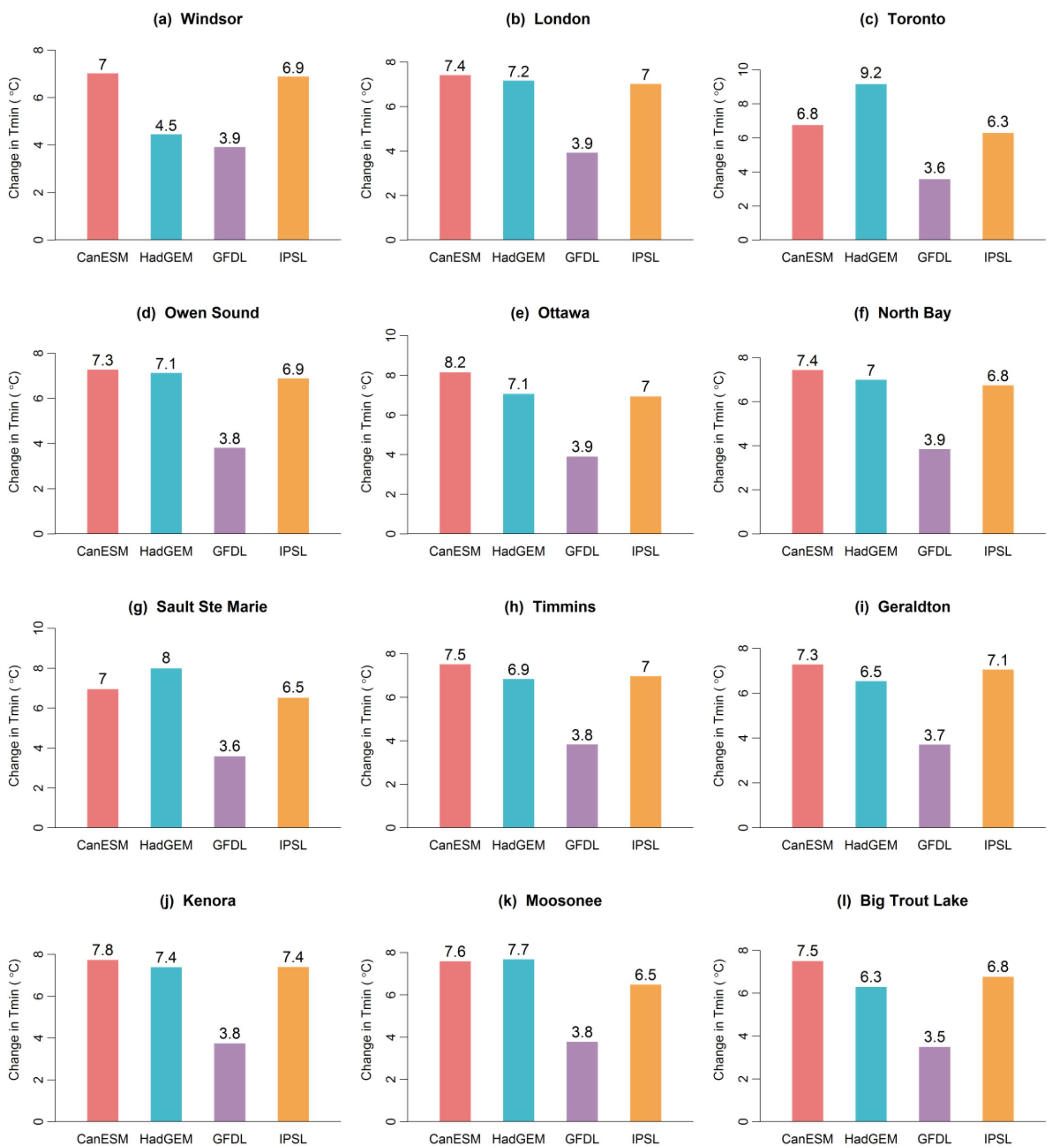

Figure 53. Changes in summer minimum temperature in 2080s

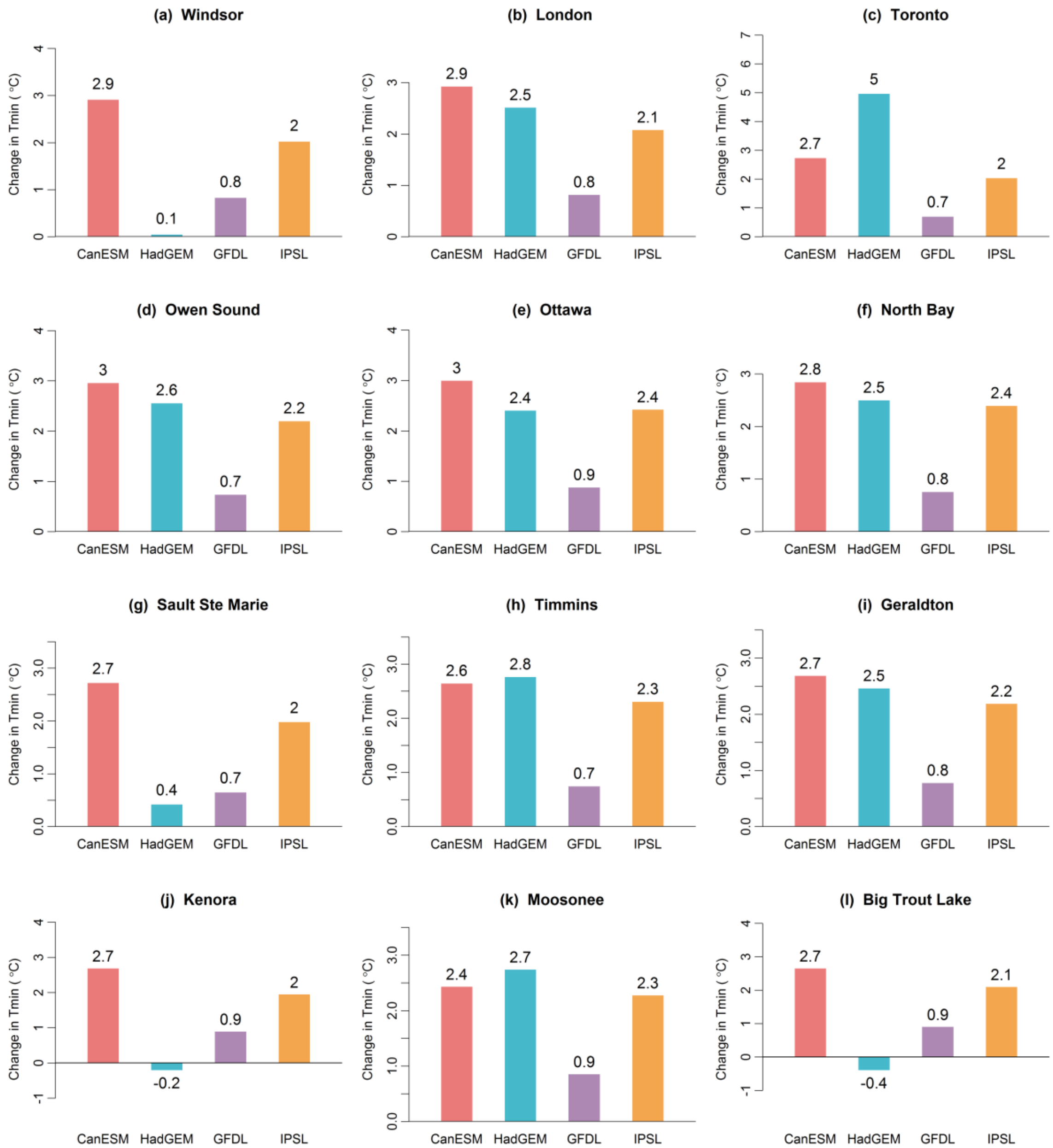

Figure 54. Changes in autumn minimum temperature in 2030s

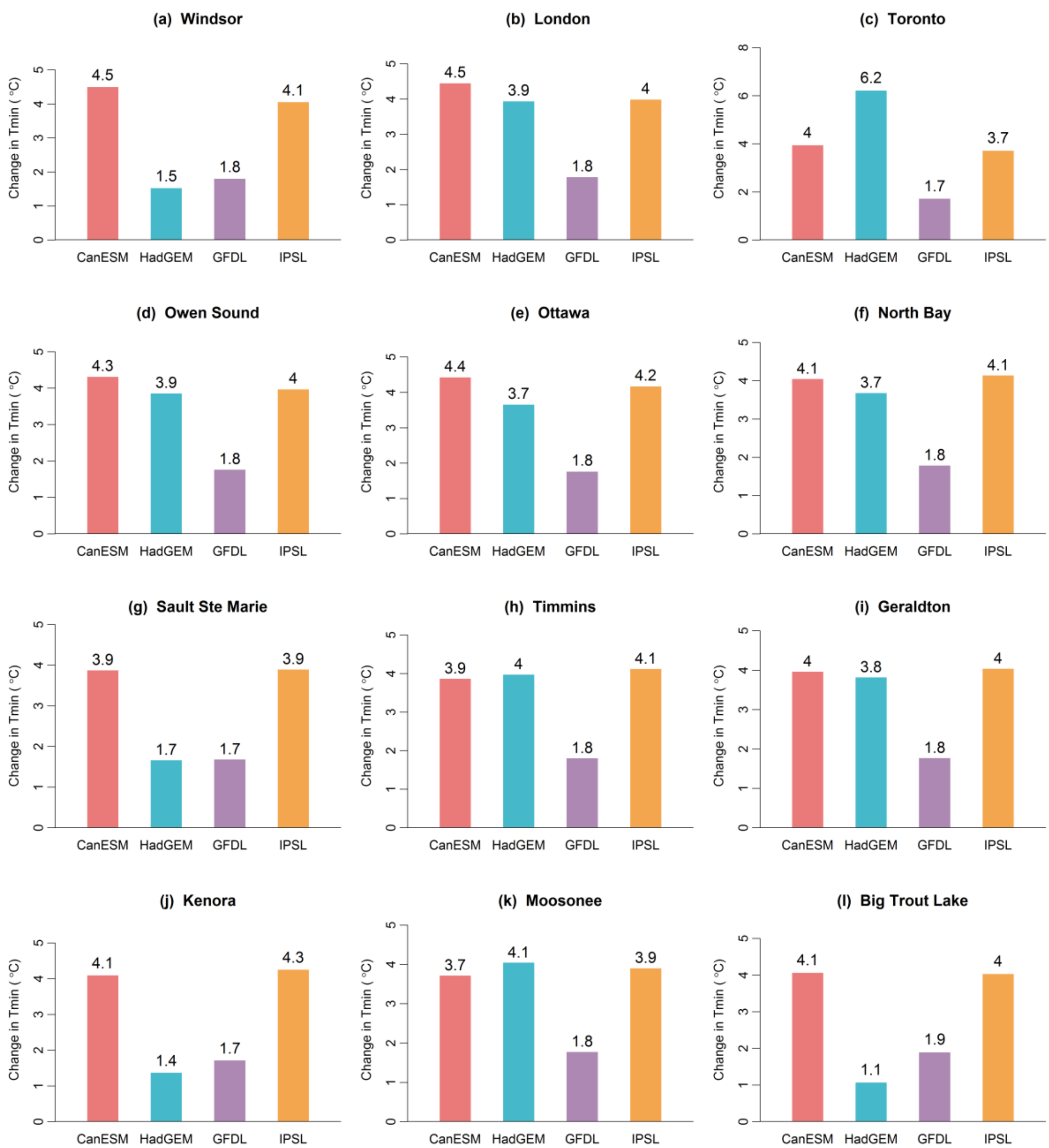

Figure 55. Changes in autumn minimum temperature in 2050s

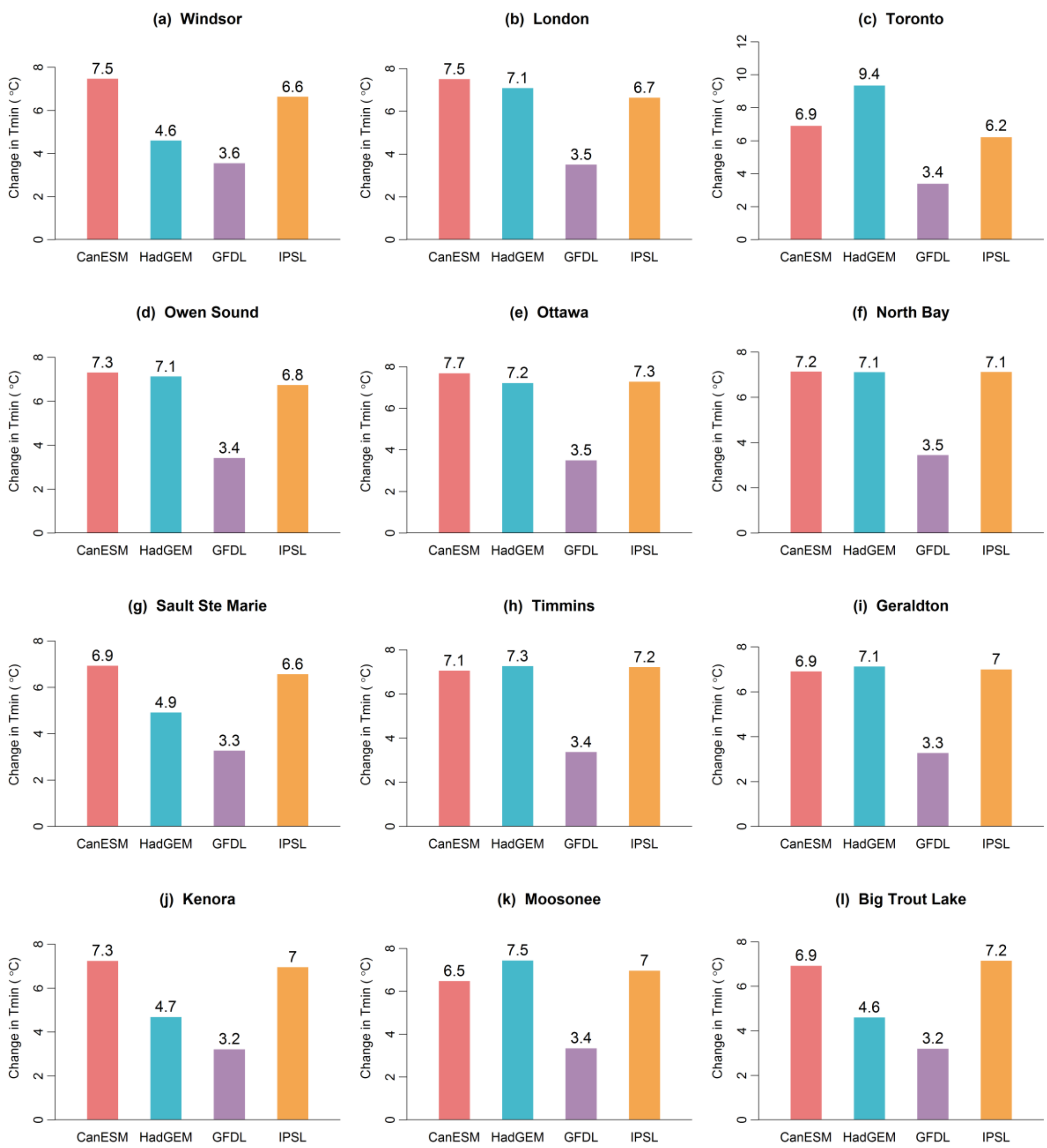

Figure 56. Changes in autumn minimum temperature in 2080s

4.4 Changes in Precipitation

This section presents the projected changes in annual and seasonal precipitation at twelve weather stations for three future periods: 2030s, 2050s, and 2080s. Figures 57-59 show the projected changes in annual precipitation by the four RegCM runs. It is apparent that the Province of Ontario is likely to receive more annual total precipitation in the 21st century as the RegCM runs demonstrate positive changes in annual total precipitation at most of the stations, although the CanESM and IPSL runs tend to project slight negative changes in annual total precipitation at a number of stations. Unlike the projected changes in temperature variables, apparent spatial variations of the changes in precipitation are found. This may suggest that analysis of the projected changes in precipitation should be performed in a case-by-case (or station-by-station) fashion. For example, annual total precipitation in the City of Windsor is projected to increase by the HadGEM, GFDL, and IPSL runs throughout this century. Specifically, the projected changes in annual total precipitation by the HadGEM run are likely to be 20.6% in 2030s and in 2050s, and 30.5% in 2080s; the projected changes by the GFDL run are only about 1.5% in 2030s, 2.1% in 2050s, and 10.2% in 2080s; the projected changes by the IPSL in 2030s can be as high as 23.6%, but would be only 1% in 2050s and 3.3% in 2080s, respectively. By contrast, the CanESM run tends to project negative changes in annual total precipitation for the City of Windsor (i.e., -4.7% in 2030s, -10% in 2050s, and -7% in 2080s).

The projected changes in seasonal precipitation by the four RegCM runs for three future periods (i.e., 2030s, 2050s, and 2080s) are shown in Figures 60-71. Apparent spatial variations are also reported for the projected changes in seasonal precipitation. For the HadGEM, GFDL, and IPSL runs, the magnitude of changes in winter and spring precipitation seems to be greater than those in summer and autumn precipitation. By contrast, it is interesting to find that the CanESM run tends to project the most significant changes of precipitation (i.e., negative changes) in summer than in other seasons.

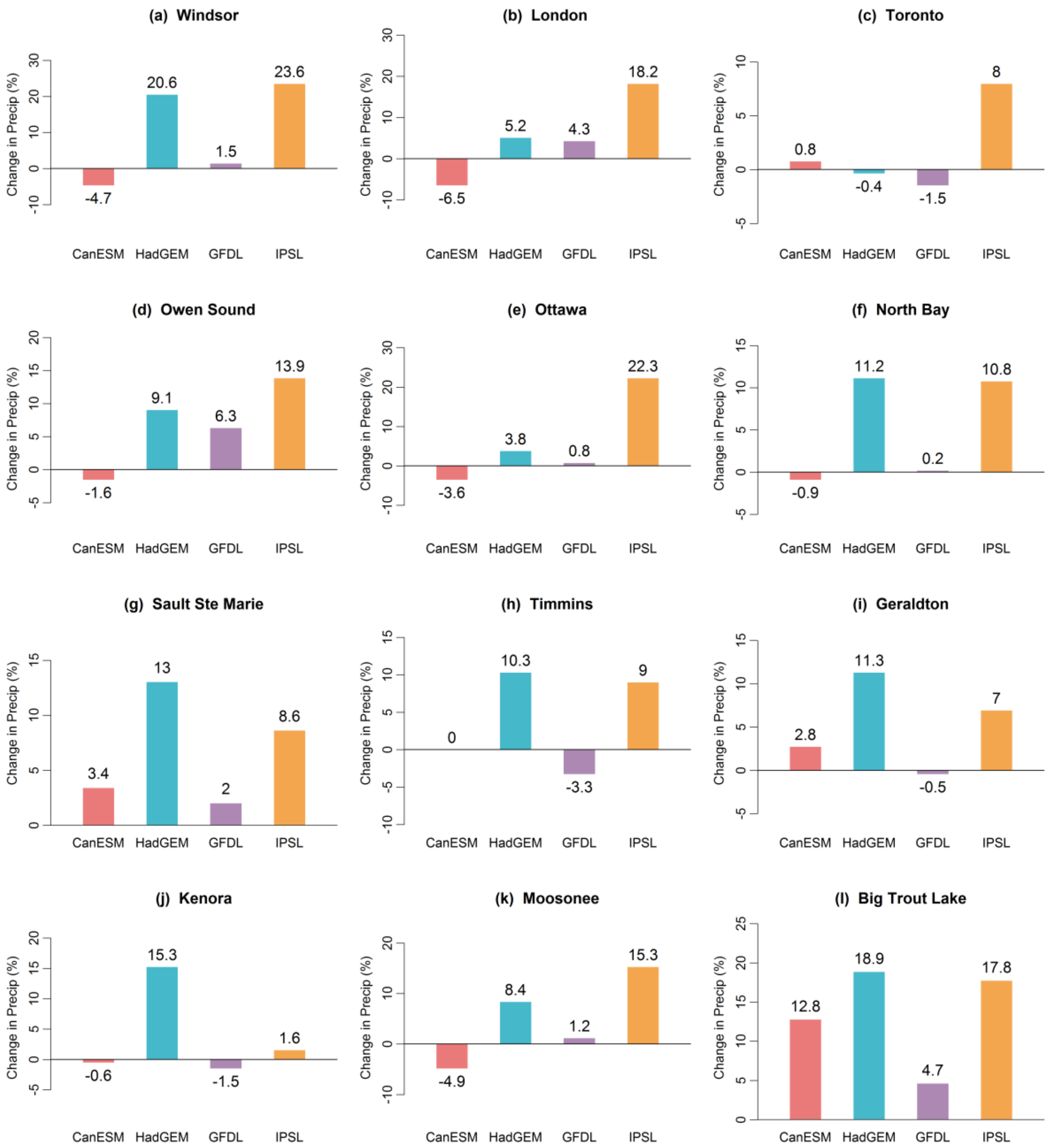

Figure 57. Changes in annual precipitation in 2030s

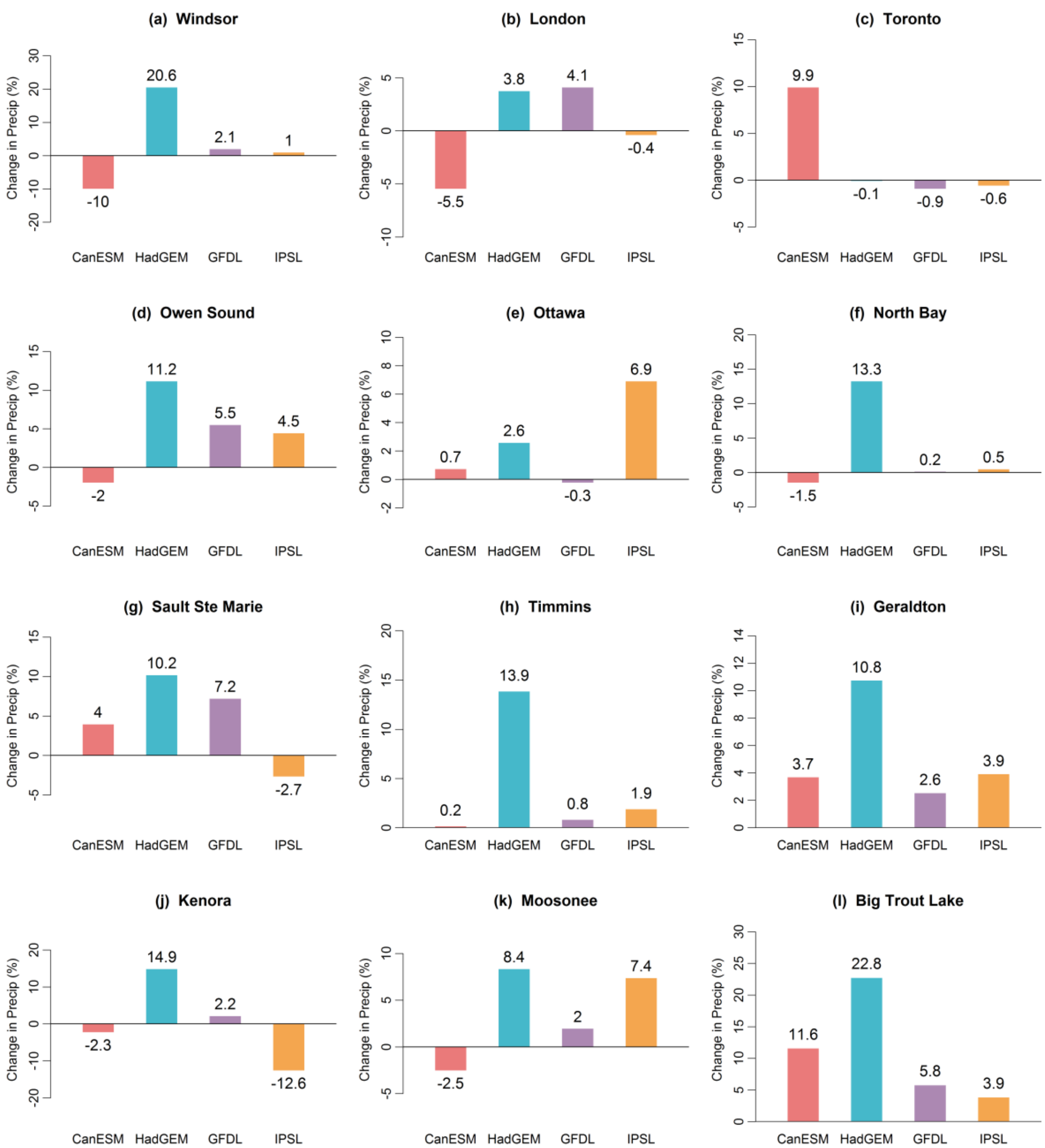

Figure 58. Changes in annual precipitation in 2050s

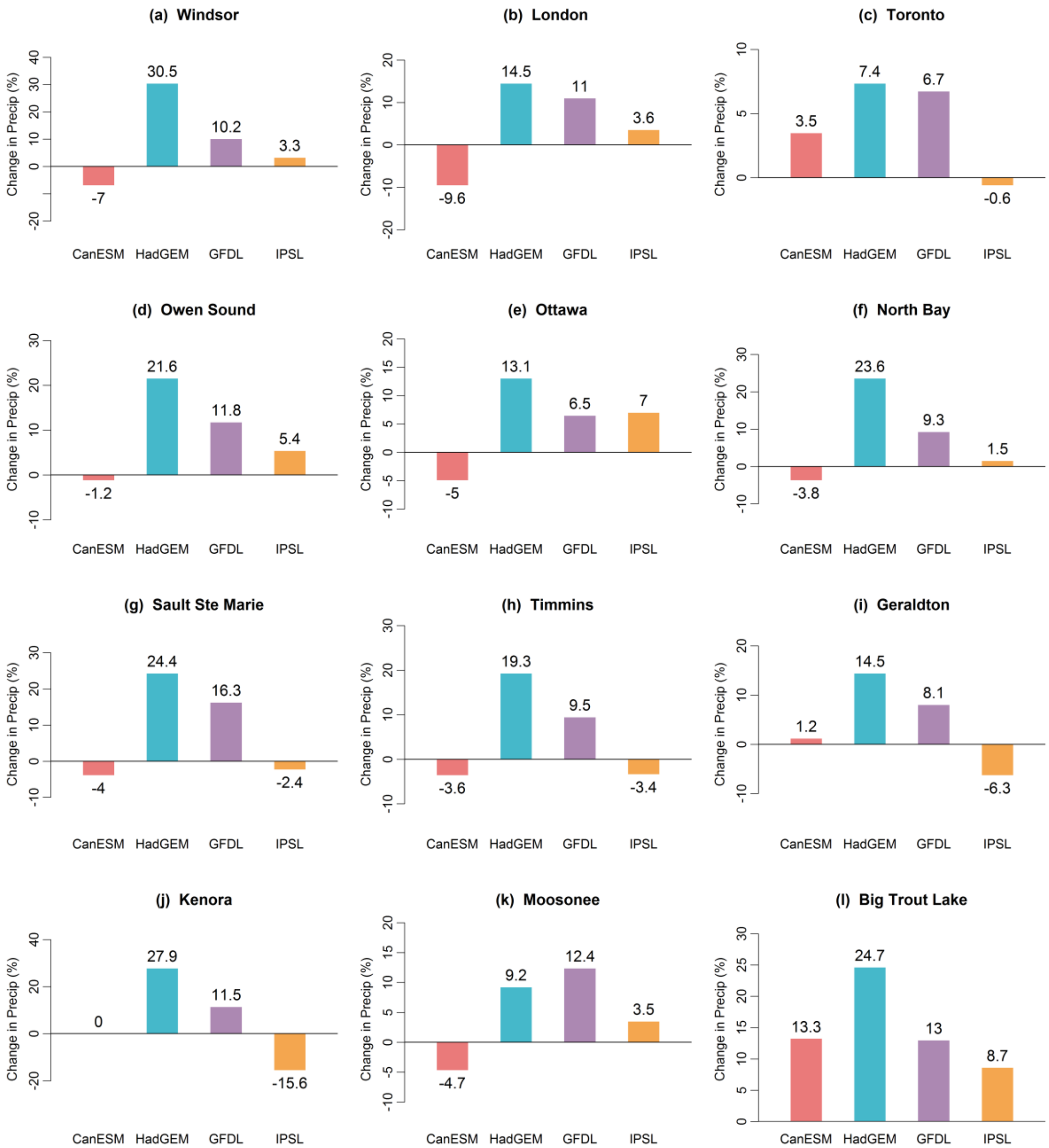

Figure 59. Changes in annual precipitation in 2080s

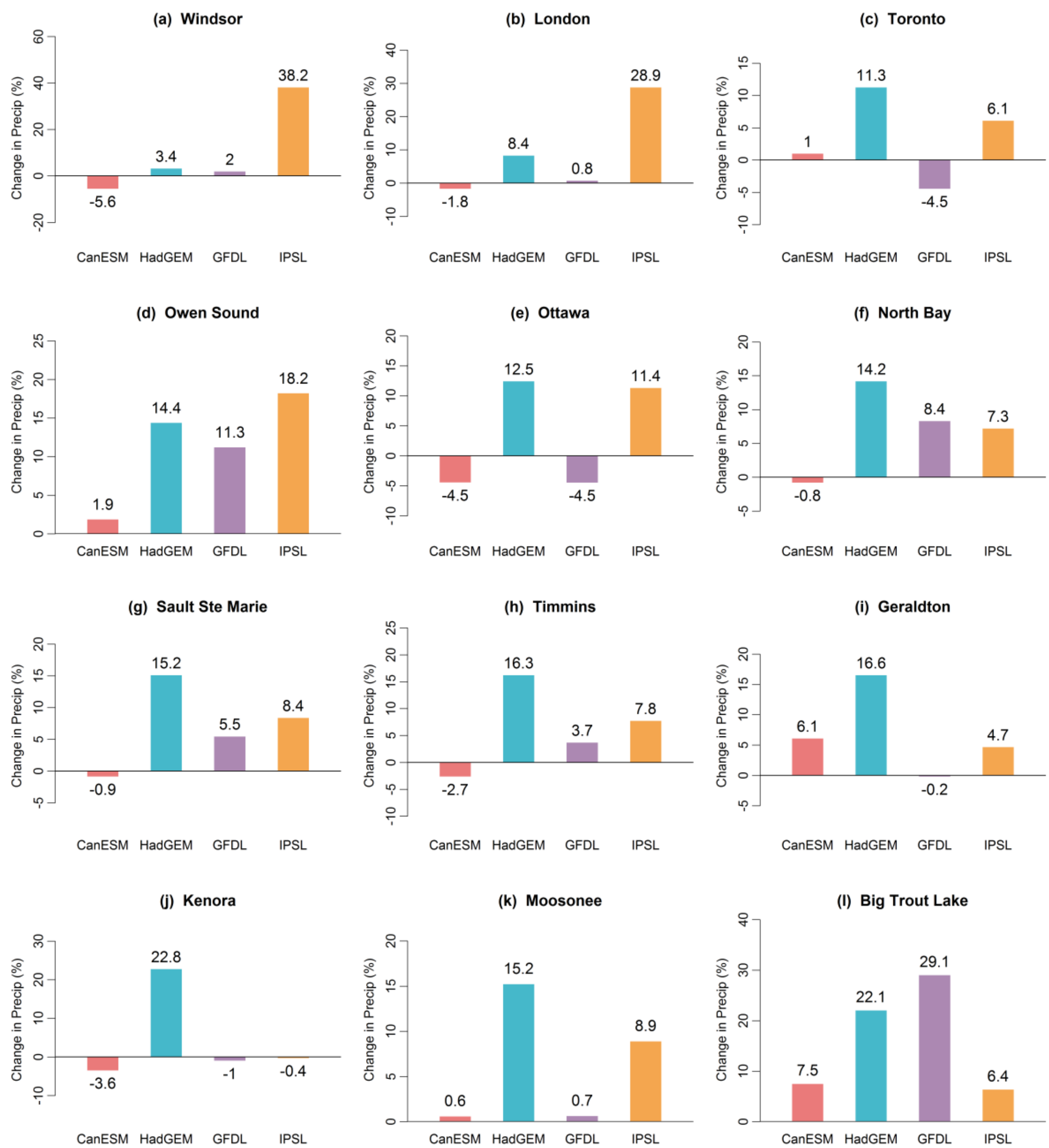

Figure 60. Changes in winter precipitation in 2030s

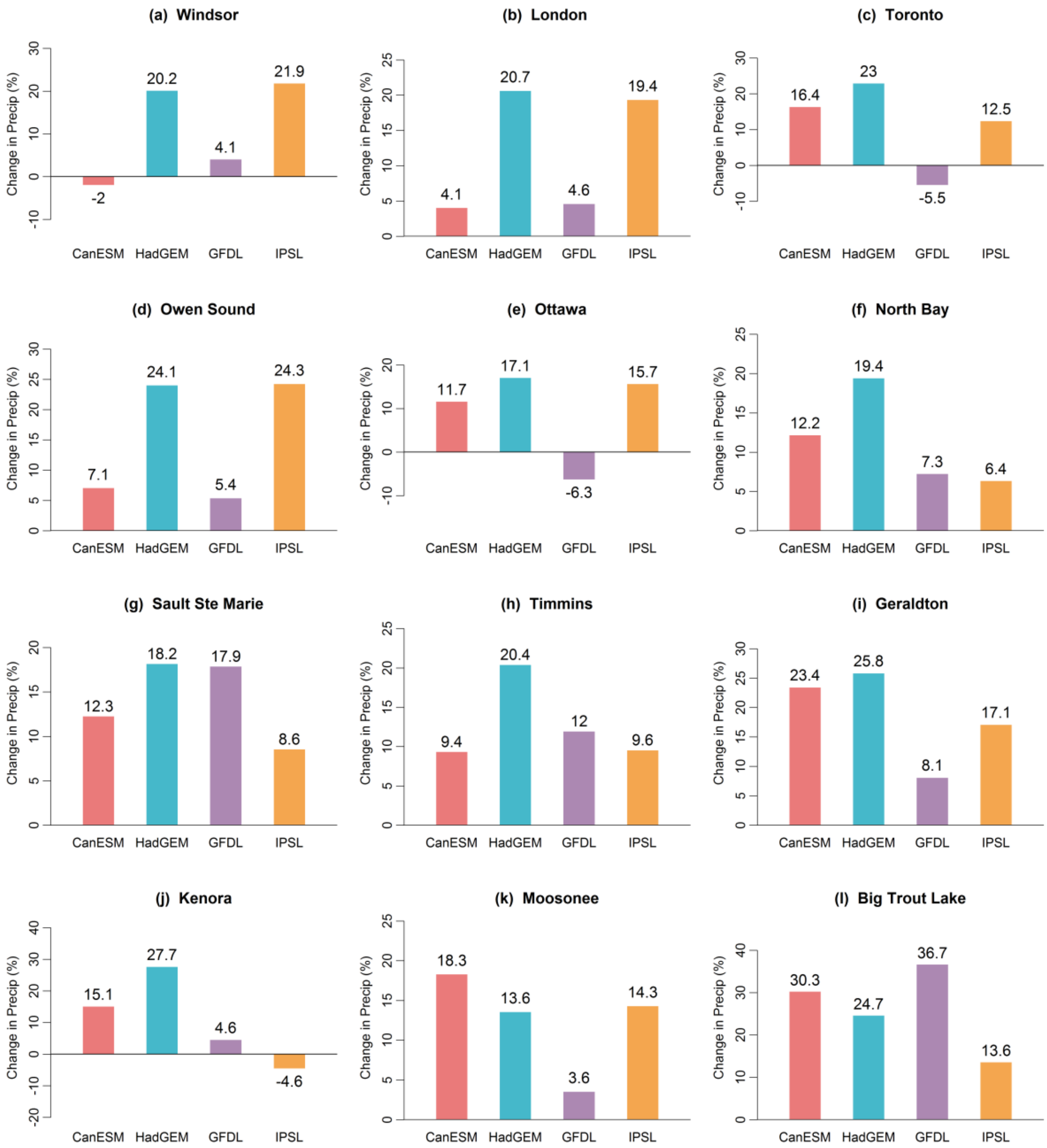

Figure 61. Changes in winter precipitation in 2050s

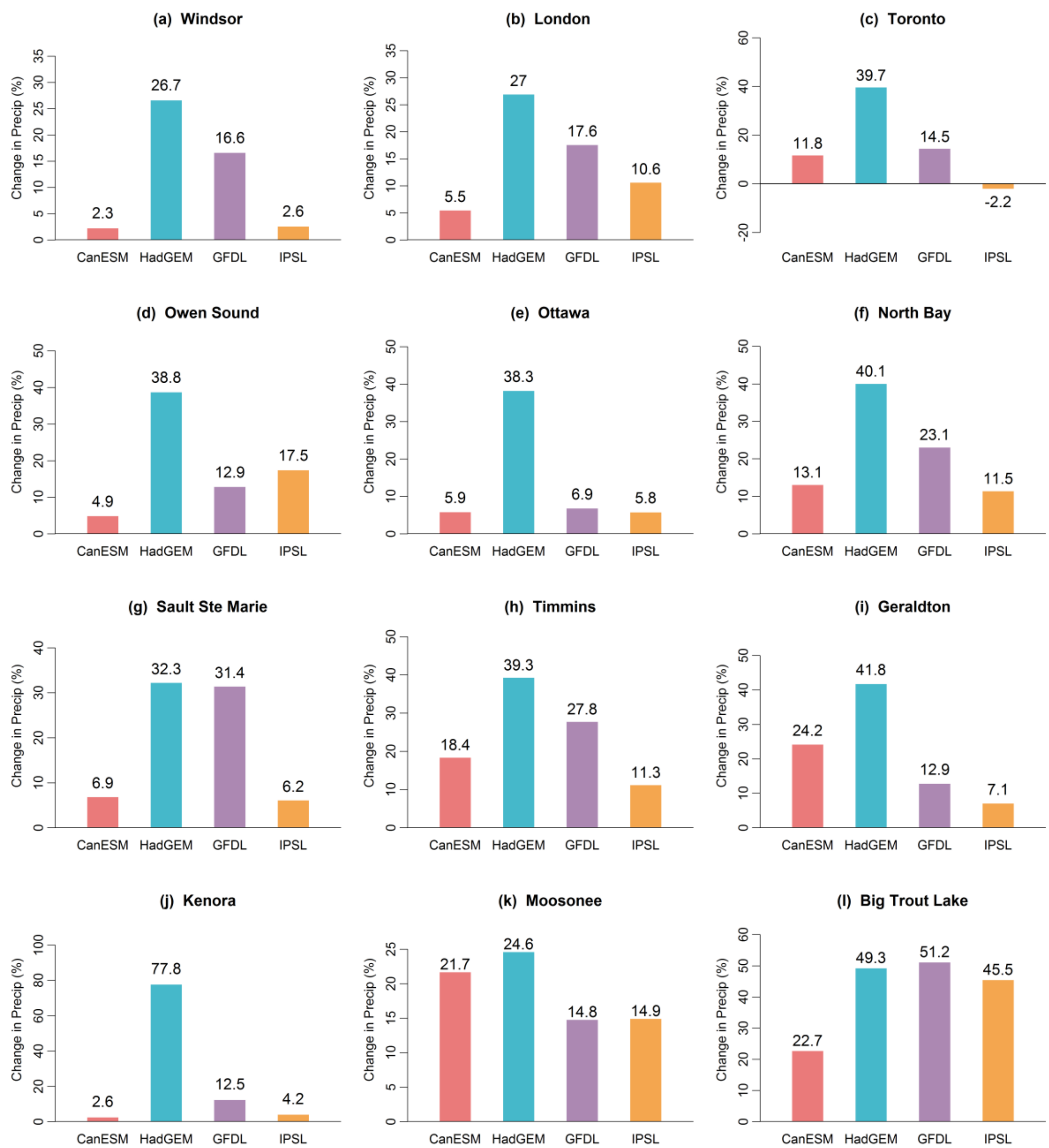

Figure 62. Changes in winter precipitation in 2080s

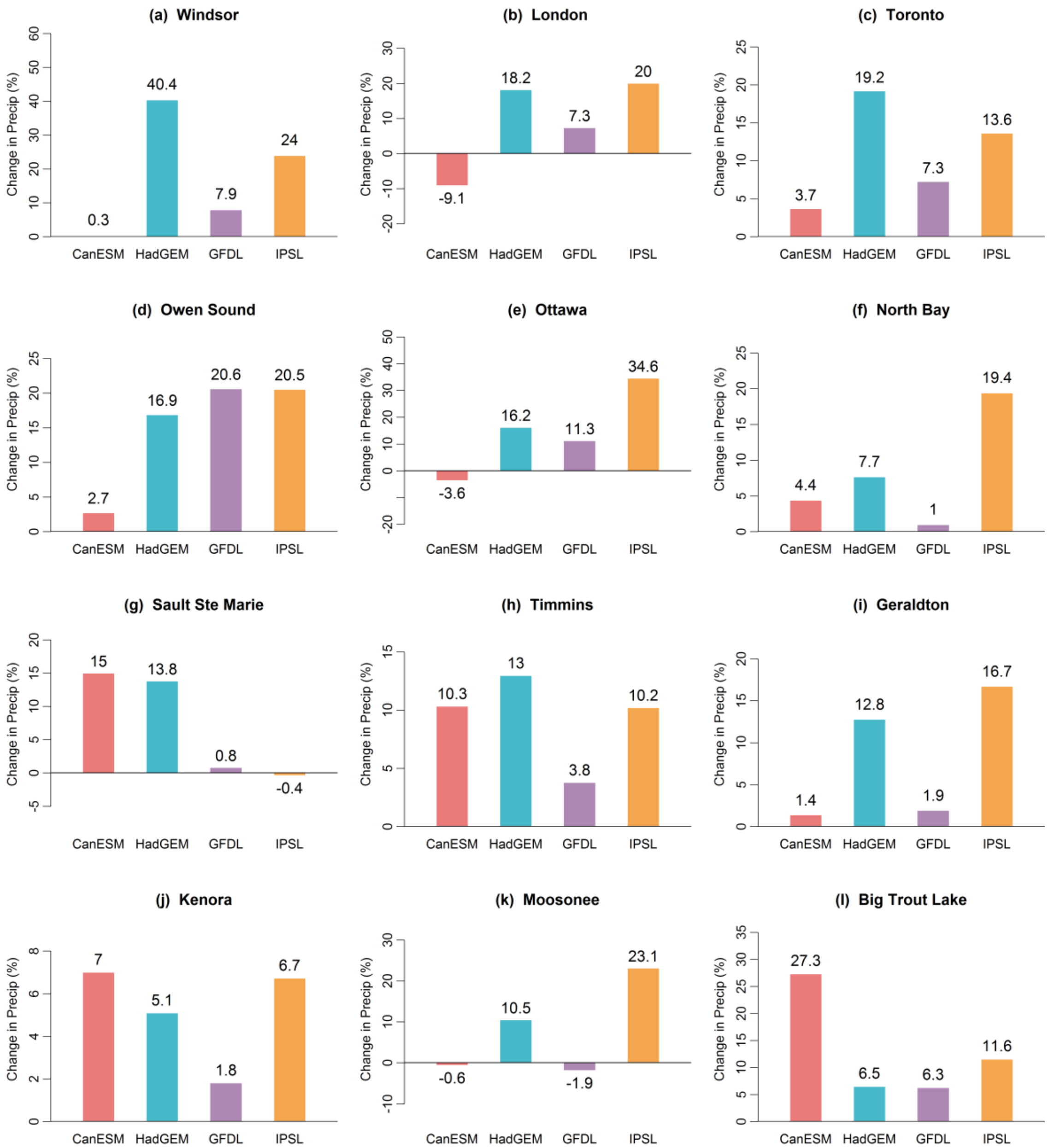

Figure 63. Changes in spring precipitation in 2030s

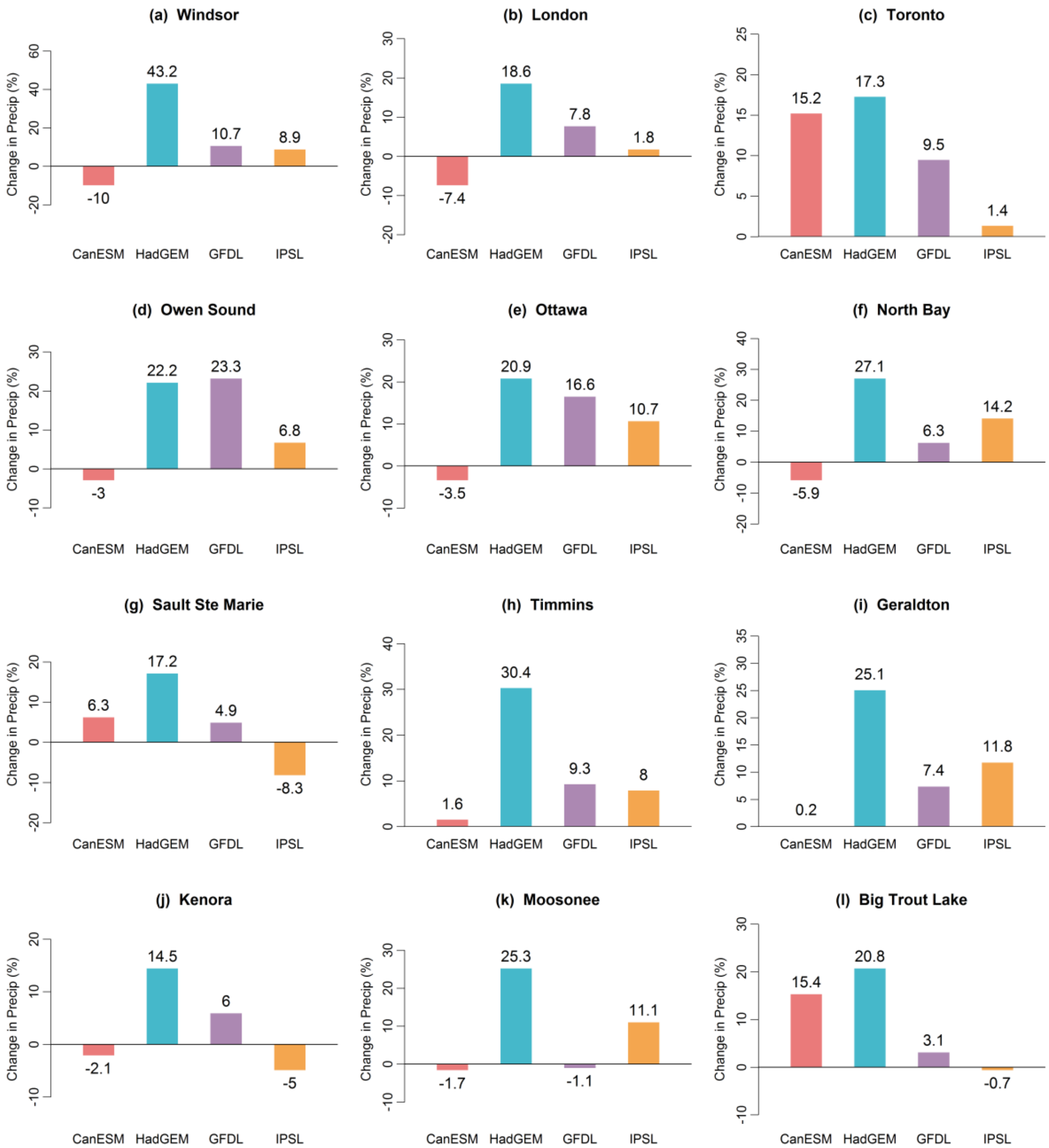

Figure 64. Changes in spring precipitation in 2050s

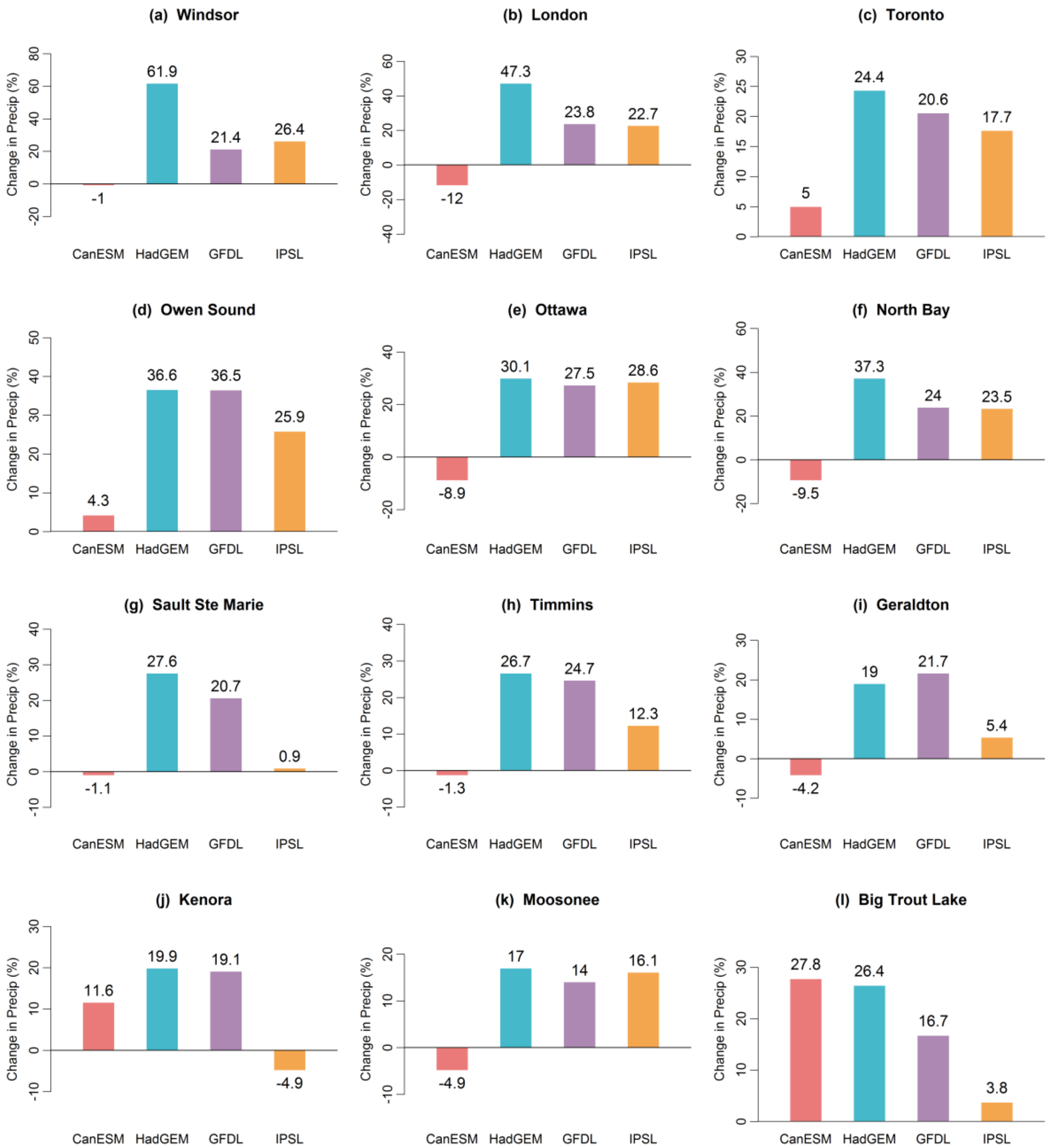

Figure 65. Changes in spring precipitation in 2080s

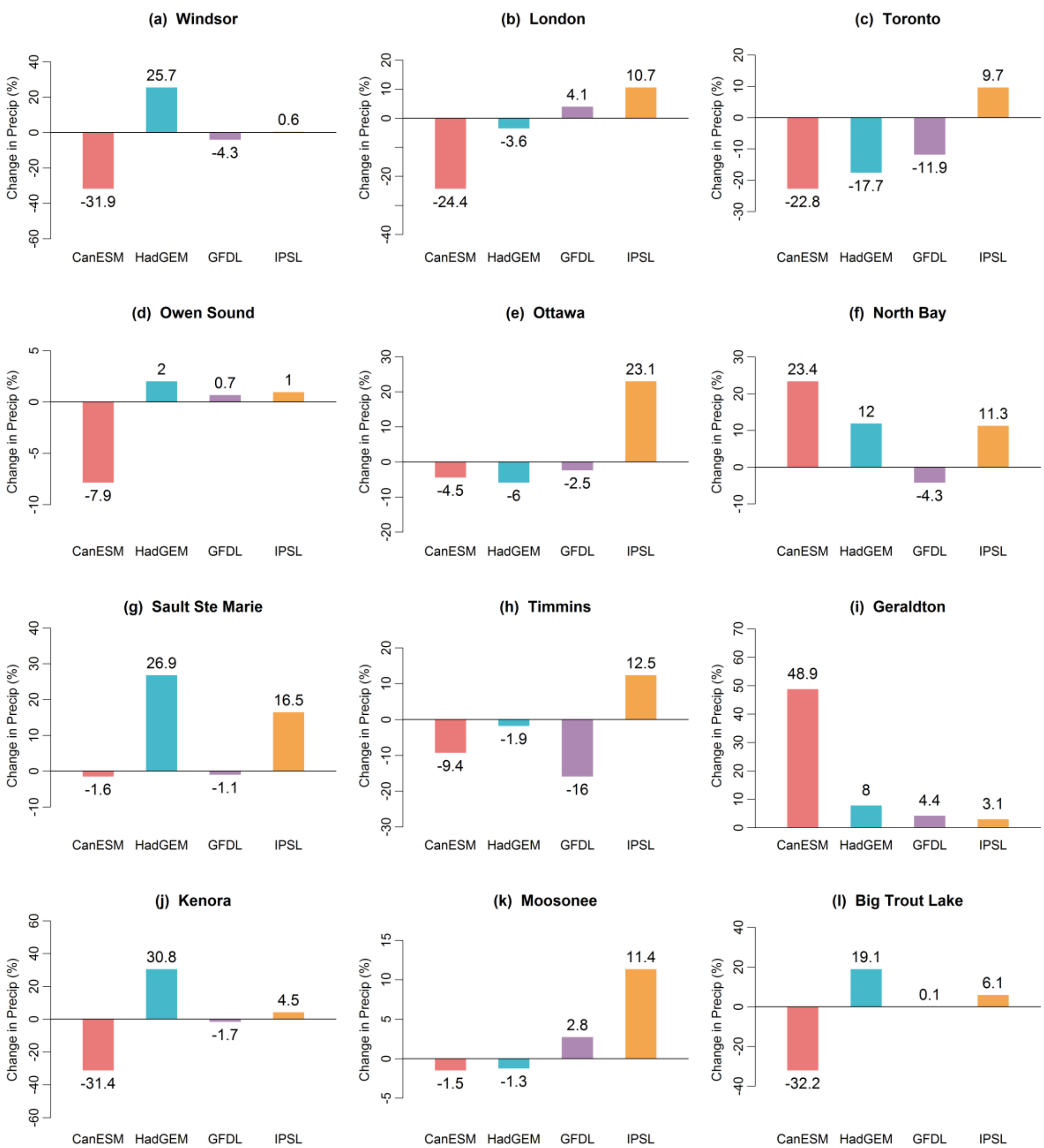

Figure 66. Changes in summer precipitation in 2030s

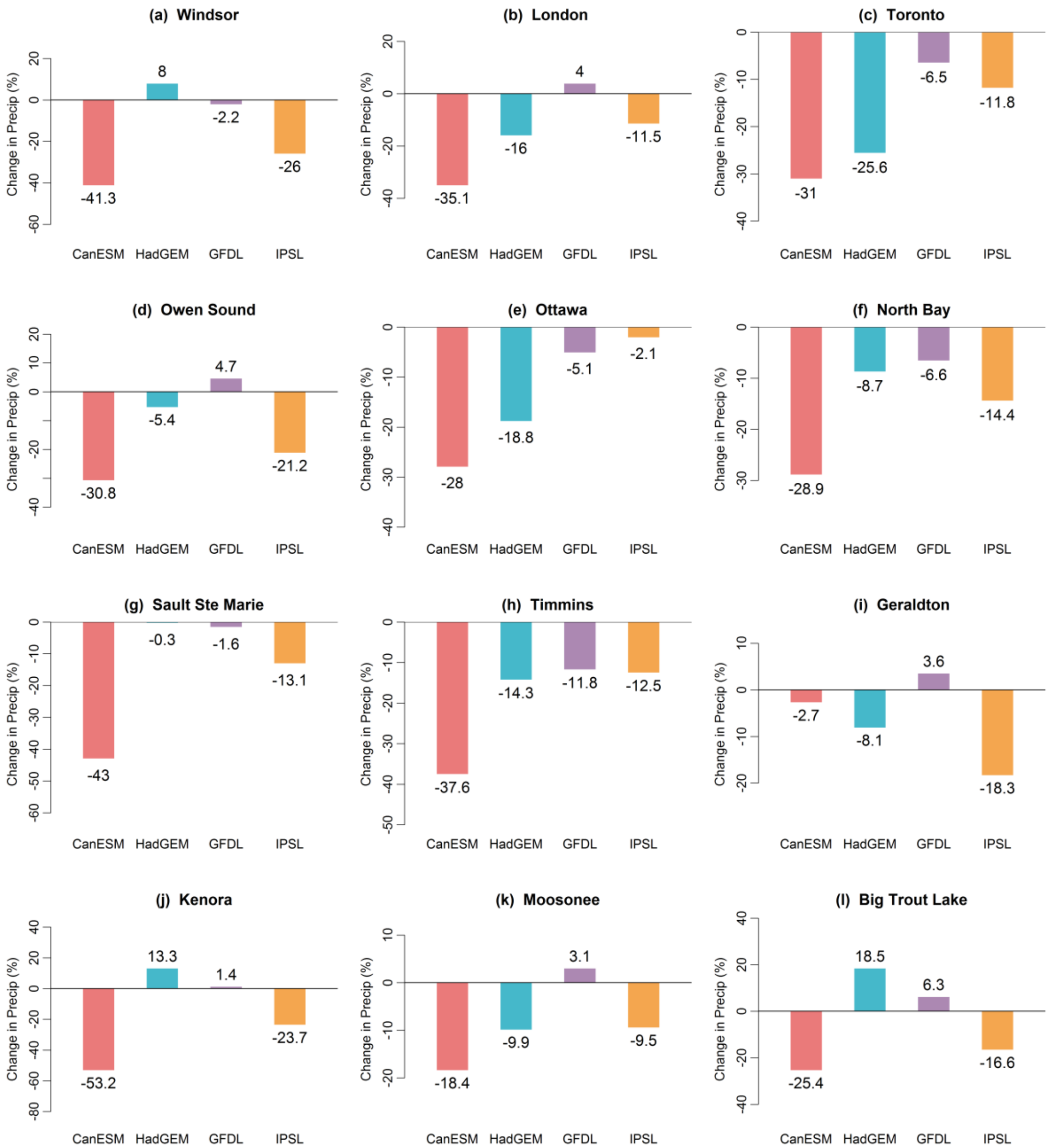

Figure 67. Changes in summer precipitation in 2050s

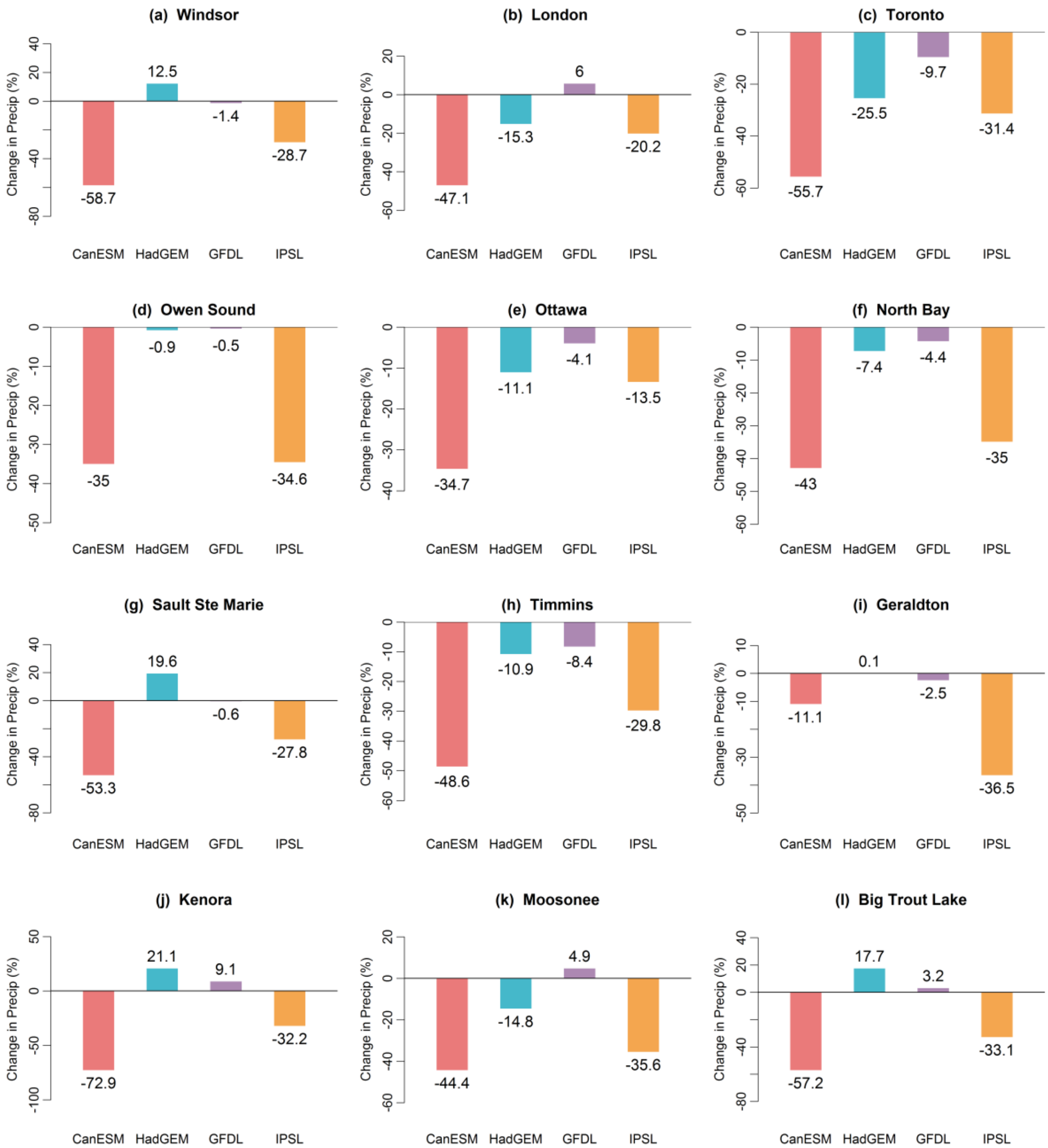

Figure 68. Changes in summer precipitation in 2080s

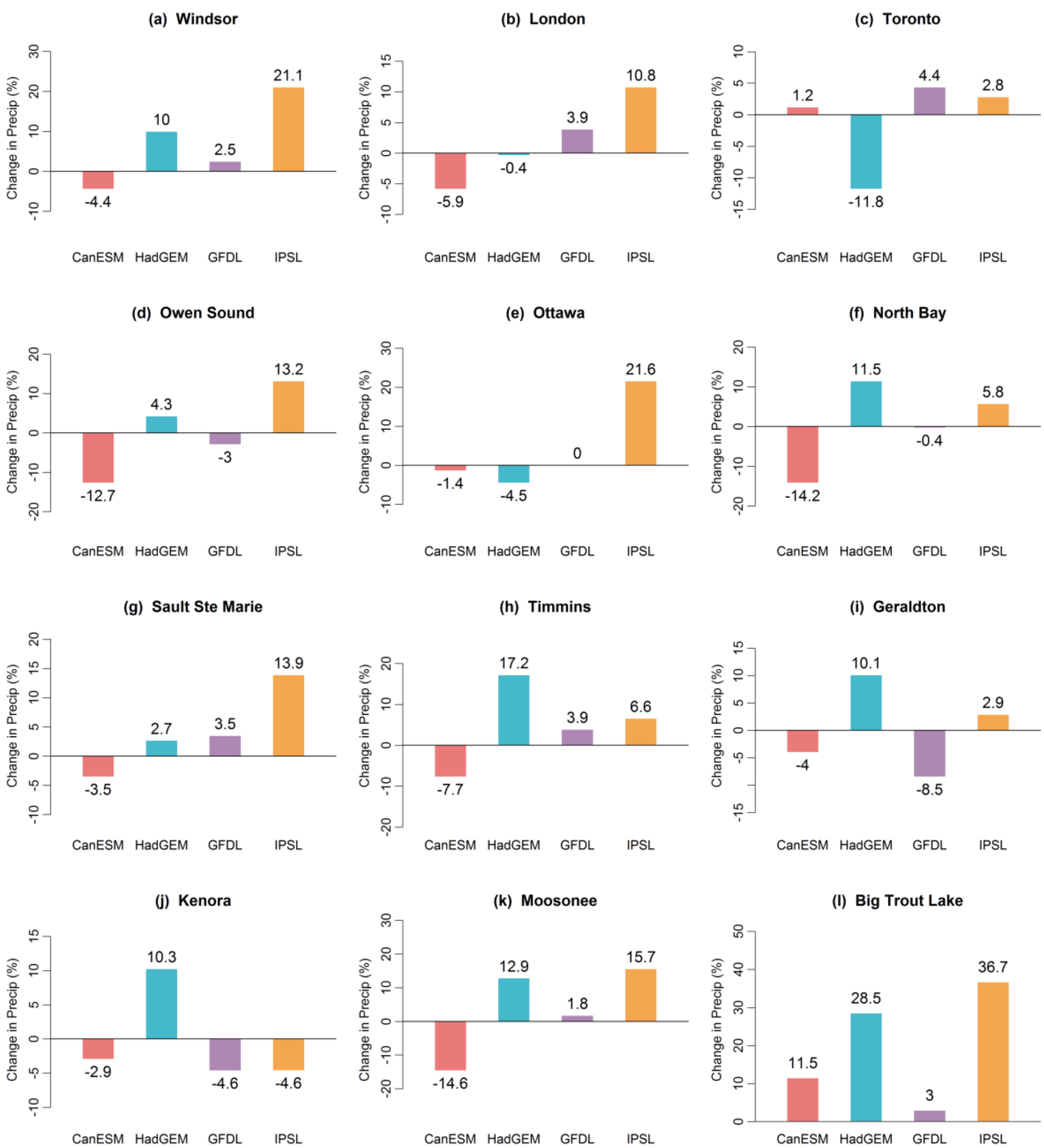

Figure 69. Changes in autumn precipitation in 2030s

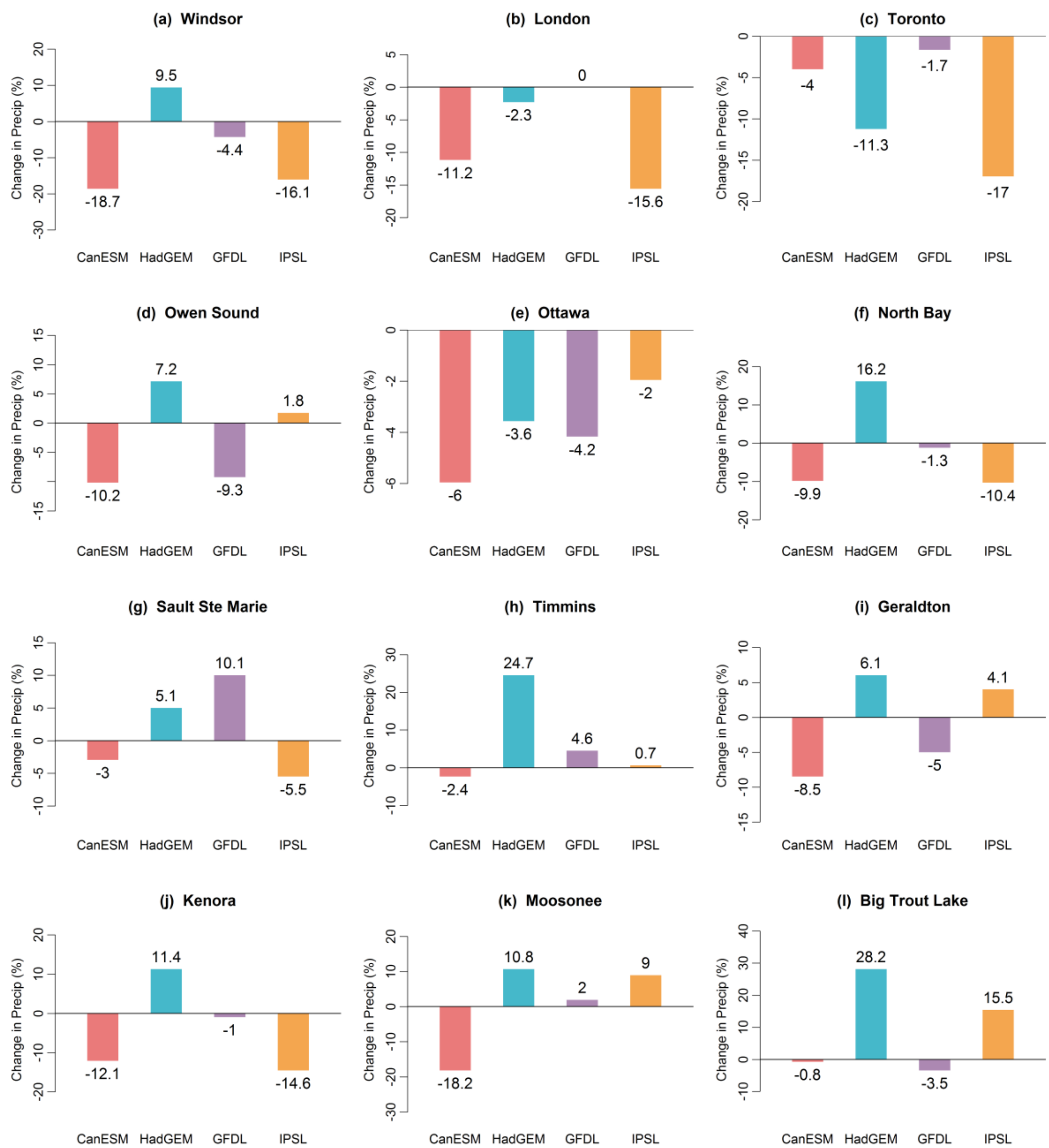

Figure 70. Changes in autumn precipitation in 2050s

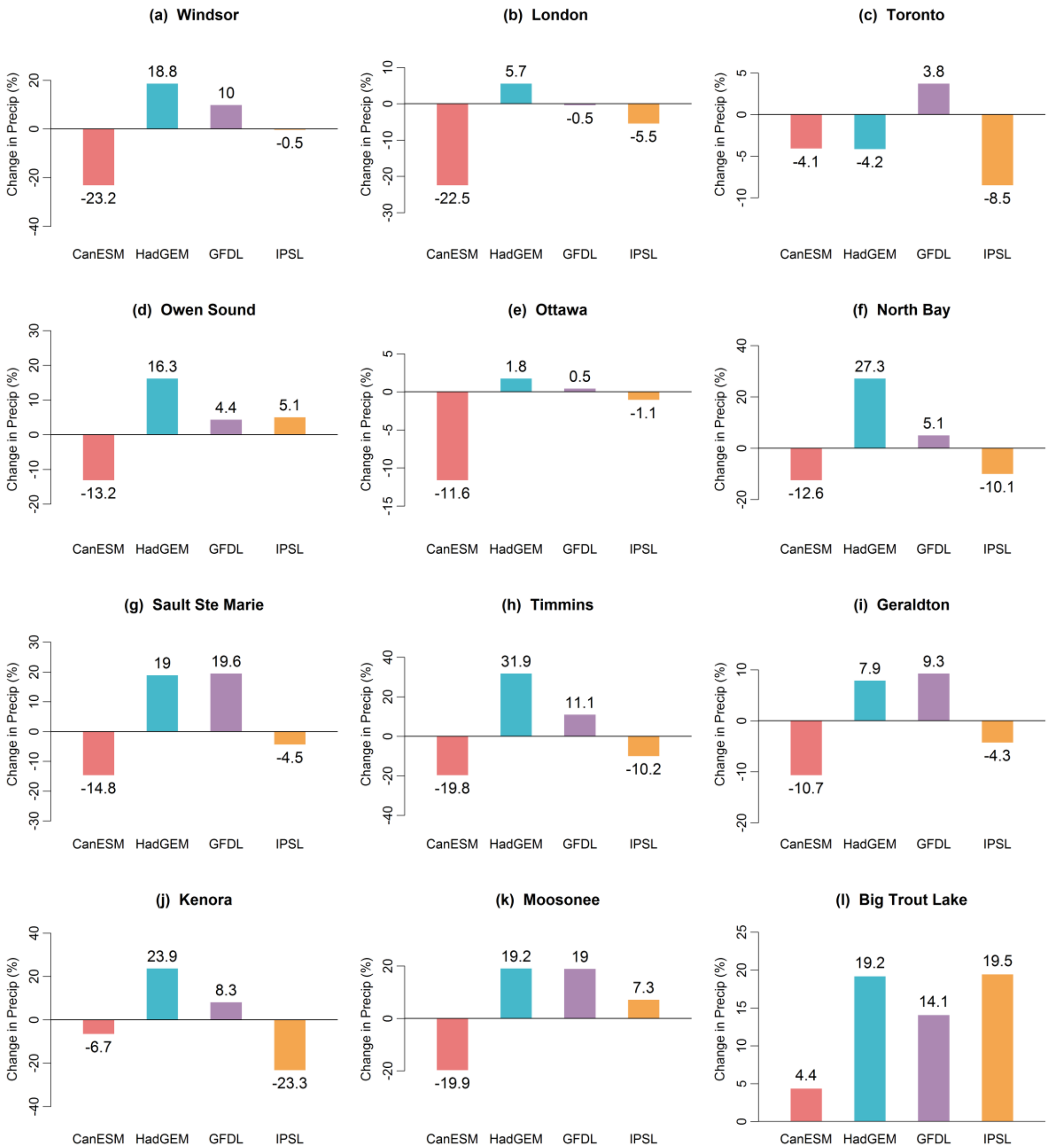

Figure 71. Changes in autumn precipitation in 2080s

5. Updates of Ontario CCDP

Since the initial launch of Ontario CCDP in January 2014, we have received more than 15700 climate data downloading requests from about 160 registered users (as of June 2015), including academia, municipal and provincial agencies, non-government agencies, and private sectors across Canada and the world. As the most important outcomes of this project, the newly-developed climate change projections under the RCP 8.5 emissions scenario for the Province of Ontario have been integrated into the Ontario CCDP such that both the existing and new users can have free access to the climate data generated by the authors.

The previous version of Ontario CCDP contains high-resolution climate projections of major climate variables, time series of climate data, and projected rainfall IDF curves at all 25 km grid cells over the Province of Ontario, which are developed under the IPCC SRES A1B emissions scenario. In the current version of Ontario CCDP, the climate data under A1B emissions scenario are places into a separate view window which is named A1B view window. The new RCP 8.5 high-resolution climate change scenarios are put into the RCP 8.5 view window. All the functions implemented in the previous version of Ontario CCDP are kept the same in the new release of Ontario CCDP. We are trying our best to make the user interface of Ontario CCDP more friendly and simple and to ensure that users can access and download the climate data of their specific interests easily and quickly. We also accept any comments and suggestions on the development of Ontario CCDP. Users who are interested to contribute or comment can contact Xander Wang by email: xander.wang@ontarioccdp.ca.

The homepage of the current version of Ontario CCDP is shown in Figure 72. It contains two clickable panels: A1B and RCP 8.5. Users may click on the corresponding panel to enter its view window. The view windows of A1B and RCP 8.5 scenarios are shown in Figures 73 and 74. There is no obvious difference between these two view windows except that the climate data contained by these two view windows are based on two different emissions scenarios (i.e., A1B and RCP 8.5). Users can refer to the technical report of the previous version of Ontario CCDP to learn more details about how to use each function of the view window (available at: http://ontarioccdp.ca/final_tech_report.pdf).

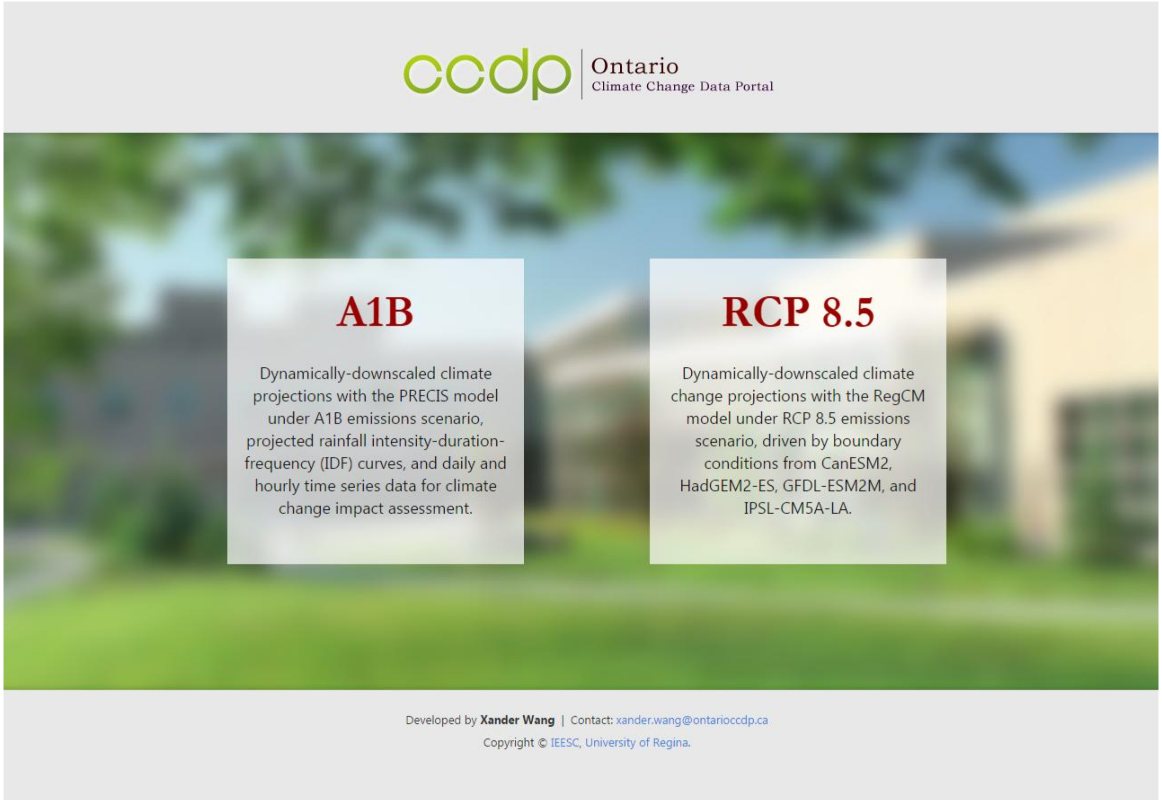

Figure 72. Homepage of Ontario CCDP

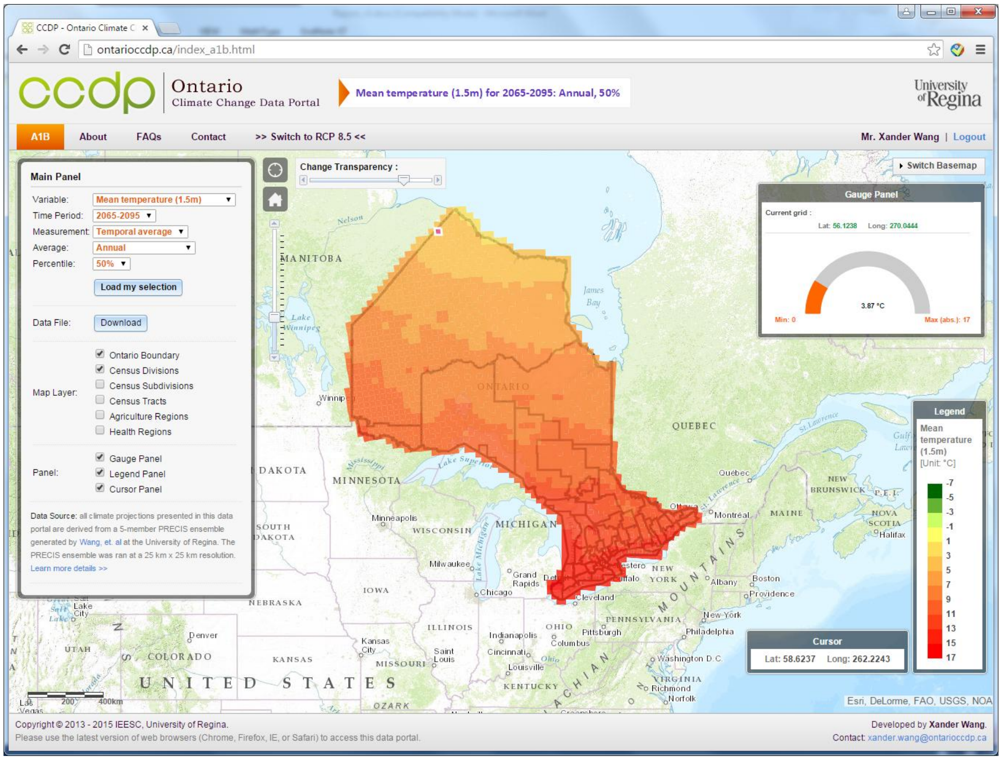

Figure 73. A1B view window of Ontario CCDP

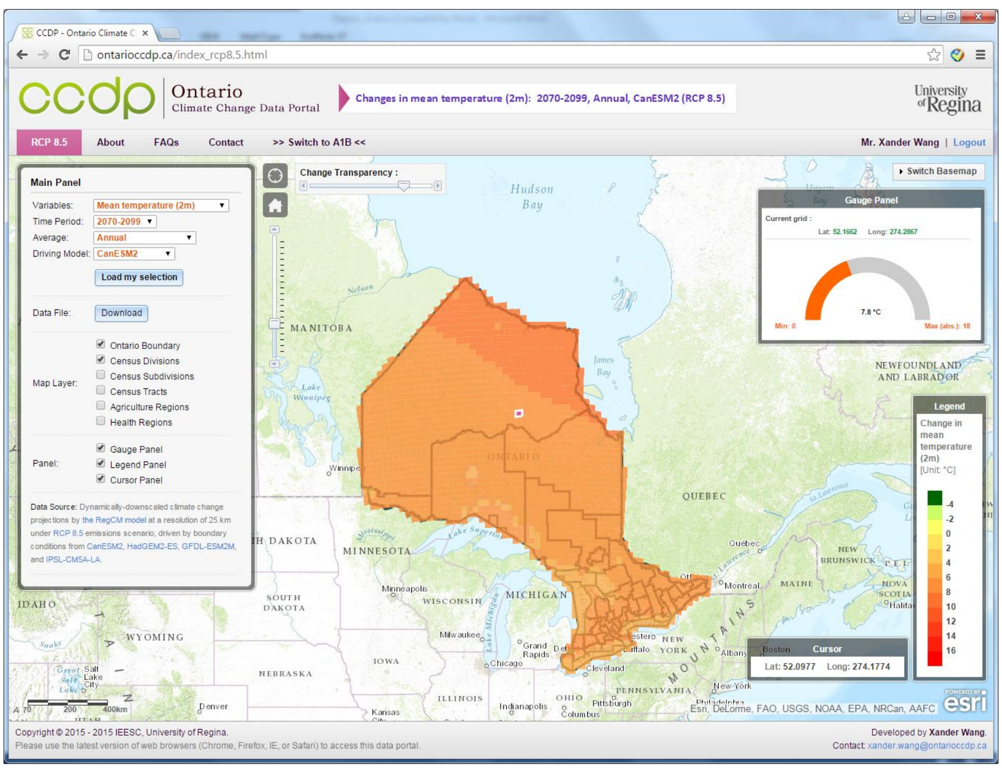

Figure 74. RCP 8.5 view window of Ontario CCDP

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