5th International Conference of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada - June 14-18, 2020

A comparative assessment of long-term trends in temperature using high-resolution climate datasets (Case study: Ontario, Canada)

Isa Ebtehaj[1], Keyvan Soltani[2], Hossein Bonakdari[1],

[1]Department of Soils and Agri-Food Engineering, Laval University, Québec, G1V0A6, Canada, email: hossein.bonakdari@fsaa.ulaval.ca

[2]Department of Civil Engineering, Razi University, Kermanshah, Iran, email: keyvansoltanii@gmail.com

Abstract

In this research, the minimum, average and maximum temperature variations for the province of Ontario in Canada were studied. The data from 1983–2005 were used to calculate future temperature parameter changes, and the data from 2006–2019 were used to validate the models, and then the temperature variations up to 2099 were studied. Observational data were obtained from 14 ground stations. To study climate change in the region between 2020-2099, the data were divided into three periods, 2020-2052, 2053-2087, and 2088-2099, and the results of their variations for the four scenarios RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 were studied and compared with the observational values. Different scenarios give different results for greenhouse gas emissions, with the lowest temperature increase for all statistical parameters in the RCP 2.6 scenario and the highest temperature increase in the RCP 8.5 scenario, while two scenarios, RCP 4.5 and RCP 6.0., are placed between these two. Due to the importance of temperature in the basic activities of plants, using Landis MODIS satellite images in the province of Ontario, land uses were extracted, and their agricultural land and area, as well as their maximum accumulation area, were extracted. It should be noted that these changes can affect the type of crops in Ontario. Then the observed temperature-zoning map and the studied temperature variations relative to the observed values in different climate change scenarios were plotted, and the amounts of these changes were determined in the range of agricultural lands.

Keywords: Climate change, Climate scenario, Ontario, Change Factor, GMST, MODIS

1. Introduction

Long-term global warming since the pre-industrialization period has increased the global mean surface temperature (GMST) by 0.87 ˚C (between 0.75 to 0.99 ˚C) from 2006-2015, which is above the average of 1800-1850. It should be noted that the global warming is increasing by an average of 0.2 ˚C (between 0.1 to 0.3 ˚C) per decade, depending on past weather and current trends. In the fourth assessment report (AR4) conducted in 2007 by the Intergovernmental Panel on Climate Change (IPCC), if the amount of greenhouse gases stabilized at 2000 levels, the Earth's surface temperature would rise by 0.1 °C per decade (IPCC 2007). Increasing air temperature can have a severe impact on various aspects of natural and social life such as access to water, food and the ecological environment (Piao et al. 2010; Lobell et al. 2008; Piao et al. 2010; 2013, Yang et al. 2013). In the latest IPCC report, in the form of the fifth assessment report (AR5) released in 2013 (IPCC, 2013), the comparison of AR5 with the previous IPCC report (fourth assessment report (AR4)) indicate that GCMs models are more diverse in AR5 (Liu et al. 2013). In AR5, with the improvement of physical conditions, numerical algorithms, and so on, a new set of scenarios has been produced that are introduced as representative concentration pathways (RCPs) (Moss et al. 2010). In this study, 22 GCMs models were used to estimate minimum temperature, maximum temperature, and mean temperature variations between 2020 and 2099, and the following questions were explored: What is the prediction of future temperature changes? What kind of climate change is expected in the future according to different scenarios? What will be the future temperature change considering the total average models? What are the consequences of these temperature changes? What is the focus of crop cultivation, and how do the minimum, average and maximum temperatures affect crops in different scenarios?

2. Materials and Methods

Ontario is one of Canada's most important provinces, located geographically in eastern Canada between Quebec and Manitoba (The Canada Country Study, 2013). In this study, 14 meteorological stations were used to study the minimum, average, and maximum temperature (Figure 1)

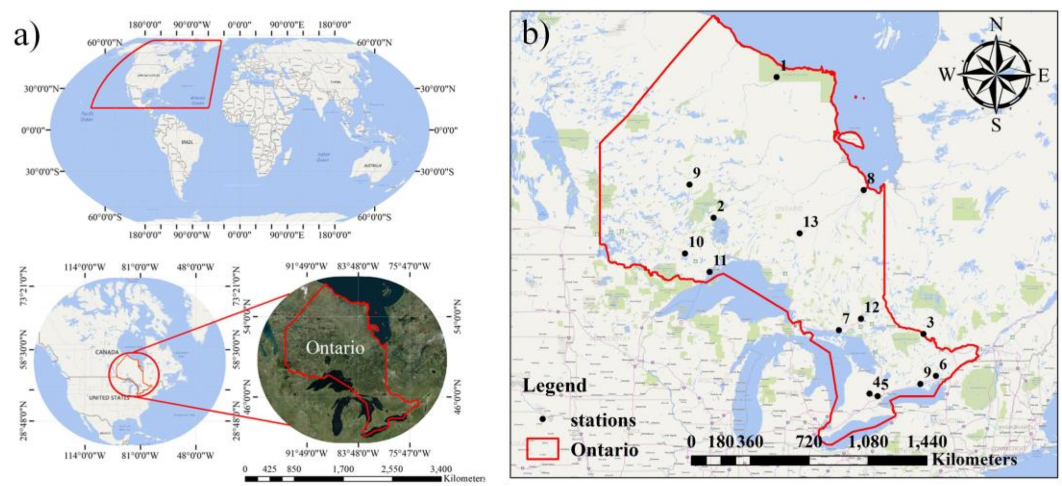

Figure 1. **a)** geographical location of the province of Ontario–Canada **b)** Locations of study stations on the map

In this study, 22 climate change models were used to study mean temperature changes and 21 climate change models were used to study minimum and maximum temperature changes in Ontario province.

2.1. Change Factor (CF) Method

Spatial and temporal analyses of GCM models at the field and station levels exhibit low accuracy (Chen et al. 2013). The Delta Factor or change factor approach is one of the statistical downscaling methods for changing climate parameters (Minville et al. 2009). The change factor value is obtained using historical data for the years 1983-2005 as well as future data for the years 2006-2099 for each scenario. Then, the obtained δ value for each month in all scenarios is multiplied by the ground data and compared with the ground data for the years 2006-2019. Then, by averaging the months of each scenario, the average error between the predicted values by the model and the ground information is calculated, and by comparing this error in the scenario and the different models, the superior model and scenario are selected and introduced. Finally, climate change models and preferred scenarios can predict the temperature parameters for the coming years (2020-2099).

2.2. Assessment of Climate Change (CC) Models

To evaluate the accuracy of the models, the value of statistical parameters included root-mean-square error (RMSE), Normalized root mean square error (NRMSE), mean absolute relative error (MARE), and Correlation Coefficient (R) were calculated to model and monitor the data (Khaledian et al. 2017, Zhang et al. 2015)

3. Results and discussion

In this section, the performance of 22 models for downscaling of precipitation and temperature parameters in Ontario was evaluated using δ method. In this study, the best model was selected based on the lowest error-index and the highest correlation coefficient among different climate change models, and used in predicting future climate parameters.

3.1. Evaluation of models

To evaluate various models and their efficiency in estimating minimum temperature, maximum temperature and mean temperature, statistical indices: RMSE, NRMSE, MARE, MAE, BIAS, r, and r^2 are employed. In Figure 2-a, Figure 2-b, and Figure 2-c, these values are set to the maximum temperature, mean temperature, and minimum temperature during the validation period.

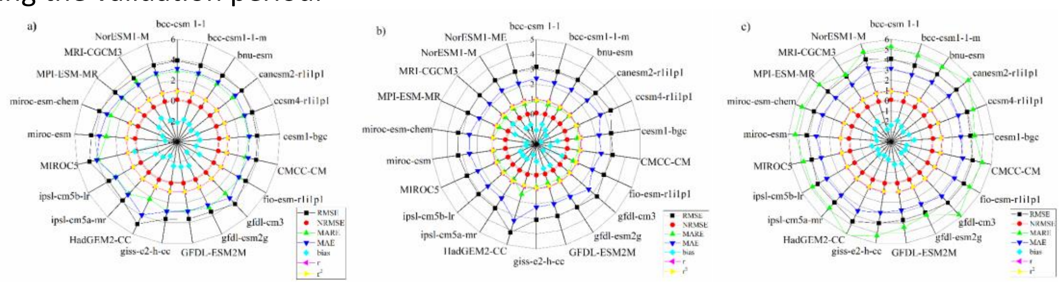

Figure 2. Continental errors and r models for parameters: (a) Maximum Temperature (b) Mean Temperature (c) Minimum Temperature

Figure 2-a shows the statistical parameters investigated for the maximum temperature. The maximum temperatures of 21 climate models are used, based on the fifth IPCC report. The results show that the error values and correlation coefficients in all models are similar to each other, and only a few models are slightly different. To evaluate the mean temperature and to estimate the accuracy of different models, 22 climate models were used, and the results are presented in Figure 2-b. Examination of the calculated error value in the parameter under study showed that different models had similar performance. The RMSE error value was found to be near 3, similar to the maximum temperature in all models, and only in the HadGEM2-CC model an increase in the RMSE error value is seen, such that the value reached 4.16, while the maximum and minimum

error values were found to be 2.994 for the MRI-CGCM3 model, up to 3.437 for the ccsm4 model, and the error values fluctuate in the other models between these two values. According to Figure 2-c, in the prediction of the monthly minimum temperature values, the error values are higher, and correlation coefficients are lower than the maximum and mean temperature values obtained. It can be said that the prediction of this parameter is less accurate than the previous two parameters. According to Figure2-c the MARE value for most models fluctuate close to 5. The RMSE error also varies slightly in different models and fluctuates close to 4 in different models. It had the highest RMSE error as the MARE model of HadGEM2-CC with 4.619 The lowest RMSE error is related to the MRI-CGCM3 model with a numerical value of 3.697, and the error value fluctuates between the two models. There is also a slight fluctuation in the magnitude of the MAE error, and almost all models have similar performance.

3.2. Maximum temperature changes for 2018-2099 years

Figure 3 shows the maximum temperature variations for the four scenarios studied over the three periods 2020-2052, 2053-2087, and 2088-2099.

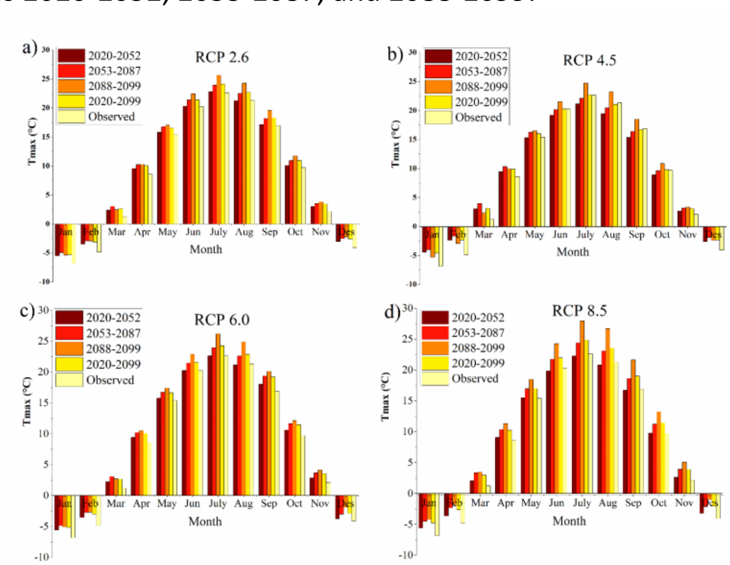

Figure 3. Average monthly maximum temperature changes (2020-2099) for (a) RCP 2.6; (b) RCP 4.5; (c) RCP 6.0; (d) RCP 8.5 (e) Mean for all scenarios

Figure 3-a shows the maximum temperature for the different months of the year in the three study periods as well as the mean of the entire periods. According to the graph, in all months of the year, an increase in the maximum temperature, which varies in different months and for different periods, is observed. From January to April, in the second period, 2020-2052, the greatest rise in temperature is seen, with the temperatures warming by 1.91, 2.13, 1.77, and 1.19 ˚C, respectively. In the first and third periods, there is an increase in air temperature, which is lower than the calculated value for the second period. The most moderate increase in temperature between the study periods and the first four months of the year is for the period 2088-2099. In the RCP4.5 scenario, the changes were relatively similar to RCP2.6, but the difference in the variations of the different periods increased with the observed value, with the mean temperature rise over the three study periods being -0.44, -0.79 and -0.89 ˚C, respectively. The temperature changes for the three periods of 2020-2052, 2053-2087 and 2088-2099 were 0.66, 1.47,

and 2.02 ˚C, respectively, which indicates greater global warming than the RCP4.5 scenario relative to the increasing trend in greenhouse gas emissions by 2099.

3.3. Mean temperature changes

Figure 4 shows the mean temperature variations for the four scenarios studied over the three periods 2020-2052, 2053-2087, and 2088-2099.

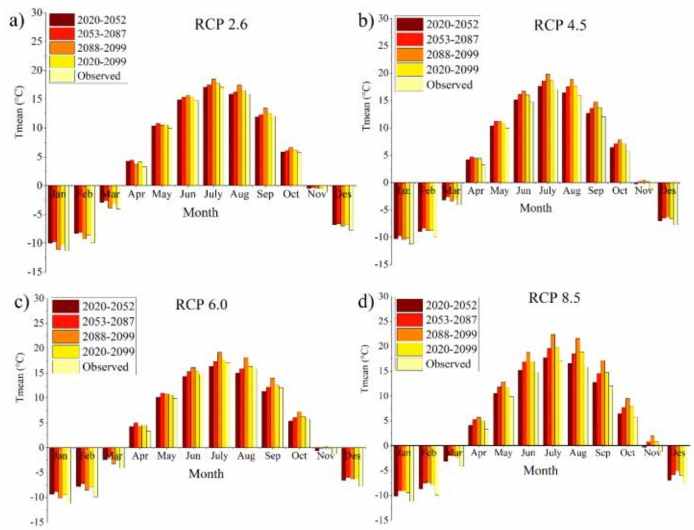

Figure 4. Average monthly mean temperature changes (2020-2099) for (a) RCP 2.6; (b) RCP 4.5; (c) RCP 6.0; (d) RCP 8.5 in three study periods

Figure 4-a to Figure 4-d plotted for the four scenarios: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. Here, the difference from observed temperature increased dramatically. Figure 4-a plotted for RCP 2.6 scenario shows that the temperature changes in January, February, March as well as the last two months of November and December, in the end, period (2088-2099) show the least temperature changes and the magnitude of temperature changes is closest to the average temperature observed. the lowest change in the third period in January was 0.13 ˚C. However, the main difference is that in the five months in the second period (2053-2087) the temperature in February increased to 1.81 ˚C. Temperature variations in the first period (2020–2052) are between the second and third study periods, with the most considerable difference occurring in February with a numerical value of 1.63 ˚C and the lowest change in November with a value of 0.66 ˚C .

3.4. Minimum temperature changes

Figure 5 shows the minimum temperature for Ontario based on four climate scenarios and three study periods. As shown in this figure, the value of the minimum temperature parameter change for different climate scenarios over three statistical periods. In the RCP 2.6 scenario, shown in Figure 5-a, January to April showed the most significant decrease in temperature in the second period (2053-2087) and the smallest changes in the third period (2053-2087). The highest temperature rise in all three periods occurred in February, with values of 2.69, 2.89, and 2.75 °C, respectively. Since May, the shift has moved to the point where most change occurs in the third period and the least in the first period. This trend continues; in December, the first and third periods are almost equal. In the first to third periods, at an annual scale of 1, 1.3, and 1.43 °C, respectively, an increase in the minimum temperature is seen. In the second scenario (RCP 4.5) from January to April, the lowest temperature changes occurred in the first period (in contrast to the RCP 2.6 scenario that occurred in the third period), and the least changes occurred with little difference in the second or third periods. In addition, from May to December, the pulse of constant changes is constant; the third period, the most changes, and the first period, the least changes relative to the observed value were seen. In this scenario and the annual dimension, increases of 1.05, 1.75, and 2.27 ˚C in the first to third periods were seen. Figure 5-c shows the magnitude of the smallest temperature changes for the RCP 6.0 scenario over the three study periods. Here, the difference in the observed value from Fig. 4 is higher than the two previous scenarios; the temperature rise in January reached 3.48, 3.98 and 2.98 °C for the 3 scenarios, respectively, which exhibited a dramatic increase compared to the 2 previous scenarios. In addition, the average annual temperature changes in the RCP 6.0 scenario for the three periods are 1.27, 1.95, and 2.14 °C respectively, which increased in the first and second periods compared to RCP 4.5, and decreased by 0.13 ˚C in the last period. However, the most significant change in temperature is from the previous scenario (RCP 8.5)

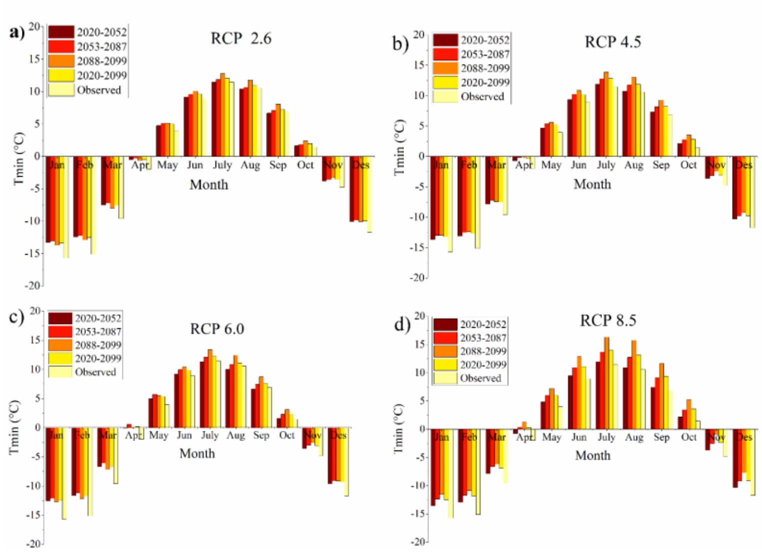

Figure 5. Average monthly minimum temperature changes (2020-2099) for (a) RCP 2.6; (b) RCP 4.5; (c) RCP 6.0; (d) RCP 8.5 in three study periods

3.5. Investigating Long-Term Temperature and Their Impacts on Regional Agriculture

Here, the BCC_CSM1.1 model was used to map 14-temperature stations' temperature zoning in the province of Ontario because of the proximity of the models to each other. It should be noted that due to the high-temperature dependence on the type and amount of crops, land use mapping has been performed to achieve temperature variations in the areas with the highest amount of agricultural land. Initially, the type of land use in Ontario is determined using the MODIS satellite images for 2018. In this area, 15 land uses have been identified by the MODIS satellite; the most significant area is mixed forests, which has an area of 302387.125 Km^2. The largest volume of agricultural land is located in southern Ontario, which experiences higher temperatures than the higher latitudes. Therefore, it can be said that temperature plays a significant role in crop cultivation (Figure 6).

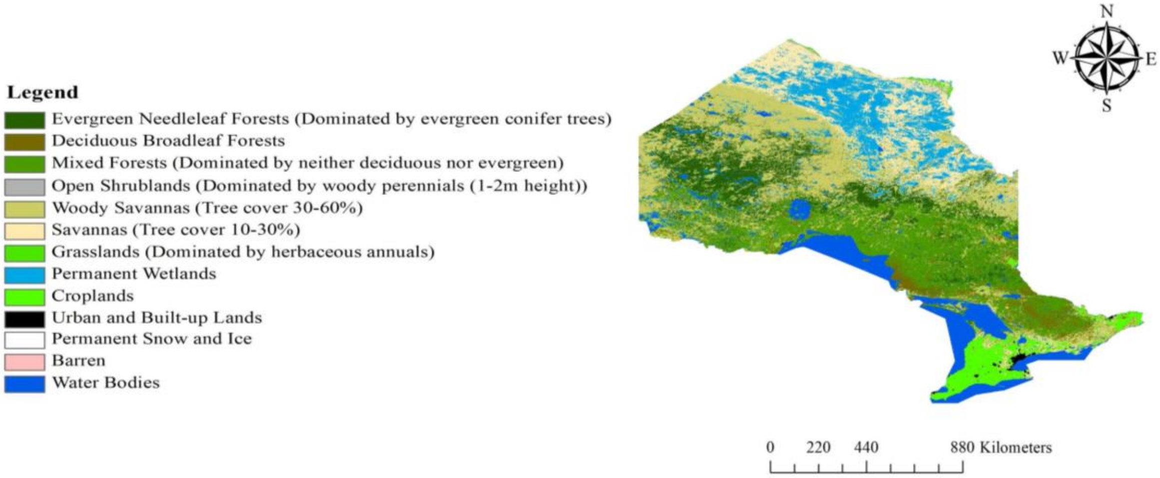

Figure 6. Land use extracted by the MODIS Satellite

Figure 7-A shows the minimum temperature changes for the observed values as well as the changes in the observed values for different scenarios and periods (Figure 7-B to Figure 7-N). Overall, the minimum temperature variations range from zero to 7 ˚C to the observed values for the different scenarios, with the lowest change for the RCP2.6 scenario being observed, and the highest increase seen in the RCP8.5 scenario. Figure 7-A, Figure 7-B, and Figure 7-C show the minimum temperature changes for the three periods 2020-2039, 2040-2059 and 2060-2099, respectively. The darker colors in these maps indicate a greater difference than the mean values. Therefore, it can be observed that the smallest changes for the minimum temperature occurred in the 2020-2039 period, indicating the magnitude of variations for almost all the scenarios. However, with a slight difference, the RCP2.6 scenario shows a lighter color, indicating a lower temperature rise than other scenarios.

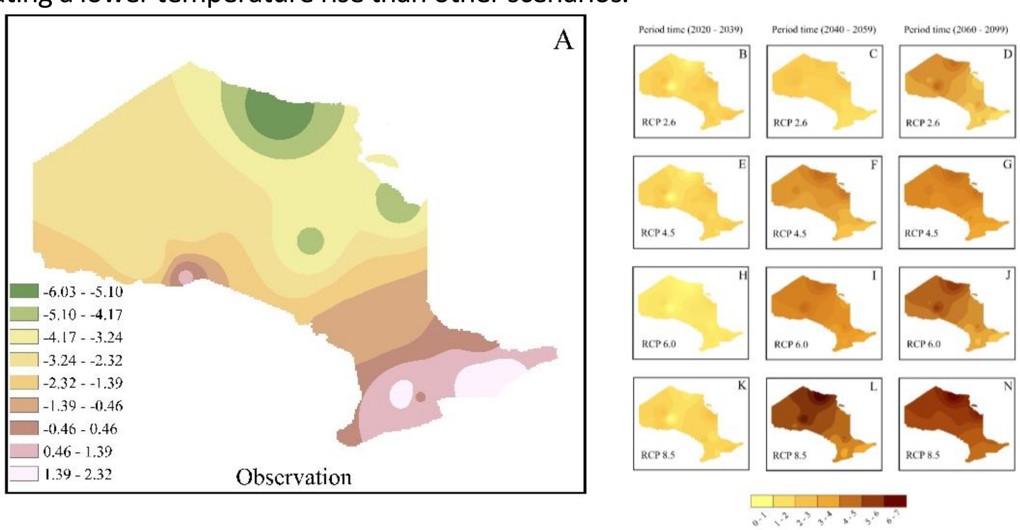

Figure 7. Map of minimum temperature variations for observed values (7-A) and differences from observed values for different Scenarios (7-B to 7-N)

The increase in temperature in 2040-2059 is more pronounced; the RCP8.5 scenario shows the highest mean difference and the RCP2.6 scenario shows the lowest mean difference. The two scenarios, RCP4.5 and RCP6.0, have relatively identical change values in different parts of Ontario. The highest temperature variations are perceived over the observed values for the 2060–2099 period, which among all the scenarios, the RCP8.5 scenario shows the highest increase over the mean.

Another key factor affecting agricultural activity is the average temperature in that area (Figure 8). The optimum temperature for plants is the temperature at which the plant grows the best. According to Figure 8-A, the mean temperature in Ontario fluctuates from -1.83 to -7.51 ˚C at various locations. The highest mean temperatures are found in the southern regions, and the lowest mean temperatures in the northern regions, and moving from north to south in Ontario, mean temperatures increase. Most of the area, 377059.89 square kilometers, located in the temperature range of 0.83 to 2.17 ° C, covers most of the northern latitude of the province of Ontario. However, the highest temperature is in the south of the province, covering an area of 97353.41 Km^2, with a temperature range of 4.84 to 6.18 ˚C, covering an area of 109923.28 Km^2. It should be noted that the spatial correlation of the concentration of agricultural land and higher temperatures in the region indicates the high importance of temperature balance in crop cultivation in the region. An analysis of the mean temperature changes relative to the observed values for different scenarios shows an increase in temperature from 0.7 to 7 ° C for various periods.

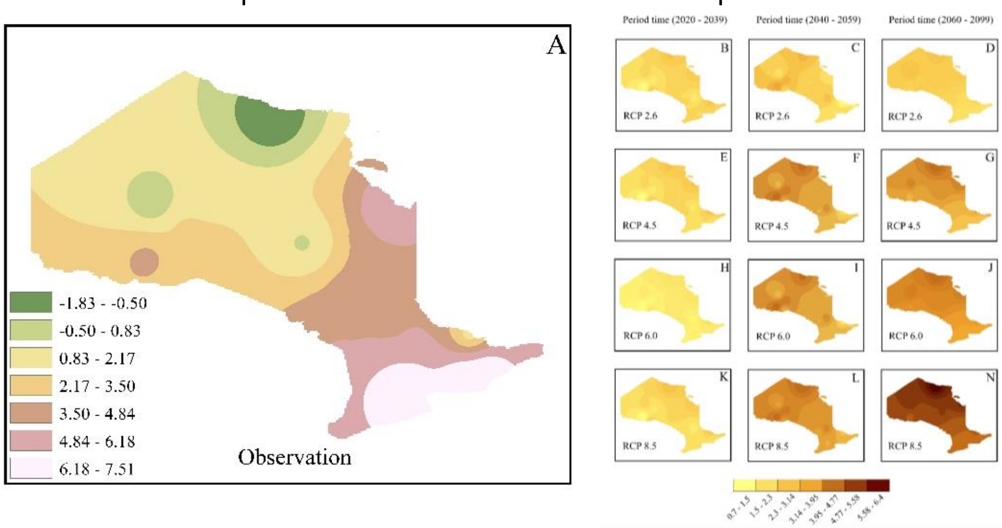

Figure 8. Map of mean temperature variations for the observed values (8-A) and the difference between the observed values for the various Scenarios (8-B to 8-N)

For the maximum temperature, the observed temperature changes are shown in Figure 9-A. According to this figure, the maximum temperature fluctuates from 0.73 to 2.47 ˚C in different parts of Ontario. Most of the range is between 1.76 to 1.98 ˚C, covering an area of 658495.19 km^2, followed by the temperature range of 1.48 to 1.73 °C, with the largest area of 375151 km^2. The period of 2020–2039, and the scenarios RCP2.6, RCP4.5 and RCP6.0, show proximity changes in the maximum temperature changes relative to the long-term mean values. Nonetheless, in the RCP8.5 scenario, which is the most pessimistic scenario in the 2020-2039 period, the maximum temperature increase was higher than the average, most of which occurred in the northern regions and decreased with the shift to lower latitudes.

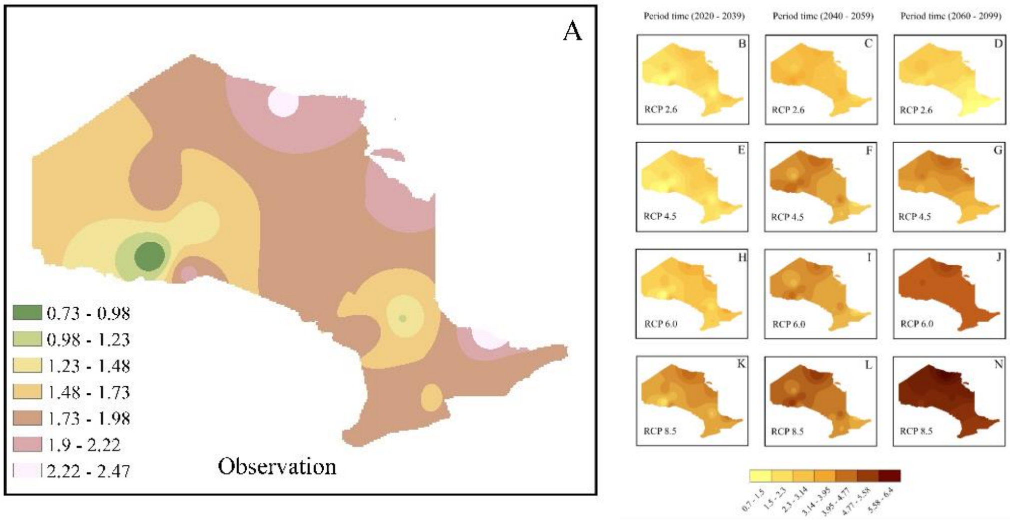

Figure 9. Map of maximum temperature variations for observed values (9-A) and difference of observed values for different scenarios (9-B to 9-N)

4. Conclusions

Temperature parameters are fundamental factors in all climatic and regional processes that affect other parameters, including hydrological parameters. Therefore, considering future temperature changes in each region is one of the factors that can influence macro planning and control of water resources. In this study, the maximum, mean and minimum temperature variations for Ontario, Canada, for the 21st century using 22 climate models for mean temperature and 21 climate models for minimum and maximum temperatures under 4 scenarios were investigated. In reviewing the results of this study, the following primary results can be highlighted:

- The changes predicted by the two climate change scenarios by 2040 are very similar, but from this year onwards, diverged. RCP 2.6 predicts the smallest changes in temperature and RCP 8.5 predicted the most changes, and two scenarios RCP 4.5 and RCP 6.0 are placed between these two.
- The highest difference of forecasts occurred in all scenarios and in all parameters studied from 2075 to 2099, which is related to the second and third periods of study. Here, the RCP 8.5 scenario exhibits the most difference from the other scenarios in estimating the temperature parameters.
- Ontario is one of the places where many blue zones and lakes, such as Lake Nipigon, Lake St Joseph, etc. are abundant. These aquatic zones play an essential role in the climate and ecosystems of the region, where elevated temperature parameters will have the most significant impact, the most important being high temperatures resulting in drying and depletion that will affect plants, animals, and human life.
- Although in Ontario an increasing trend in temperature leads to a high degree of onshore drought in water zones and lakes, in areas where the high seas exist, the relationship is the opposite and will result in higher water levels. The ice that is also abundant in northern Canada raises the sea level with its melt, and will have many consequences, including coastal submergence.
- Land use surveys using the MODIS satellite show that the entire province of Ontario has a crop area of 56187.38 Km^2, almost all of which is located in the southern part of the province.

One of the main reasons for this is the higher temperature of the region compared to the higher latitudes, which results in higher productivity and crop quality.

- For all scenarios studied, all temperatures (min, mean, and max), the highest difference from the mean is at higher latitudes, and this decrease when moving to lower latitudes.
- The study of temperature variations using the BCC_CSM1.1 climate change model shows that the minimum temperature is 0-7 °C, and the average and maximum temperature is 0.7-6.4 °C compared to the observed values in different parts of Ontario.

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